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Land Suitability Assessment for Olive Mill Wastewater Disposal by Integrating Multicriteria Decision Support Tools

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Abstract

Many on-site waste disposal systems fail regularly due to problems concerning suitable location and management. A potential environmental threat is inevitably propagated through on-site, off-site, downstream, soil surface and ground water pollution. Soil is a key component of land suitability for waste disposal. This paper presents a Geographic Information Systems (GIS) – based integrated multicriteria decision support system for evaluating the land suitability for olive mill wastewater (OMWW) disposal in the Mediterranean region. Two-scaled classification schemes are developed, the global scheme for Central and South Greece (scale: 1:30.000) and the local scheme for the study area in Xiromero, Aetolia-Acarnania Prefecture, Western Greece, scale 1:10.000. Constrains and factors are included into the spatial decision-making framework, where geostatistical and fuzzy set theory techniques, as well as Analytical Hierarchy Process (AHP) are appropriately integrated. Physical, chemical, and socioeconomic variables adapted to the Mediterranean soil conditions are incorporated as driving forces for the land suitability assessment and the produced maps reveal valuable results for final end-users, such as municipal authorities, agriculturalists, farmers and other national and local stakeholders.

Introduction

Most of the world's olive oil (98%) is produced in Mediterranean countries (Shabou *et al.*, 2009a; Jarboui *et al.*, 2010); Spain produces 36%, Italy 24% and Greece 17% of global production (Lopes *et al.*, 2009). Olive oil extraction generates a high amount of waste that requires appropriate management due to the negative impact in case of uncontrolled disposal. Several methods have been applied to OMWW treatment: a) disposal in soil, b) incineration and c) fermentation products (Komnitsas and Zaharaki, 2012).

No common policy practices are applied in the European Union, and therefore each European country applies its own restrictions on OMWW management. Nevertheless, some main EU directives, such as 86/278/EEC, 91/271/EEC, 91/689/EEC and 91/676/EEC, are partially used to handle the existing gap (Williams, 2005). There is an undoubted need to adopt common soil and site evaluation criteria, and also to plan for strategic management activities involving all relevant stakeholders *e.g.*, farmers, decision makers, public bodies. Therefore, any management plan should consider human participation factors along with any environmental or socio-economic variable.

Our approach uses multicriteria decision support tools to assess the soil land and site suitability for olive mill wastewater (OMWW) disposal. These tools consist of commonly used practices which are highly validated

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for a number of land evaluation applications (Joerin *et al.*, 2001; Goncalves *et al.*, 2002; Geneletti and van Duren, 2008; Chen *et al.*, 2010; Rahman *et al.*, 2012; Sahnoun *et al.*, 2012; Papadopoulou-Vrynioti *et al.*, 2013; Triantakonstantis *et al.*, 2013). Traditional land classification techniques that use the most limiting factor for each class (Davidson *et al.*, 1994; Hossain and Das, 2010) are adopted. Moreover, Analytical Hierarchy Process (AHP) combined with fuzzy set theory techniques and geostatistical methods are also used for assessing the land suitability for OMWW disposal. AHP is a widely accepted modelling framework for decision making problems (Saaty, 1980; Saaty, 1994a,b; Saaty, 1995), while fuzzy sets produce a more realistic suitability classification system by applying the uncertainty and continuously changing nature of our environment (Burrough *et al.*, 1992; Burrough *et al.*, 2015).

Our principal objective is to produce a land evaluation model framework for OMWW disposal to support current legislation within the European Union, using multi-criteria decision tools under a Geographic Information System (GIS) umbrella. The results will be useful to any decision-making authority and planning organization, enriching their capabilities when facing OMWW disposal problems.

Materials and Methods

Study Area and Data Sources

Our land evaluation model is applied in two scaled-study areas. The first refers to a global scale using about half of the Greek territory (Central and South Greece), where olive trees are cultivated, while the local-scaled area is in the Xiromero rural area (Aetolia-Acarnania prefecture). The global study area, in which most olive production occurs, includes twenty prefectures with a total area of 1.47 million ha.

For the global area, open data including the soil map of Greece (Payment and Control Agency for Guidance and Guarantee Community Aid - OPEKEPE, scale: 1:30.000) as well as rivers, water bodies and urban areas www.geodata.gov.gr were used. The area of the mapping units is 1.470.836 ha. For the local areas, the soil maps of ELGO "DEMETER" (scale: 1:10.000) was used. The Xiromero area is 2.601ha. Figure 1 presents the global and local study areas.

The driving factors for OMWW disposal

In Table 1 a literature review of synthesis of OMWW is presented (Tsagaraki *et al.*, 2007; Doula *et al.*, 2012). The most important organic properties of OMWW are phenolic compounds, sugars, and some organic acids. Concerning inorganic compounds, OMWW has high potassium content (≈4 g/L) and important levels of nitrogen, phosphorous, calcium, magnesium, and iron compared to other organic wastes (Tsagaraki *et al.*, 2007). The proper management of OMWW disposal highly depends not only on chemical characteristics, but also on physical and socioeconomic properties, which are important for an effective waste management system. The suitability of these properties for OMWW disposal on soils is analytically presented below.

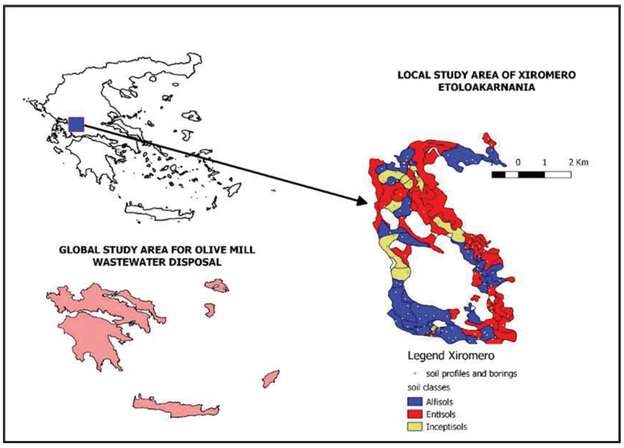

Figure 1. Global and local study areas for OMWW disposal.

Physical Properties

Generally, soil should be deep, well-structured with high microbial activity, permeable enough to appropriately filter and adsorb nutrients and degrade pollutants such as phenols.

Sufficient soil volume, that is determined by plentiful soil depth and coarse fragments amount, may prevent waterlogging or excessive runoff. Soil permeability declares the capability of soil to store water before it is recharged by flow to groundwater. High saturated or unsaturated permeability may allow waste to directly reach the ground water lever and produce contamination in underground water, while not permeable soils may result to stagnation and surface runoff in slopping soils. More specifically:

Soil permeability – Soil structure – Soil texture: Soil permeability greatly influences the time and the 3-D fate and distribution of waste how much pollutant is reaching ground and surface water before the soil microorganisms involvement escaping an OMWW disposal site. According to the characteristics of soil texture of the area, soils having high rate of permeability are sandy soils and are considered unsuitable for being used as an OMWW disposal site, while soils with very low permeability are clay soils and are considered fairly suitable and optimal to site an OMWW disposal. (Aydi *et al.*, 2016).

Groundwater depth: The OMWW disposal site mapping should consider the ground and surface hydrology; the existence of the depth of vadose zone and the aquifers to prevent groundwater contamination. In this study, a 50-cm minimal depth to groundwater is considered unsuitable for OMWW disposal (Theocharopoulos *et al.*, 1996).

Soil Units: Vertisols are soils with high content of clay (montmorillonite) that forms deep cracks in drier

Table 1. A literature review of synthesis of OMWW.

Property	Azbar *et al.* (2004)	Niaounakis and Halvadakis (2004)	Borsani and Ferrando (1996)	Paredes *et al.* (1999)	Sierra *et al.* (2001)	Galiatsatou *et al.* (2002)	Eroglu *et al.* (2004)	Al-Malah *et al.* (2000)	Doula *et al.* (2012)
pH	3–5.9	4–6		4.8–5.5	4.5–6	4.9–6.5	4.86	4.52	5.23
Water (%)			83						
BOD (g/L)	23–100	35–110			35–100	15–120	17.88	13.2	45.5
COD (g/L)	40–220	40–220			40–195	30–150	72.20	320	86
Carbohydrates (%)			2–8	3.37–32.91		2–8			
Polyphenols (g/L)	0.002–80	0.5–24		1.32–3.99%	3–24	1.5–2.4	0.13	3.12	2.7
Fats, oils (g/L)	1–23		0.03–1%	0.55–11.37%	0.3–23	1.3			5.8
Pectins (%)			1–1.5			1–1.5			
VOC (g/L)		25–45							
TS (g/L)	1–102.5						42.24		
SS (g/L)							3.48	2.17	
N (g/L)	0.3–1.2			0.58–1.13%	5–15	0.5–2%			0.4
K (g/L)		4	0.87% K_2O	3.30–6.94%	2.7–7.2		7.81		0.95
P (g/L)			0.22% P_2O_5	0.06–0.32%	0.3–1.1				0.18
Ca (g/L)				0.32–0.53%	0.12–0.75		0.55		0.07
Na (g/L)				0.04–0.48%	0.04–0.90		0.41		0.03
Mg (g/L)				0.06–0.22%	0.10–0.40		0.28		0.09

seasons or years. They are considered a limiting factor, due to their shrink and swell properties that depend on the moisture content, making the management very difficult (Oliveira *et al.*, 2016).

Soil depth: In small soil depth, contaminants can flow into groundwater. Moreover, in a single application at high rates of waste, they may produce potential waste overloading in the soil (USDA, 1996).

The suitability of other physical characteristics should be carefully taken into consideration in land evaluation of OMWW disposal. For example, slope needs to be shallow enough to avoid surface runoff and therefore, soils with high slopes are excluded. Drainage should be appropriate, and the ground water level should not be fluctuated in a way to reach the surface applied pollutants of the waste to prevent waste movement away from the application area.

Slope: Slope is a crucial factor for OMWW disposal since higher slopes would increase runoff of pollutants from the disposal site. Therefore, the contamination will increase in the surrounding areas. Slope values over 10 % are considered a limiting factor for hazardous waste landfill siting (Sharifi *et al.*, 2009).

Drainage: In poorly drained soils, the application and incorporation of waste should be made during periods when flooding is unlikely, because contaminants can enter surface water (Rowe *et al.*, 1981).

Chemical Properties

Electrical Conductivity: In severe soil salinity (EC > 8 mS cm^{-1}) the application of high C:N and low salt wastes may improve soil infiltration, permeability, and structure and reduce plant toxicity. Moreover, the application of saline wastes may increase soil salinity if applied at continuous high rates (USDA, 1996). Generally, values of EC greater than 4 mS cm^{-1} are considered excessive and therefore, any OMWW disposal should not increase the EC more than this threshold (MAFF, 1988; Ilaco, 1985).

pH: High soil pH values and high content of calcium carbonate neutralize the strong acidity of the waste, both in the areas of disposal containers, and in places where there is land surface disposal. Normal range of soil pH is 6 – 8 (CCME, 2007) and should be kept at this range after the OMWW disposal considering the soil resilience.

Organic Matter: Organic matter improves soil aggregation, water-holding capacity, hydraulic conductivity, bulk density, fertility and resistance to water and wind erosion. Moreover, soil organic matter is a crucial source of nutrients for the microflora, microfauna and plants. Therefore, the organic matter of soil is not a limiting factor for OMWW disposal. Values greater than 3.4 % on soils are considered normal (Loveland and Webb, 2003).

Calcium (Ca), Magnesium (Mg) and Potassium (K): OMWW contains high concentrations of calcium, magnesium and particularly potassium (Arienzo and Capanso, 2000). Calcium has a positive effect on soil

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properties. It improves soil structure, increases water penetration, and contributes to the growth of plant roots and soil microorganisms. Magnesium is essential to produce chlorophyll. As soil pH increases, the supply of available calcium and magnesium to soils increases. If potassium is more than adequate to meet a crop's needs, it will be adsorbed by the soil colloids absorbed by plants and will lead to high concentrations of K in plants, which is called "luxury consumption", with no negative impact on plant growth (Kaiser *et al.*, 2016). Low values of these cations are more suitable for OMWW disposal, because OMWW increases their concentrations, and risk of toxicity is much higher in case of high values of cations. Carrow *et al.* gave the normal / average range of the concentrations of these elements on soils: 2.5-3.8 cmol kg^{-1} for Ca, 1.2-2.2 cmol kg^{-1} for Mg and 0.26-0.60 cmol kg^{-1} for K.

Phosphorus (P): Phosphorus (P) is an essential element in food production, but its availability is limited in global scale. Therefore, the supply of this non-renewable resource is more than urgent. OMWW disposal can enhance the long-term supply of this important plant nutrient and areas with low values of P are more suitable for OMWW disposal. Large values may produce toxicity in plants. Normal values of P on soils range between 12-28 mg kg^{-1} (Carrow *et al.*, 2001), while values of 40-50 mg kg^{-1} are considered high (MAFF, 1988; Ilaco, 1985).

Cation Exchange Capacity: Cation exchange capacity (CEC) is the ability of the soil to hold positively charged ions. It influences soil structure stability, nutrient availability, pH and the soil's reaction to fertilizers and other soil additives (Hazelton and Murphy, 2007). High CEC is more suitable for OMWW disposal because cations of waste can be easier retained and given back to plants and enhance ion exchange with the cations of the waste.

Degree of base saturation: The degree of base saturation is the percentage of exchangeable cations Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} in Cation Exchange Capacity. The degree of base saturation is an important soil property which reflects the extent of weathering of the soil. The easiness of cation absorption by plants is related to the degree of base saturation. The availability of plant nutrients increases with the degree of base saturation. High degree of base saturation is more suitable for OMWW disposal because cations of waste can be easier retained and given back to plants (Cabrera *et al.*, 1996).

Socioeconomic properties

These are some other site properties which have a socioeconomic effect on OMWW disposal. For example, keeping a buffer distance from residential areas, water bodies and drainage channels is highly recommended. Additional details of these characteristics are given in the following paragraphs:

Distance from Residential Areas: Sitting an OMWW disposal site close to residential areas may possibly cause negative health impacts and smells on the population and create negative effects on waste recycling. Therefore, distance should be kept to protect the general public health from possible environmental hazards released from OMWW disposal site (Aydi, 2016). While some studies suggest different range of distance to residential areas for OMWW disposal (*e.g.* Abessi and Saeedi 2010), in our study, distance smaller than 200 m is considered unsuitable, while distances greater than 500 m are acceptable for allocating OMWW disposal site.

Distance from Rivers: According to the EU directives, a landfill should not be close to any source of water. It is suggested that a distance up to 500 m away from water bodies could be acceptable (Kontos *et al.*, 2003). In our study, a buffer distance of 200 m for water bodies is considered unsuitable for allocating OMWW disposal sites (Shabou *et al.*, 2009b), always depending on the pattern of channels and the general hydrology of the first order catchment.

Land Evaluation Assessment Methods

Land Suitability Classification by FAO

According to the United Nations Food and Agriculture Organization—FAO (1976):

- Land evaluation is the process of estimating the potential of land for alternative kinds of land use, so that the consequences of change can be predicted.
- Land suitability is the fitness of a given area for a land utilization type (or land use), or the degree to which it satisfies the land user. It is generally presented as a class or rating.

If a landscape characteristic does not meet the selected criteria for a particular land use, a potential limitation or "constraint" is appeared. The suitability classes outlined by FAO are internationally acceptable and can be adapted and applied to any scale. FAO (1976) suitability classes are: S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N1 (not suitable) and N2 (not suitable). These classes have been adopted to the Mediterranean soils of Greece by Davidson et al. and Theocharopoulos et al. for sewage sludge application.

Analytical Hierarchy Process (AHP)

The AHP multicriteria method was employed to define the OMWW disposal in local study areas of Xiromero Aetolia-Acarnania and Eleonas Phocis study areas. Analytical hierarchy process (AHP) is a mathematical method, where complex decisions can be made by multiple criteria selection. It measures the relative importance of the factors and has been widely applied to tackle environmental problems (Schmoldt *et al.*, 2001).

The AHP method (Saaty 1977) is a common technique for tackling spatial decision-making problems. It is a multi-attribute method based on the weights assigned to each factor. The importance of each factor is then determined. A total score is calculated by multiplying each weight by the scaled value of each factor. The AHP methodology presented in Saaty (1977) calculates the final factor weight.

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First, AHP makes pairwise comparisons of all factors. It is expressed on a nine-point scale. Pairwise weights of 1, 3, 5, 7 and 9 indicate equal preference, weak preference, strong preference, very strong preference, and extreme preference respectively of one variable over the other. The values of 2, 4, 6 and 8 are intermediate values (Saaty, 1977). Because pairwise comparison based on human decisions usually have inconsistencies, AHP calculates the degree of inconsistency of the comparison matrix (consistency index, CI, and consistency ratio, CR). A CR of 0.1 or less is usually considered acceptable. If the CR is greater than 0.1 then the pairwise comparison should be reconsidered (Saaty, 1994a, b).

Geostatistics - Kriging interpolation

In-depth discussions about interpolation techniques are given by Journel and Huijbregts (1978), Isaaks and Srivastava (1989) and Burrough *et al.* (2015). The values of each soil property were used for the prediction of values at unknown points using the interpolation methods or Ordinary Kriging.

The spatial prediction of the values of a soil variable Z at an unsampled point x_0 is given by Eq (1):

$$Z'(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i) \tag{1}$$

where x denotes the set of spatial coordinates $\{x_1, x_2\}$ and λ_i are the weights of the sampling points x_i.
In Kriging, the weights are chosen so that the value of Eq (1) for $z(x_0)$ is unbiased, and the prediction variance $\sigma^2(x_0)$ is minimized. That is:

$$E[Z'(x_0) - Z(x_0)] = 0 \text{ and } \sigma^2(x_0) = \\ var[Z'(x_0) - Z(x_0)] = minimum \tag{2}$$

To ensure that the prediction is unbiased, the weights placed on each neighbouring point must satisfy Eq (3):

$$\sum_{i=1}^{n} \lambda_i = 1 \tag{3}$$

The spatial variation of the soil properties was quantified by semivariogram. The semivariogram is a function that connects the semivariance (γ) with h, where:

$$\gamma\ (h) = (1\ /\ 2m(h)).\Sigma\{Z(x) - Z(x + h)\}^2 \tag{4}$$

where $m(h)$ is the number of pairs within a distance h.
A variable of the semivariogram satisfies the following conditions, Eqs (5-8):

$$E\ \{Z\ (x)\} = m \tag{5}$$

$$C\ (h) = E\ [\ \{Z\ (x) - m\}\ \{Z\ (x + h) - m\} = \\ E\ [Z\ (x) - Z\ (x + h)] - m^2 \tag{6}$$

$$C\ (0) = E\ [Z\ '(x)] - m^2 = \sigma^2 \tag{7}$$

$$c\ (h) = C\ (0) - C\ (h) \tag{8}$$

The type of the theoretical model, which fitted best to the experimental variogram of each variable, was the spherical model, which is given from the following Eqs (9-11):

$$\gamma(h) = C_0 + C\{3h/2\alpha - 1/2(h/\alpha)^3\}, \\ for\ 0<h<=\alpha \tag{9}$$

$$\gamma(h) = C_0 + C,\ for\ h > \alpha \tag{10}$$

$$\gamma(0) = 0 \tag{11}$$

Fuzzy Sets

Considering a set $X = \{x\}$, where x may be entities, properties, a fuzzy subset A of X, is defined by a function μA as the set of pairs $A = \{x, \mu A(x)\}$ for each x of X. The value $\mu A(x)$ represents the membership grade of x in A. The membership grade of an object takes values in [0,1]. A value of 1 indicates full participation in the fuzzy set and as the degree of involvement approaches zero the participation in the fuzzy set becomes weaker (Zadeh, 1965; 1978, Comber *et al.*, 2016). The membership grade of an object in a fuzzy set is usually calculated by a membership function. In the literature, there is a large number of membership functions that describe soil data (Kandel, 1986; Burrough, 1989).

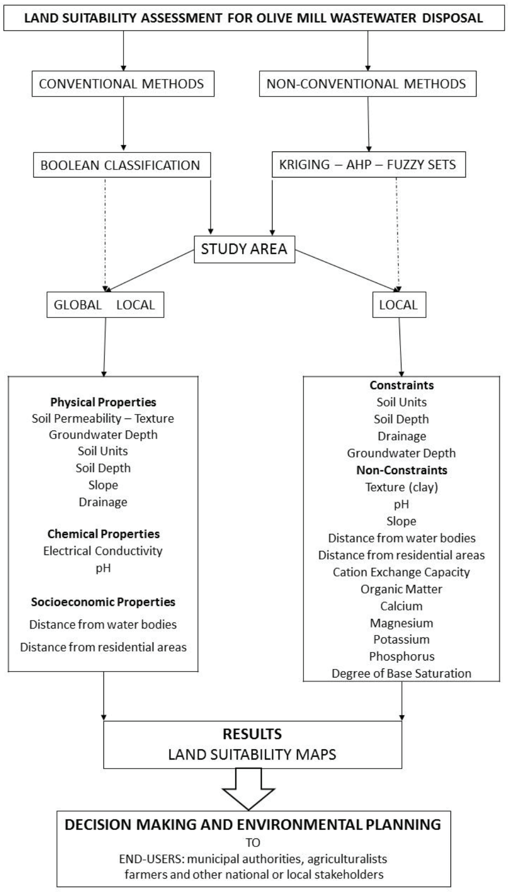

Figure 2. Flowchart of land suitability assessment for OMWW disposal.

Table 2. Soil and site characteristics for land suitability for OMWW disposal of global study area.

Physical Properties	**S1**	**S2**	**S3**	**N1**	**N2**
Soil Permeability Texture	medium clay, clay	Medium textured	Sandy	High sandy	High sandy
Groundwater Depth	All except				
S3, N1, N2	All except				
S3, N1, N2	50-150 cm	>50 cm	>50 cm		
Soil Units	All except Vertisols	All except Vertisols	All except Vertisols	Vertisols	Vertisols
Soil Depth (cm)	>120	80-120	50-80	30-50	<30
Slope %	<3	3-8	8-12	12-18	>18
Drainage	Very well-drained	Well-drained	Moderate drained	Poorly drained	Very Poorly drained
Chemical Properties	**S1**	**S2**	**S3**	**N1**	**N2**
Electrical Conductivity (mS/cm)	<2	2-4	4-6	6-8	>8
pH	>7,3	6,6 – 7,3	5,6 – 6,5	<5,6	<5,6
Socioeconomic Properties	**S1**	**S2**	**S3**	**N1**	**N2**
Distance from water bodies (m)	>500	300-500	200-300	<200	<200
Distance from residential areas (m)	>500	300-500	200-300	<200	<200

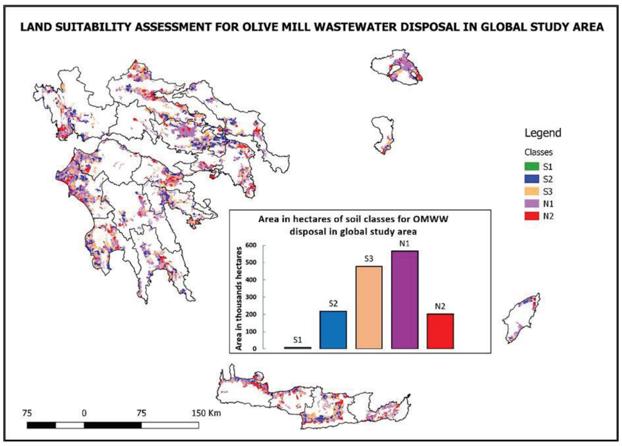

Figure 3. Land suitability for OMWW disposal in global study area.

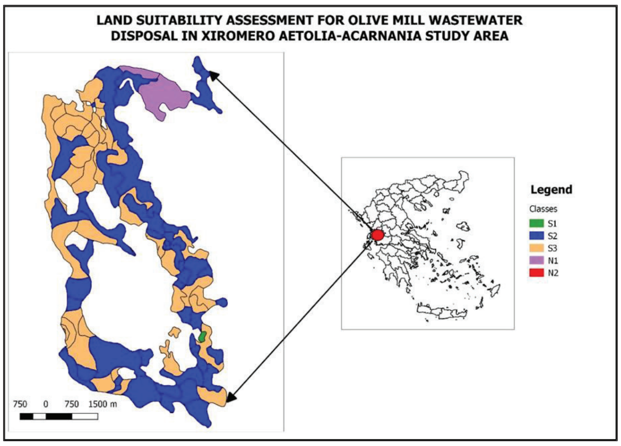

Figure 4. Land suitability for OMWW disposal in Xiromero Aetolia-Acarnania study area.

The research methodology adopted in this study is graphically presented in Figure 2. This flowchart describes the steps needed to reach our overarching goal.

Results and Discussion

Land Evaluation (FAO Classification) of Global and Local Study Areas

The Land Suitability Classification (FAO, 1976; Theocharopoulos *et al.*, 1996; Doula *et al.*, 2013) using the selected criteria (physical, chemical, and socioeconomic properties of Table 2) produce the results of Figures 3 and 4. In the global study area, most of area (70,9%) belongs to S3 and N1 classes, while only 15,3% is classified to S1 and S2. In Xiromero study area, most of area belongs to S2 and S3 classes.

Land Evaluation (AHP – Kriging - Fuzzy)

The land evaluation using the AHP, Kriging and Fuzzy Sets methods was applied in Xiromero Aetolia-Acarnania study area. Four OMWW disposal constraints were chosen according to the Greek legislation (Part B, 3924/07.12.2016 FEK - Government Gazette Issue). The

Table 3. The resulting weights for the criteria based on pairwise comparisons.

Category		Priority
1	clay	8.9%
2	pH	7.3%
3	slope	15.5%
4	Distance from water bodies	16.3%
5	Distance from residential areas	17.0%
6	CEC	6.2%
7	organic matter	7.3%
8	Ca	4.0%
9	Mg	4.0%
10	K	4.0%
11	P	4.0%
12	Degree of base saturation	5.5%

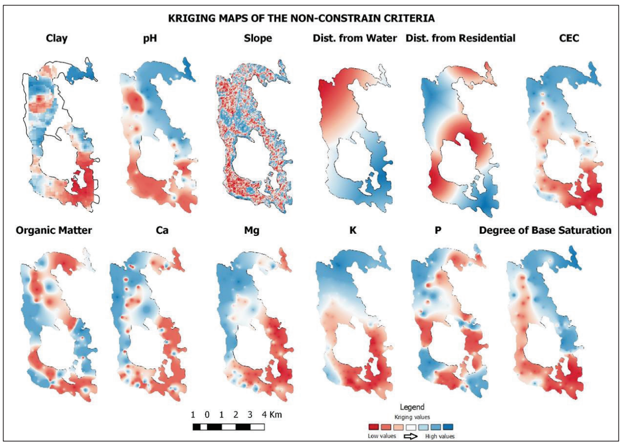

Figure 5. The Grids of Non-Constraint Criteria after Kriging interpolation.

constraints criteria include soil units, soil depth, drainage, and groundwater depth. Twelve factors including texture (clay), pH, slope, distance from rivers, distance from residential areas, cation exchange capacity, organic matter, calcium, magnesium, potassium, phosphorus and degree of base saturation were calculated using the geostatistical method of Kriging on a point coverage. This point coverage contains the values of the variables after chemical analysis of the respective borings. The grids after Kriging interpolation are given in Figure 5. These maps were standardized using fuzzy membership functions, which were set after experience and statistical analysis of the data. The fuzzy functions for each of these factors are presented in Figure 6.

The pairwise comparison method was used to assign weights and establish importance of the non-constraint criteria (Table 3) using experience and characteristics of the study area. The highest weights were assigned to

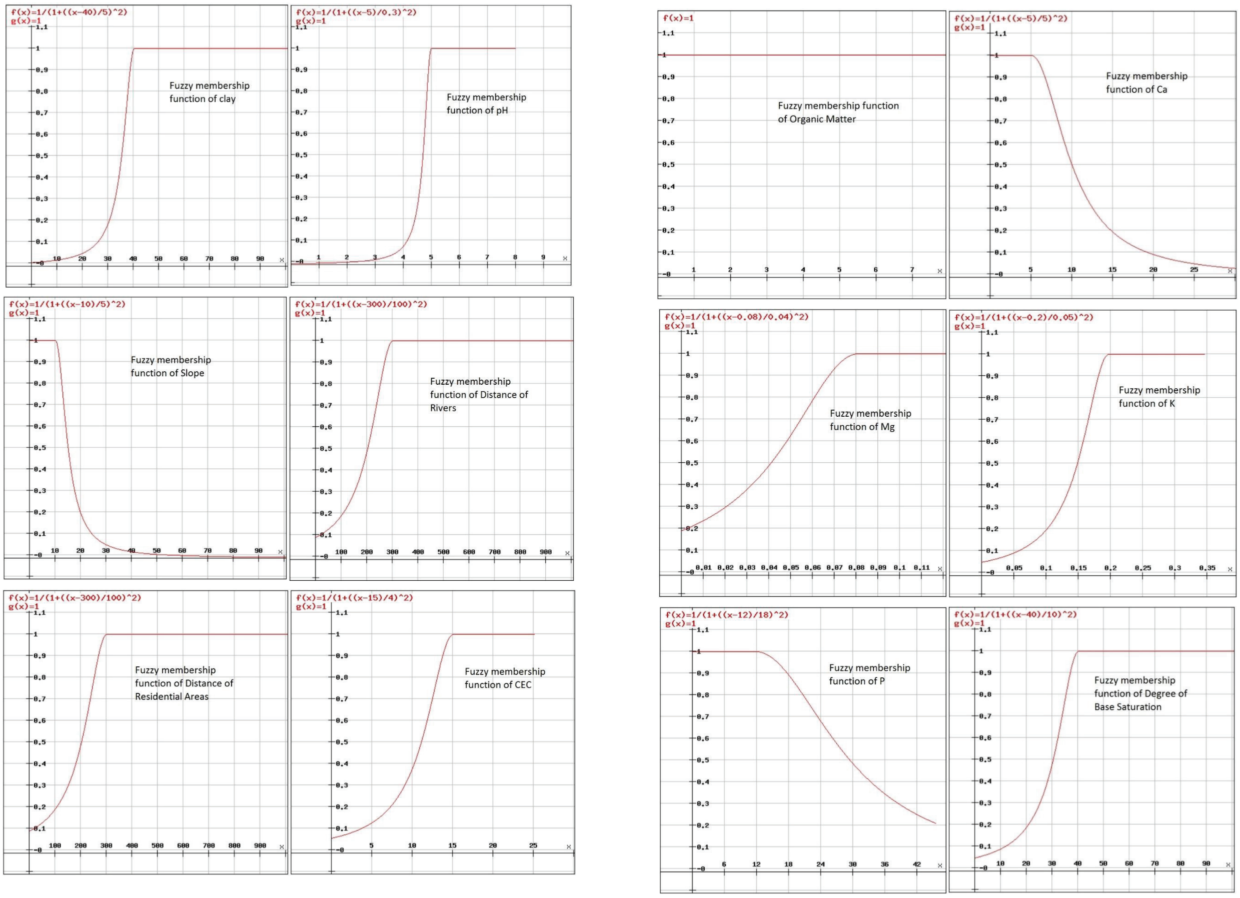

Figure 6. Fuzzy membership functions for the non-constrain criteria.

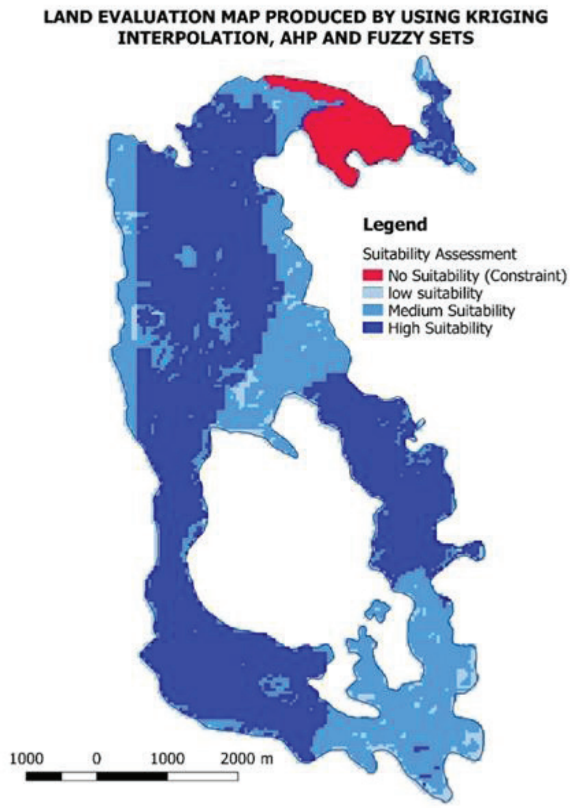

Figure 7. Final Land Evaluation Map of Xiromero Aetolia-Acarnania study area.

the distances from rivers and residential areas, as well as slope, as the most important for OMWW disposal. Nutrients, *i.e.* Ca, Mg, K, P, were considered to have equal importance and therefore, they were assigned equal weights. The Consistency Ratio (CR) is 0.027 which is considered acceptable (less than 0.1).

Intermediate suitability maps were created for these criteria respectively. Final aggregation was implemented to demonstrate the importance of the weights and therefore, the final OMWW disposal site suitability map was produced considering the constraint and non-constraint criteria (Figure 7). The higher values on the final map indicate more suitable areas for OMWW disposal.

Conclusions

OMWW disposal on soils is undoubtedly an existing need. To this challenge, spatial analysis combined with conventional and non-conventional methods is a promising field where valuable decision support tools can be developed. Conventional methods include land suitability, where Boolean logic is used for determining soil suitability classes. Non-conventional methods used in this study are geostatistical interpolation techniques, analytical hierarchy process and fuzzy set theory. Conventional methods were applied in both global and local scales, while non-conventional methods were applied only for local scale where analytical soil data were available in point coverage (soil borings).

The proposed methodology would aid the decision-making procedure taking into consideration constraints and factors. Depending on the defined goal, decision makers and environmental planners could design their strategies for waste management more efficiently, and therefore treat waste with environmentally friendly zero-waste practices. Our approach illustrates the flexibility of the methods applied and provides a valuable tool for multi-criteria decision support processes.

While the proposed methodology is not exhaustive, our future endeavors will rely on deeper analysis of multicriteria methods by incorporating the feedback of our approach with real data and applications. Therefore, the end-users of our methodology, such as municipal authorities, agriculturalists, farmers and any other national or local stakeholders, can evaluate and further enhance this approach with their contribution.

Key Points

- An integrated GIS multicriteria decision support system for evaluating the land suitability for olive mill wastewater disposal.
- Physical, chemical, and socioeconomic variables adapted to the Mediterranean soil conditions are used as driving forces to the land suitability assessment.
- Geostatistical, fuzzy set theory techniques, as well as Analytical Hierarchy Process (AHP) are appropriately integrated.
- A valuable tool for municipal authorities, agriculturalists, farmers, and other national and local stakeholders.

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