Mapping Spatial Variability Status of Criteria Influencing Crop-Land Suitability Using Geographic Information System

Olsid Mema, Etleva Jojic, Perparim Laze, Ilir Salillari and Stephan Mäs

***Abstract*—The assessment of crop-land suitability is crucial for optimizing agriculture productivity and resource allocation. By employing Geographic Information system (GIS), we can effectively analyze and visualize the spatial distribution of various factors that impact crop suitability, such as soil properties, climate conditions, topography and land use patterns. The aim of the study is to investigate the spatial variability status of criteria that influence crop-land suitability through utilization of GIS techniques. The research methodology involves collecting and integrating multi-source data, including soil samples, climate data, digital elevation model and land use land cover. These dataset are processed, analyzed and classified, using the GIS tool to generate spatial layers representing criteria. Each spatial layer was classified, according to FAO guidelines for land evaluation, into four categories of suitability (highly suitable, moderately suitable, marginally suitable and unsuitable) for crop cultivation. By analyzing these layers, we can identify areas with high or low suitability for specific crops, enabling informed decision-making for agriculture planning and management. The result of this study will provide valuable insights into the spatial variability of crop-land suitability, allowing land managers and farmers to make informed decisions regarding land use, crop selection and resource allocation. The utilization of GIS techniques in this research enhances our understanding of the complex relationships between various criteria and their spatial distribution, contributing to sustainable and efficient agricultural practice.**

***Keywords*— Geographic Information System, Inverse Distance Weighting (IDW), Spatial Interpolation, Sustainable Agriculture**

I. INTRODUCTION

The increasing food demands have placed immense pressure on current agricultural producers due to the rising population and limited availability of land and resources [1]. According to the United Nations Development program (UNDP), the world's population is estimated to grow to almost 10 billion people by 2050 and this requires more food production [2].

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Knowledge of soil, land and climate properties is crucial for effective optimization of agriculture practices. By understanding the spatial distribution of these properties, farmers can better select and manage crops based on soil suitability. They can optimize crop yield and quality by matching crops to areas with suitable soil and climate condition, reducing the risk of crop failure and improving overall sustainability. The spatial distribution of soil, land, climate and land use patterns is essential in sustainable agriculture planning, as it can aid in optimization of effort and time for cultivation processes [3]. In this regard utilization of Geographic Information System (GIS) is at a paramount importance because soil properties, land properties, climate properties and land use patterns can be effectively visualized and interpreted, facilitating better understanding and informed decision making for agricultural practices and management. GIS is conventionally seen as a set of tools for the input, storage and retrieval, manipulation and analysis, and output of spatial data [4]. The data output component of a GIS provides a way to see the data and information in the form of maps, tables, diagrams etc. and furthermore the fundamental part of a GIS is a database orientation [5].

In terms of assessing the appropriateness of land for growing crops, the Food and Agricultural Organization (FAO) proposed an approach for land evaluation. This approach involves assigning suitability ratings, which range from highly suitable to unsuitable, to areas based on various criteria such as climate, topography, soil and social economic data [6], [7]. The first step for assessing the crop-land suitability is to identify the criteria and once the data is collected, it needs to be mapped to visualize the spatial distribution of the criteria. A study carried out in Izmir [8] took in consideration five criteria: elevation, slope, aspect, land capability (chemical and physical soil properties) and solar radiation to assess the suitability for vineyard production. Another case study, in the Marvdasht plain, of Fars province, Iran was carried out to generate land suitability maps for maize through employment of GIS and selecting of ten criteria: annual average temperature, annual minimum temperature, annual maximum temperature, elevation, slope, pH, electric conductivity, cation-exchange capacity, soil texture and exchangeable sodium percentage [9]. In the Tozanli sub-basin located in the upper part of Yesilırmak Basin, Turkey topographic (elevation, slope, aspect) characteristics of the basin and some physical and chemical properties of the soil (texture, pH, electrical conductivity, lime, organic matter, and soil depth) were used as a criteria in determining the suitability classes for wheat cultivation and generating a suitability map through GIS [10]. To resolve the problem of mapping the spatial variability status of criteria various spatial interpolation techniques have been employed. Spatial interpolation is a procedure of predicting the value of attributes at unobserved locations from measurements made at point locations within the same geographical area [11]. Three well-known spatial interpolation techniques commonly used for characterization the spatial variability and interpolation between sampled points and generating the prediction maps are Ordinary Kriging (OK), Inverse Distance Weighting (IDW) and Radius Basic Functions (RBF). There is currently much controversy about which interpolation method is ideal for different properties and case studies. Several studies [12], [9] have reported that OK is the best for mapping soil characteristics. In some other studies [13], [14] IDW seems to be an appropriate method for mapping soil fertility elements. In some cases [15] RBF reported better results comparing to IDW or OK.

In Albania, agriculture provides 50% of employment and 19% of GDP. Of the total agricultural area of 695,000 ha (24% of the area of the country), 80% is under private ownership and 20% is under state ownership [16]. Among all types of crops, Cereals (maize, wheat, barley, etc.) are the major food crops which form the basis of the food diet and are essential to our economy. In both developed and developing countries, cereals and cereal products are main foods in most human diets, providing a major proportion of dietary energy and nutrients [17]. However, the production level of cereals in Albania remains at a problematic level in relation to consumption, covering approximately 40% of the demand, while the rest is imported from countries such as Serbia, Ukraine, Russia, etc., and furthermore due to the war in Ukraine nowadays grain markets are unstable. According to Ministry of Agriculture and Rural Development of Albania, for year 2023, wheat has the biggest reduction in the planted area, where compared to 2005, the area planted with wheat has been reduced by 35%.

In this context, in order to use the available agricultural land in an optimal way, to have sustainable agricultural production, mapping the spatial variability status of soil, land, climate and land use patterns influencing land suitability for wheat cultivation is essential. The scarcity of investigations attending the mapping of soil, land and climate properties at regional scales is evident, highlighting the need to provide accurate mapping techniques for various properties. Therefore, the main objectives of this study are: (i) to identify the criteria influencing land suitability for wheat cultivation based on the accessibility and the relevance of the data within the biophysical and socioeconomic condition of the study area (ii) to set the relative importance of classes of criteria according the suitability thresholds of wheat (iii) to generate criteria maps using spatial interpolation in GIS environment.

II. MATERIALS AND METHOD

A. Study Area

The study was carried out in Mollaj administrative unit, between latitudes 40^0 28’ 45’’- 40^0 34’ 57’’ N and longitudes 20^0 39’ 46’’- 20^0 47’ 40’’ E, located in Korça municipality, in southeastern of Albania (Fig.1). The area where the research was held covers approximately 2600 ha. The average annual temperature is around 13^0 and the average annual rainfall is

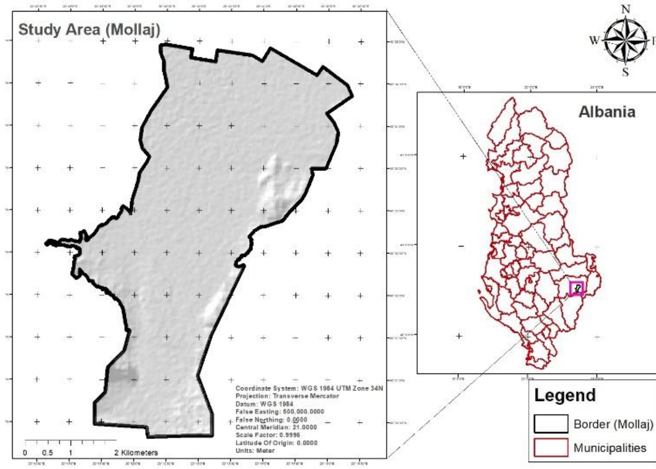

Fig.1. Location of the study area

around 800 mm [18]. The administrative unit consist of plain area that lies on the northwest, north and northeast side of the municipality. Slopes in the plain area vary from 0.7 to 2.5% and at the bottom of the hills vary from 3.5 to 17 %. In the rest of the land slopes are greater than 25%. Erosion is not very problematic, it appears mainly in the hilly area of Floq and Kamenica villages. Also the study area is not affected by the flood phenomenon. The area is mainly used for the cultivation of wheat, fruit trees, alfalfa, corn, vegetables, beans, beets, vineyards [19].

B. Soil Samples

The field survey was undertaken using a hand probe to examine the soil profile at a depth of 1.2 m with grid points 300 m apart. At each drilling point, a series of soil characteristics were described and recorded [20]. A number of 265 survey points and 6 soil profile were collected and a database containing all the information of the soil for the study area was prepared. Soil samples taken for all the horizons of the soil profile were sent and analyzed to the Analytical Laboratory of the Agricultural Transfer Center, Fushe-Kruje, Albania. In this study, for mapping the soil properties only the upper layer at a 30 cm depth of the soil was used.

C. Criteria Selection, Description and Source

There is no technique for selecting evaluation criteria. The process of selecting the criteria for suitability analysis is an iterative process [21]. The selection of evaluation criteria relies on literature reviews, analytic studies and expert opinions [22]. The criteria are chosen from two main categories: the physical environment and the social-economic environment. In this study eight criteria: texture, soil depth, pH, organic matter (OM), cationic exchange capacity (CEC), slope, rainfall, land use and land cover (LULC) were incorporated. Texture is considered as one of the most important characteristics with regard to physical soil qualities. Soil texture is determined by the proportions of sand, silt and clay within the soil. It influences such important soil properties as soil water availability, infiltration rate, drainage, tillage conditions and capability to retain nutrients [23]. Soil depth is important because it provides insight into the growth of roots and the availability of moisture and air within the root zone [24]. Soil pH is a master variable in soils because it controls many chemical and biochemical processes operating within the soil. Soil pH shows the degree of acidity or alkalinity of a soil and ranges from 1 to 14 where the optimum range for most agricultural crops is between 5.5 and 7.5 [23]. Soil organic matter refers to the decomposed materials in the soil that originate from living organisms, such as plants or animals. It plays a vital role improving various aspects of the soil health. Additionally organic matter has positive influence on soil on decreasing chemical fertilizer use, reducing herbicide and pesticide use, minimizing erosion and increasing productivity [25]. Cation exchange capacity influence suitability as defines the presence or absence of a mineral reserve and influence the retention for nutrients and water [23]. Another significant aspect influencing the suitability of land for wheat cultivation is slope magnitude. Slope degree has a direct effect on erosion, irrigation, tillage, use of mechanization in agriculture, etc. Both soil and water lose are directly influenced by the steepness of the slope [26]. Rainfall has also significant effect on the production of rainfed winter wheat. In general, crops are more sensitive to water deficits during emergence. Present land use and land cover is necessary to successfully detect changes and identify appropriate agriculture land [27].

The physical-chemical soil data (pH-H2O, texture, soil depth, organic matter, Cationic exchange capacity) were obtained from Agriculture Technology Transfer Center, Fushë Kruje, part of Ministry of Agriculture and Rural Development of Albania after they were analyzed in laboratory. The land use and land cover map (LULC 2022), derived from Esri New 2020 Global Land Cover Map with a resolution of 10 meters, was created utilizing satellite imagery from the European Space Agency (ESA) Sentinel-2 satellite [28]. The slope raster was generated in ArcGIS environment, using a Digital Elevation Model (DEM) at a resolution of 30 m, obtained from the Shuttle Radar Topographic Mission (SRTM). The precipitation data were obtained from Climate Research Unit (University of East Anglia) and UK's National Centre for Atmospheric Science (NCAS) [29].

D. *Generation of Thematic Maps*

IDW interpolation technique was used in ArcGIS 10.8 environment, for mapping soil parameters such as texture, soil depth, pH, organic matter, cationic exchange capacity and climate parameters such as rainfall. The IDW approach is a deterministic spatial interpolation technique used in many GIS-based location selection application for mapping various parameters [30], [31], [32]. IDW will use the measured values surrounding the prediction location in order to predict a value for any unmeasured location. The points closest to the target location are given more weight [33]. The model used in IDW is given in (1) and (2) [34]:

$$a(x) = \frac{\sum_{i=1}^{n} w_i a_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

$$w_i = d_i^{-p} \quad (2)$$

where a_i is known data; *a(x)* is the unknown data; *n* is the number of known data; d_i is the distance between point *i* (known data) and unknown point; w_i is the weight allocated to point *i*; *p* is the power or control factor, influencing the extent of weight reduction.

In ArcGIS format (shape file or raster) all the thematic maps were created as layer maps and were converted and geo referenced into Universal Transverse Mercator (UTM) projection zone number 34 N of WGS 1984 as a coordinate reference system to support the mapping of Albanian territory [35]. Reference parameters of the Coordinative Reference established by Military Topographic Institute of Albania after 1994 year are [36]: Ellipsoid origin of North: Earthy Equator $(\varphi = 0^0)$; Ellipsoid origin of East: Central Meridian $\lambda = 21^0 E$; Map Projection name: UTM zone *34 N*; False northing, in grid units: *0.000* m; False easting, in grid units: *500 000.000* m, in west of meridian $\lambda = 21^0$; Scale factor at natural origin in central meridian $(\lambda_0 = 21^0)$: $k_0 = 0.9996$; Magnitude of projection zone: 6^0; Projection Zone: *34*; Projected CRS axes units name: meter.

E. *Standardization Criteria Layers according to Suitability thresholds of wheat*

The suitability classes in the output maps are according FAO framework for land evaluation [37], and are as follows:
Class S1 (highly suitable) where the land has no significant limitations to sustained application of a given use.
Class S2 (moderately suitable) where the land has limitations which in aggregate are moderately severe for sustained application of a given use.
Class S3 (marginally suitable) where the land has limitations which in aggregate are severe for sustained application of a given use.
Class N1 (currently not suitable) where the land has severe limitations that preclude the given type of use, but can be improved by specific management.
Class N2 (permanently not suitable) where the land has so severe limitations which are very difficult to be overcome.

In this study as in other studies [38], [39] the last two classes N1, N2 are combined in one class.

For this study we selected winter wheat due to popularity on cereal cultivation, area coverage, climate favorability, high market demands and production per hectare in Albania.

III. RESULTS AND DISCUSSIONS

Table I shows four limitation levels, from highly suitable to not suitable using appropriate categories and their respective rate values. Existing literature review was used as a basis for processing Table I [40], [41], [38], and was adopted to the Albanian conditions. Land suitability maps were generated and the area was calculated for eight criteria including texture, pH, cation exchange capacity, soil depth, slope, organic matter, land use land cover and rainfall. Regarding the cation exchange capacity the result reveal that 67% of the study area was highly suitable (Fig.2). 32.2 % of the study area was classified as moderately suitable while 0.8 % was categorized as marginally suitable. Loam, clay loam and silt clay loam are considered the best for wheat production. The characteristics of the soil

TABLE I: STANDARDIZATION CRITERIA USED FOR WHEAT SUITABILITY

Criteria	S1	S2	S3	N
Slope	0-4	4-8	8-16	>16
Rainfall	450-1250	1250-1500	1500-1750	>1750
pH	6.5-8.0	8.0-8.3	8.3-8.5	>8.5
Soil depth	>100	75-100	50-75	<50
OM	>1.5	1.5-1.0	<1.0	-
CEC	>24	16-24	5-16	<5
Texture*	L,CL,SiCL	C, SCL	C>60%,LS	S
LULC	Crops	Barren land		Other classes

*L-loam, CL-clay loam, SiCL- silty clay loam, LS- sandy loam, S-sandy

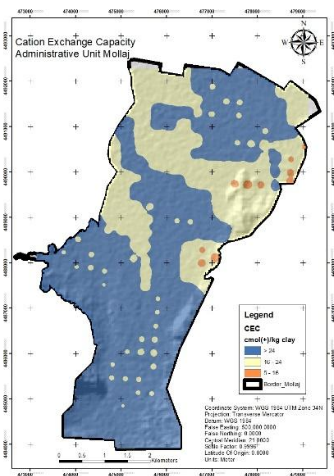

Fig.2. Cation exchange capacity

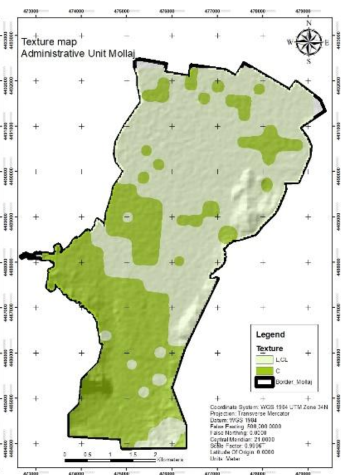

Fig.3. Texture (cmol (+)/kg clay)

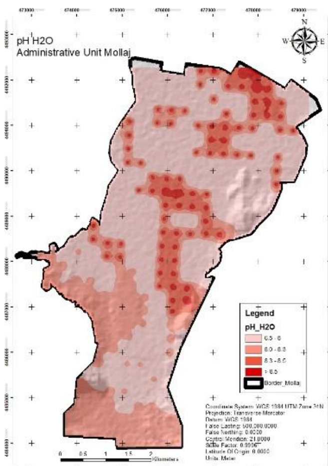

Fig.4. pH

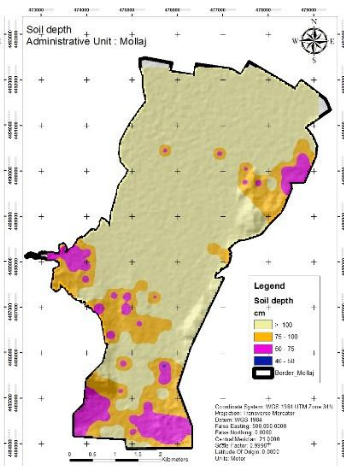

Fig.5. Soil depth (cm)

such as moisture holding capacity, electric conductivity, pH, salinity, soil structure and nutrient contents as well as biological components like microbial biomass, show variations depending on the texture of the soil [42]. Regarding the texture the result of this study showed that 57.8 % of the area was highly suitable and 42.2 % of the area was moderately suitable for wheat cultivation (Fig.3). The majority of the land dedicated to growing wheat (55.7%) had pH levels that fell in optimal range from 6.5-8 [40] making it highly suitable for cultivation. About 29.3 % of the area was deemed moderately suitable and 11.5% marginally suitable, while a small portion of 3.5 % was found

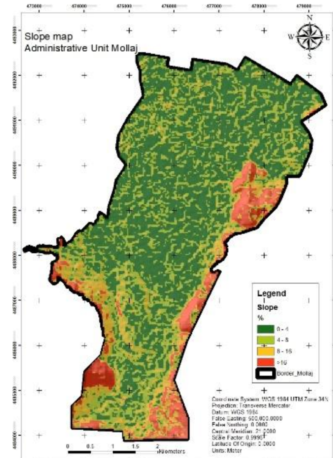

Fig.6. Slope (%)

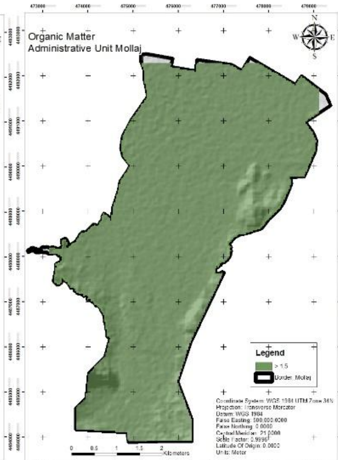

Fig.7. Organic matter (%)

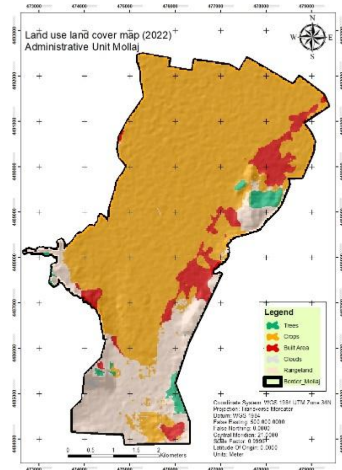

Fig.8. Land use and land cover

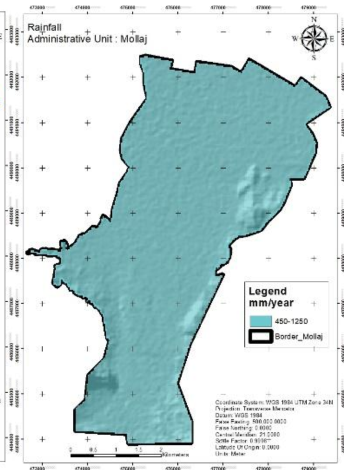

Fig.9. Rainfall (mm/growing cycle)

to be not suitable (Fig.4). For wheat production, the minimal soil depth is 0.1 m and the optimal conditions are met in soils with an available depth >1 m [41]. According to the results, a vast portion, specifically 73.7 % displayed a high level of suitability for wheat production due to the presence of very deep soils. These deep soils constitutes 17.7 % of the entire area, rendering them moderately suitable for growing wheat. Additionally, 8.6 % of the total land area possessed shallow soil depth, suggesting a marginally suitable condition for wheat production (Fig.5). Slope shape and slope length are important factors which directly affect wheat cultivation. Taking into account the slope of the land is crucial to mitigate the risks stemming from natural disaster like floods and landslides. The slopes exhibit varied distribution of soil qualities, such as soil depth, soil moisture, soil texture and nutrient availability [43]. The results demonstrated that a significant portion of the total area, specifically 50.9% exhibited a high level of suitability in relation to slope. Furthermore, an additional 29% of the area was deemed to possess a moderate level of suitability. However, it is worth noting that 11.1% of the area fell under the category of marginal suitable and only 9% of the study area was not suitable (Fig.6). The results from the organic matter distribution in the study area indicates that the whole area is extremely well-suited (Fig.7). LULC classification of the area gives idea about the present status of the land. LULC analysis enables the identification and assessment of various land types such as agriculture areas, tree cover, forest, water bodies, built areas revealing their spatial arrangement and distinctive. Various studies have used LULC for land suitability assessment [27], [42], [44]. 72.1 % of the study are was highly suitable as an agricultural area, 18.6 % of the study area was considered moderately suitable and 9.28 % was found not suitable (Fig.8). Wheat cultivation regions require a minimum of 200 mm of rainfall per growing season. The average yearly precipitation should ideally range from 450-1250 mm. The results demonstrated that the study area is highly suitable regarding precipitation for wheat production (Fig.9).

IV. CONCLUSION

Utilization of Geographic Information System (GIS) in mapping the spatial variability status of various factors has proven to be highly valuable. This technology allows integration of different spatial datasets and the analysis of multiple criteria together. By analyzing the spatial variability, it become possible to evaluate the present conditions of crop-land suitability within a specific area. By targeting areas with the highest suitability, farmers can optimize their yields, reduce resource wastage and mitigate the environmental impacts associated with agricultural activities.

In addition, the utilization of GIS allows for data to be visually displayed, thereby enhancing comprehension among stakeholders regarding intricate connections among various factors. Moreover, the ability to generate high-resolution maps using IDW interpolation technique assist in identifying precise areas within a region where specific crops are likely to thrive. However, it is important to note that IDW interpolation also has limitations. Depending only on the proximity of data points may not account for certain spatial patterns or variations in the landscape. Other interpolation techniques can complement IDW. It is essential to compare the results obtained through different interpolation methods to ensure the accuracy and reliability of the suitability assessments.

In conclusion, as GIS technology continues to progress, it holds immense potential to improve agricultural practices and promote sustainable land use management.

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