

## RESEARCH ARTICLE

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# Sensitivity Analysis of Multi-Criteria Based Wheat Suitability Mapping Using One-At-a-Time (OAT) Approach in Frakulla Administrative Unit

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## Abstract

Accurate land suitability assessment is fundamental to sustainable agricultural planning, yet the reliability of GIS-based Multi-Criteria Evaluation (GIS-MCE) models remains sensitive to the subjective assignment of criterion weights. This study presents a systematic One-At-a-Time (OAT) sensitivity analysis of a wheat (*Triticum aestivum* L.) suitability model developed for the Frakulla Administrative Unit, Fieri Municipality, southwestern Albania. The baseline suitability map was constructed using a Weighted Linear Combination (WLC) approach, integrating five main criterion groups: climatic conditions, physical soil properties, biological and chemical soil characteristics, flood and erosion risk, and infrastructure accessibility, with weights derived through the Analytic Hierarchy Process (AHP). All criteria were standardized into four suitability classes (Not Suitable, Marginally Suitable, Moderately Suitable, and Highly Suitable) across a 30 × 30 m raster grid. Sensitivity was evaluated through systematic ±10% and ±20% weight perturbations applied independently to each criterion group, generating 20 perturbation scenarios in total. Spatial agreement with the baseline classification ranged from 71.3% to 89.1%, indicating high model stability under weight perturbations. These results provide a quantitative uncertainty assessment that strengthens the scientific credibility of the wheat suitability map and offers actionable guidance for evidence-based agricultural land use planning in the Fieri region.

**Keywords:** Analytic Hierarchy Process; Crop-land suitability analysis; GIS-based Multi-Criteria Evaluation; Model Uncertainty; OAT sensitivity analysis; Weighted Linear Combination;

## 1. Introduction

Land suitability assessment has long been considered a cornerstone of rational agricultural planning. Since the pioneering framework proposed by the Food and Agriculture Organization [1], evaluating the compatibility between land characteristics and crop requirements has guided countless decisions related to agricultural development, land use planning, and food security policy. Wheat (*Triticum aestivum* L.) occupies a particularly strategic position in this context, as it remains one of the most widely cultivated and consumed cereal crops worldwide, providing a substantial share of the caloric and protein intake for billions of people across diverse agro-ecological zones [2]. As population growth continues to exert mounting pressure on finite agricultural land resources, the need for accurate, spatially explicit and scientifically defensible wheat suitability assessments has never been more urgent.

Over the past two decades, the integration of Geographic Information Systems (GIS) with Multi-Criteria Evaluation (MCE) techniques has fundamentally transformed how researchers and planners approach land suitability analysis [3]. Rather than relying on single-factor assessments or purely qualitative judgments, GIS-MCE frameworks allow the simultaneous consideration of multiple biophysical, environmental and socioeconomic factors within a spatially coherent analytical structure [4]. Among the various aggregation methods available within this framework, the Weighted Linear Combination (WLC) approach has gained particular prominence in agricultural suitability studies [5]. Its appeal lies not only in its methodological simplicity and computational tractability but also in its capacity to reflect the relative importance of different criteria through the explicit assignment of weights. In practice, WLC-based suitability maps are constructed by multiplying standardized criterion scores by their respective weights and summing the results into a composite suitability index, a process that is both

intuitive and readily interpretable by non-specialist audiences such as agricultural planners and policy makers [6]. That said, the apparent simplicity of the WLC method should not obscure a fundamental challenge that pervades its application: the determination of criterion weights. Whether derived through expert consultation, pairwise comparison using the Analytical Hierarchy Process [7], or participatory stakeholder approaches, weight assignments inevitably carry a degree of subjectivity that can meaningfully influence the spatial pattern of the resulting suitability map. This is not merely a theoretical concern. In applied settings, even modest differences in how much importance is assigned to, say, soil texture versus precipitation can shift substantial portions of a study area from one suitability class to another, with direct implications for where agricultural investments are directed and which communities benefit from development interventions [8]. Acknowledging and systematically examining this source of uncertainty is therefore not optional, it is an essential component of responsible spatial modeling. Sensitivity analysis offers precisely the kind of structured, reproducible framework needed to address weight-related uncertainty in GIS-MCE models. By deliberately varying input parameters within defined ranges and observing the corresponding changes in model output, sensitivity analysis allows researchers to identify which criteria exert the greatest influence on the final suitability classification and conversely, which criteria the model can tolerate being adjusted without significant consequence [9]. Among the available sensitivity analysis techniques, the One-At-a-Time (OAT) method stands out for its transparency and practical applicability in spatial modeling contexts [10]. The OAT approach works by perturbing one criterion weight at a time, while proportionally rescaling all remaining weights to ensure the total always sums to unity and then comparing the resulting map against the original baseline classification. Repeating this process across all criteria and multiple perturbation levels produces a comprehensive picture of the model's sensitivity landscape [11]. The value of this approach has been demonstrated across a growing body of literature. In agricultural applications specifically, a study from Chen et.al [12] confirmed that OAT-based sensitivity testing adds a meaningful layer of credibility to suitability assessments by making explicit the conditions under which classification outcomes remain stable or begin to break down. These

contributions collectively make a compelling case for embedding sensitivity analysis as a standard validation step in any GIS-MCE based land evaluation study. Nevertheless, wheat-specific suitability mapping studies that simultaneously account for flood and erosion hazard, soil physical properties, soil biochemical characteristics, climatic conditions and infrastructure accessibility within a unified sensitivity analysis framework remain relatively scarce in the literature. Each of these criteria captures a distinct dimension of land capability for wheat production and their combined interaction under varying weight assumptions warrants careful investigation. Against this backdrop, the present study undertakes a systematic OAT sensitivity analysis of a GIS-MCE based wheat suitability map, with weight perturbations of  $\pm 10\%$  and  $\pm 20\%$  applied across all five main group criteria.

The analysis pursues three specific objectives. First, to spatially identify and map where suitability classes change across the study area under each weight perturbation scenario, through a criterion-by-criterion visual comparison between the original and perturbed suitability maps. Second, to quantify the degree of spatial agreement between each perturbed scenario and the original map using a comprehensive agreement heatmap, enabling a direct numerical assessment of map stability across all criteria and perturbation levels. Third, to examine how the overall balance of suitability classes shifts across perturbation scenarios relative to the original map, providing a landscape-level perspective on the sensitivity of the wheat suitability assessment. Together, these objectives form a coherent evaluation of the robustness and reliability of the original wheat suitability map for informed agricultural planning.

## 2. Material and Methods

### 2.1. Study Area

The study area, located in the Frakull administrative unit within Fieri municipality in southwestern Albania ( $40^{\circ} 35' 12''$  N to  $40^{\circ} 40' 41''$  N and  $19^{\circ} 28' 49''$  E to  $19^{\circ} 32' 44''$  E), experiences a Mediterranean climate with warm, arid summers and temperate, rainy winters, with a mean annual temperature of approximately  $18^{\circ}\text{C}$  and annual precipitation ranging from 750 to 1250 mm [13]. The region's agricultural activity is predominantly characterized by the cultivation of alfalfa, fruit orchards, vegetables, maize, wheat, olive plantations,

and vineyards, mainly concentrated in the lowland areas [14].

## 2.2. Data and main criteria groups

Land suitability assessment for wheat production was based on five main groups of criteria: climate indicators (temperature and rainfall during the crop cycle), physical soil properties (depth, texture, drainage, water availability and coarse particle content), biological and chemical soil characteristics (fertility class, electric conductivity, exchangeable percentage sodium and cation exchange capacity), flood and erosion risk (slope, aspect, erosion risk, and flood frequency) and infrastructure availability (distance to water sources and roads) [15]. Soil samples were taken from Agricultural Technology Transfer Center in Fushe-Kruje, Albania, although for the purpose of soil property mapping, only the uppermost soil layer at a depth of 30 cm was considered in this study. Data on road infrastructure, necessary for calculating road proximity values, were sourced from OpenStreetMap (OSM), a freely accessible open-source geospatial database [16]. The land use and land cover map was produced using the Esri New 2020 Global Land Cover Map at a 10-meter resolution, derived from satellite imagery acquired by the European Space Agency (ESA) Sentinel-2 satellite [17], while the slope raster was developed within the QGIS environment using a 30-meter resolution Digital Elevation Model (DEM) obtained from the Shuttle Radar Topographic Mission (SRTM). All criteria layers were standardized to a common suitability scale with four discrete classes: Not Suitable, Marginally Suitable, Moderately Suitable, and Highly Suitable [1]. Raster layers were resampled to a common spatial resolution (30\*30 m) and spatial datasets were projected to a common coordinate reference system WGS 84 / UTM zone 34N, consistent with Albanian national mapping standards.

## 2.3. Multi-Criteria Evaluation and Weight Assignment

The Analytic Hierarchy Process (AHP) [7] was employed to establish the relative importance of each main group criterion. Expert consultations and priority judgments drawn from the literature informed the construction of a pairwise comparison matrix. To ensure reliability, the Consistency Ratio (CR) was used to assess the coherence of comparisons, with only those weight sets yielding a CR below 0.10 being retained, in

accordance with widely accepted standards [18]. The weighting results indicated that Flood and Erosion Hazard (32.2%) and Soil Physical Characteristics (25.6%) were the most influential factors in determining land suitability, followed by Soil Biological and Chemical Characteristics (22.3%), Climate (14.1%), and Accessibility (5.8%) in descending order of importance [19]. The internal consistency of the pairwise comparison matrix was verified by a Consistency Ratio (CR = 0.04), which falls well below the acceptable threshold of 0.10. The normalized weights derived from this process capture the varying degrees to which each criterion influences overall wheat suitability. The final wheat suitability map (WSM) was produced using the Weighted Linear Combination (WLC) method, one of the most widely applied aggregation techniques in GIS-based MCE frameworks [20] computed as (1):

$$WSM = \sum(SSVi \times WEIGHTi) \quad (1) \quad \text{where } SSVi \text{ denotes the standardized suitability value of criterion } i, \text{ and } WEIGHTi \text{ is the relative weight of criterion } i.$$

## 2.4. One-At-a-Time (OAT) Sensitivity Analysis

To evaluate the robustness of the final wheat suitability map with respect to weight uncertainty, a One-At-a-Time (OAT) sensitivity analysis was conducted [21]. The OAT method was selected for its transparency, computational efficiency and suitability for MCE models involving a limited and well-defined set of criteria [22]. Unlike global sensitivity methods, OAT isolates the individual contribution of each criterion to output variability by perturbing one weight at a time while keeping all others adjusted proportionally [23]. Each criterion weight was systematically varied across four perturbation levels, namely -20%, -10%, +10%, and +20% of its baseline value. When a given criterion weight  $w_i$  was perturbed by a variation  $d$ , the new perturbed weight was computed as (2):

$$wi^* = wi + d \quad (2)$$

where  $wi^*$  is the perturbed weight of criterion  $i$  and  $d$  is the perturbation magnitude applied.

An important constraint in this process is that the sum of all criterion weights must always remain equal to one, as is required by the WLC method. Therefore, whenever one criterion weight was increased or decreased, the weights of the remaining four criteria were automatically adjusted upward or downward in

proportion to their original baseline values. This proportional rescaling ensured that no single criterion was artificially inflated or deflated beyond what the perturbation of the target criterion alone would justify, and that the overall weight structure remained internally consistent throughout all scenarios. This procedure was repeated independently for each of the five criteria and across all four perturbation levels, generating a total of 20 (5 criteria x 4 perturbation levels) perturbation scenarios in all. Each scenario produced an independently classified wheat suitability map that was subsequently compared against the original map to measure the degree of spatial change introduced by the weight perturbation.

### 2.5. Comparison Against the Original Suitability Map

Each of the 20 perturbed suitability maps was compared directly and independently against the original wheat suitability map on a pixel-by-pixel basis. This direct comparison was considered the most appropriate validation approach, as it measures the actual spatial divergence between each perturbed scenario and the map that would be used in practice for agricultural planning decisions. To provide a spatially explicit visualization of these changes, five comparison figures were produced, one for each criterion. Each figure presents the original suitability map alongside the four perturbed scenario maps corresponding to that criterion, arranged in a side-by-side panel layout.

### 2.6. Agreement Heatmap

Agreement Heatmap was constructed to present the overall spatial agreement between each perturbed scenario and the original suitability map in a compact and visually interpretable format. The heatmap displays all five criteria along one axis and all four perturbation levels along the other, with each cell colored according to its agreement percentage. This visualization allows patterns of sensitivity to be identified at a glance, for instance, whether certain criteria show consistently low agreement across all perturbation levels, or whether the map is particularly sensitive to weight reductions compared to weight increases.

### 2.7. Suitability Class Distribution Analysis

To further characterize the effect of weight perturbations on the overall composition of the suitability map, the distribution of suitability classes

was examined for each of the 20 perturbed scenarios and compared against the original map. For each scenario, the percentage of the study area falling into each of the four suitability classes: Not Suitable, Marginally Suitable, Moderately Suitable, and Highly Suitable was computed and displayed in a stacked bar chart format. All spatial analyses were performed in R statistical software [24] for data visualization combined with QGIS.

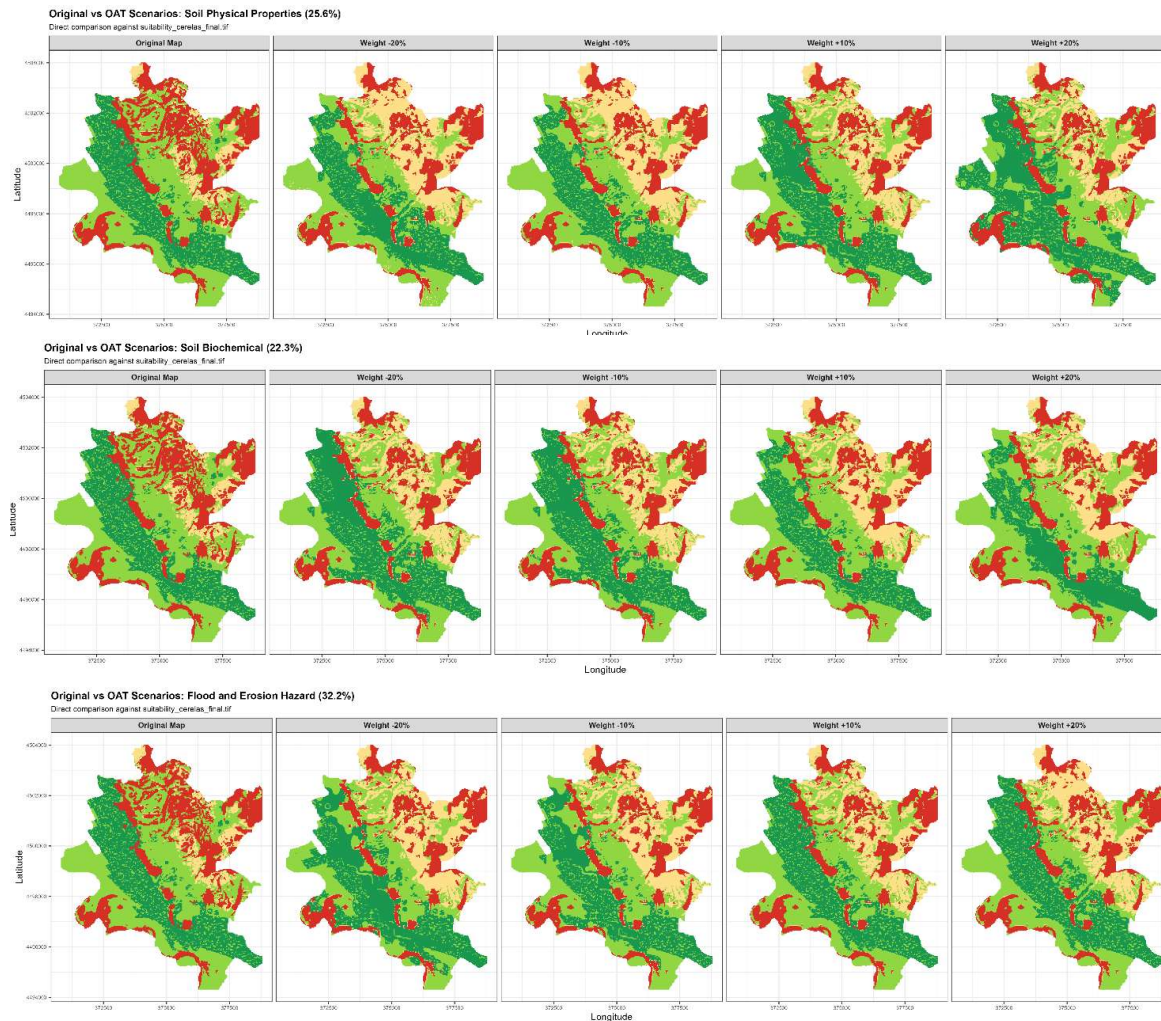
## 3. Results and Discussion

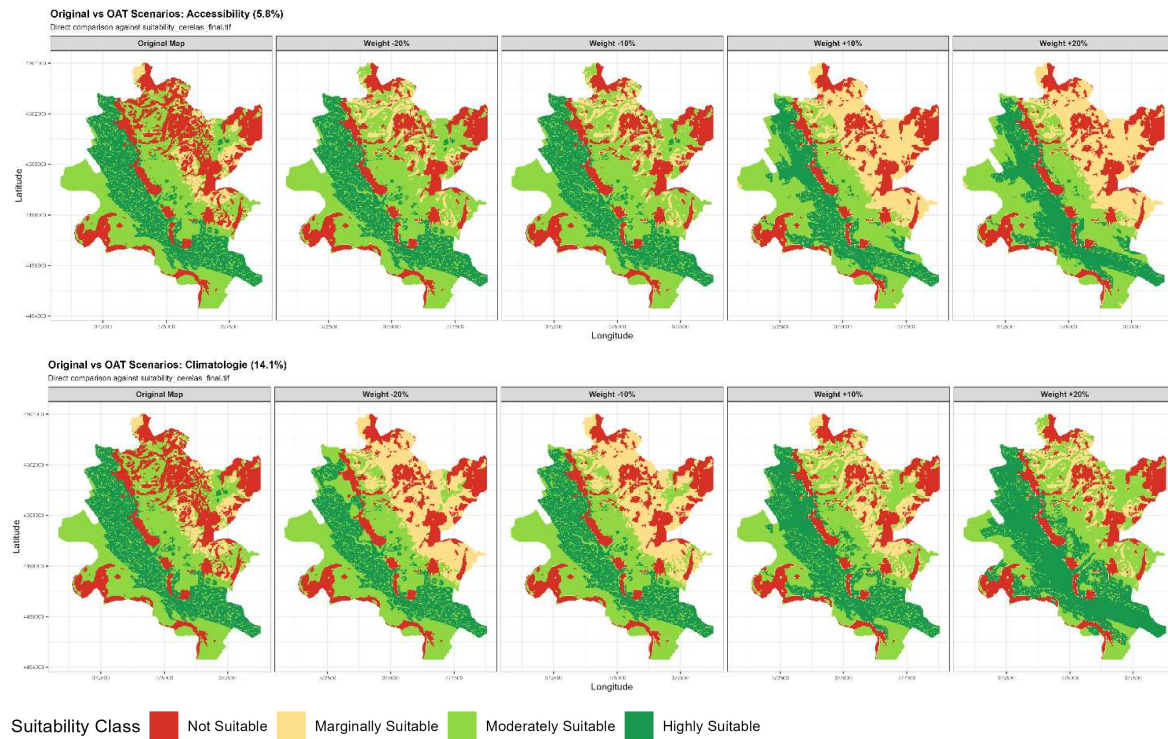
A one-at-a-time (OAT) sensitivity analysis was conducted by systematically varying each criterion weight by  $\pm 10\%$  and  $\pm 20\%$  from the baseline, generating a total of 20 perturbed wheat suitability maps. The spatial distribution of suitability class changes between the original and each perturbed scenario is presented in Figure 1, which provides a comprehensive visual overview of where and how classifications shift across the study area under each perturbation condition. Overall agreement with the baseline classification ranged from 71.3% to 89.1%, indicating high stability of the suitability model under weight perturbations (Figure 2). The agreement heatmap (Figure 2) clearly illustrates that the highest agreement values cluster around smaller perturbations ( $\pm 10\%$ ), while larger deviations ( $\pm 20\%$ ) tend to produce the most pronounced classification changes across all criteria. Among all criteria, Flood and Erosion Hazard demonstrated the highest sensitivity at the  $+10\%$  perturbation level, yielding the greatest overall agreement (89.1%), while a  $-20\%$  perturbation reduced agreement to 74.7%, with 16.0% of units being upgraded and 9.4% downgraded, suggesting an asymmetric response to weight reduction, a pattern also spatially discernible in Figure 1. Accessibility exhibited a notably asymmetric behavior: negative perturbations ( $-10\%$  and  $-20\%$ ) produced identical agreement levels (86.8%), implying a threshold effect below the baseline weight, whereas positive perturbations ( $+10\%$  and  $+20\%$ ) resulted in substantially lower agreement (72.8% and 71.3%, respectively), primarily driven by downgraded classifications (16.7% and 16.9%), highlighting the disproportionate influence of increased accessibility weighting on marginal-to-unsuitable transitions. The Climatology criterion showed the most pronounced response to a  $+20\%$  perturbation, with overall agreement dropping to 73.6% and 25.2% of units being upgraded, the highest upgrade proportion recorded

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across all scenarios, accompanied by a marked increase in Highly Suitable designations, as clearly visible in the suitability class distribution chart (Figure 3) and spatially confirmed in Figure 1. Soil Physical Properties at +20% similarly recorded a high percentage of changed units (25.8%), predominantly through upgrades (20.0%), suggesting that increasing this criterion's weight systematically promotes higher suitability classifications, likely reflecting the dominance of favorable soil textures in the study area. In contrast, Soil Biochemical properties yielded relatively stable classifications across all perturbation levels (agreement: 81.9%–85.4%), indicating lower sensitivity and a more uniform spatial distribution of biochemical suitability scores, a pattern consistently

observed across all three figures. Collectively, these results demonstrate that while the suitability model is generally robust, criteria related to Climatology, Accessibility and Soil Physical Properties introduce the greatest classification uncertainty under weight variation, and should be prioritized for further empirical validation and expert re-evaluation in future iterations of the decision-support framework. Overall, the consistency of class distributions across all OAT scenarios, as illustrated in the stacked bar distributions (Figure 3), reinforces the robustness of the suitability model, confirming that the baseline weight configuration produces reliable and stable spatial outputs that are not unduly sensitive to moderate variations in individual criterion weights.

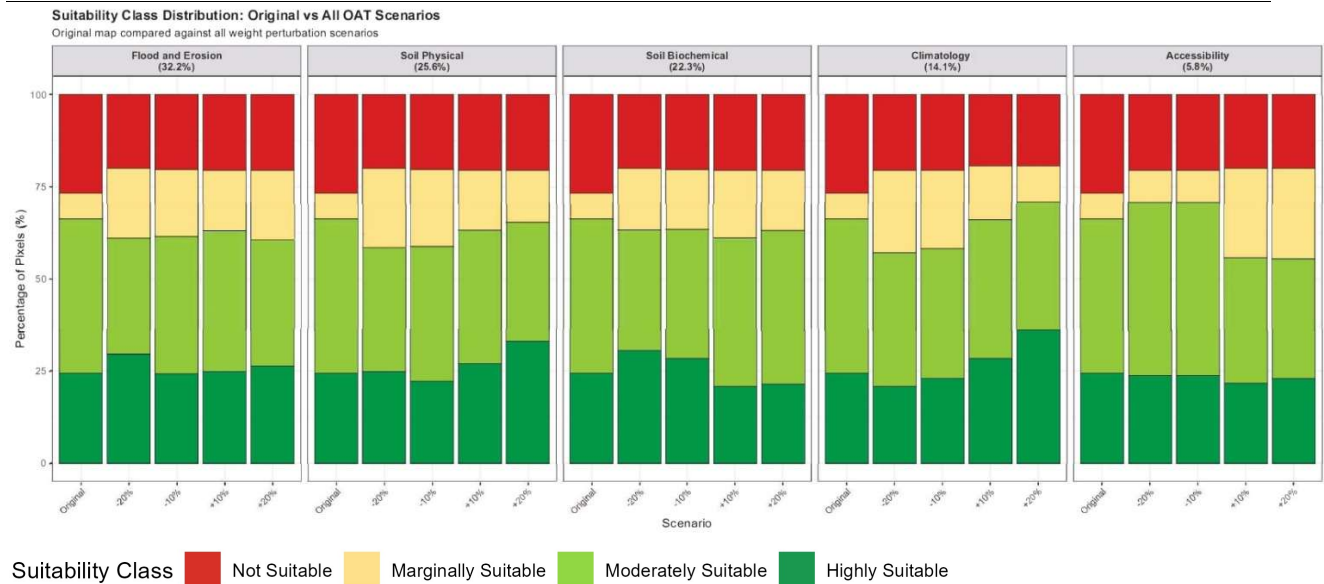




**Figure 1.** Spatial comparison of suitability class changes between the original and 20 perturbed wheat suitability maps.



**Figure 2.** Agreement Heatmap: Spatial agreement (%) between original map and perturbed maps



**Figure 3.** Suitability class distribution, comparison of original map against all weight perturbation scenarios

#### 4. Conclusions

This study applied an OAT sensitivity analysis to a GIS-MCE [25] based wheat suitability map in the Frakulla Administrative Unit, Albania, testing weight perturbations of  $\pm 10\%$  and  $\pm 20\%$  across five criterion groups. The results confirm that the original suitability map is generally robust, with the majority of the study area maintaining stable classifications across perturbation scenarios.

Regarding limitations, the OAT method evaluates criteria independently and therefore cannot capture interaction effects between simultaneously varying weights. As a local sensitivity technique, its conclusions are conditioned on the specific baseline weight configuration, and the selected perturbation levels ( $\pm 10\%$ ,  $\pm 20\%$ ), while standard in the literature, remain inherently bounded choices. Future research should consider global sensitivity methods, such as variance-based approaches [26] or Monte Carlo simulation [27], to produce probabilistic suitability maps that more fully characterize model uncertainty. Incorporating uncertainty from input data layers and engaging stakeholders in participatory weight elicitation would further strengthen assessment credibility [28].

From a policy perspective, spatially stable zones identified in this study should be prioritized for wheat cultivation investments and agricultural development programs. Transitional zones exhibiting high sensitivity warrant cautious, adaptive planning.

Albanian agricultural authorities are encouraged to adopt sensitivity analysis as a standard component of land evaluation workflows, particularly in the context of EU pre-accession rural development strategies, ensuring that spatial decisions are transparent, scientifically defensible and equitable for farming communities in the Fieri region.

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