LAND SUITABILITY CLASSIFICATION FOR SUSTAINABLE AGRICULTURAL PRODUCTION AND CLIMATE CHANGE ADAPTATION IN SLOVENIA

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ABSTRACT

Project RajonSI is developing a national methodology for agricultural land-suitability classification in Slovenia to support sustainable land use, risk reduction, and the adaptation of agricultural production to climate change. The technical framework and pilot models were established in 2025 by harmonising multi-source spatial datasets representing relevant factors for agricultural production and implementing them in a GIS-based multi-criteria evaluation. All input layers are prepared as rasters at a target resolution of 10 m. Natural factors include soil properties (texture parameters, skeletal content, depth, pH, organic matter, plant-available P_2O_5 and K_2O), climate indicators (T_{min}, T_{max}; derived indices such as the number of days with $T_{max} > 30/35$ °C and $T_{min} \leq -1$ °C in the growing season, precipitation totals, evapotranspiration, and drought indices), topography (slope, elevation, aspect, topographic wetness index), and other environmental and spatial data (flood areas, water protection areas, land use map). Suitability (*S*) is computed using the Weighted Linear Combination method. Suitability maps were created for arable land, permanent grassland, intensive orchards, general viticulture, and key crops (maize, cereals – wheat and barley, potatoes, apples/pears, strawberries, American blueberries, pasture-cut grassland, and pasture grassland). The approach is designed to run under multiple climate scenarios (EURO-CORDEX RCP 2.6/4.5/8.5) to assess future suitability envelopes. Output maps will serve decision-makers (MAFF) and practitioners and will be available via a web GIS viewer and open-data services.

Keywords: Agricultural zoning; land suitability; GIS; WLC; climate change adaptation

INTRODUCTION

Agricultural zoning classifies land according to its suitability for specific agricultural uses by integrating natural and management constraints [1,2]. It is based on a detailed analysis of natural factors such as soil, climate, altitude, topography, water resources and other environmental factors together with technological and economic parameters that influence agricultural production [3].
For the implementation of land-suitability classification, reliable and sufficiently precise spatial data are essential. These include data on the chemical and physical properties and

potentials of agricultural soils, soil-degradation processes, soil-management technologies, on macro- and micro-climatic conditions, agrometeorological indicators and relief characteristics, as well as data on agricultural plant species adapted to climate change, alongside various additional datasets [4]. In Slovenia, the increasing frequency of droughts, heatwaves and floods underscores the need for spatially explicit guidance to support sustainable land use, reduce environmental and economic risks, and inform adaptation to climate change.
The three-year RajonSI research project (2024–2027) aims to: (i) compile and harmonise national spatial datasets relevant to agricultural suitability; (ii) design a transparent multi-criteria evaluation (MCE) based on the Weighted Linear Combination (WLC) approach; (iii) define sector- and crop-specific criteria; and (iv) deliver zoning maps and a web-based GIS viewer for policymakers and farmers.

MATERIALS AND METHODS

Data and GIS standards

All factors are presented as spatial input layers and prepared as raster GeoTIFFs in the national coordinate system (D96/TM, EPSG:3794) with a target resolution of 10 m (tested at 20–100 m). Factors are grouped into soil, climate, topography, and other spatial factors. Some factors are used as constraints to limit suitability (e.g. built-up areas, water bodies, floodplains, water protection areas).

Soil factors and derivation

Soil attributes were derived from the geometry of the national soil map PK25 [5] using three complementary approaches:
(1) polygon-level attribution from soil samplings of national soil-monitoring programs stored in the Agriculture Institute of Slovenia soil database “eTLA”(values calculated as median per polygon);
(2) aggregation of soil parameters from “eTLA” to soil-mapping units (PKE); and
(3) soil data from representative soil profiles [6], aggregated to soil typological units (PSE) and interpolated to the soil map using weighted averages based on PSE shares in soil-mapping units (SMU).
Target attributes include pH ($CaCl_2$), organic matter, plant-available P_2O_5 and K_2O, texture fractions (sand, silt, clay), and skeletal content.

Climate datasets and indicators

EURO-CORDEX regional climate simulations created by Slovenian Environment Agency (ARSO) were used for a reference period (1981–2010) and near-future period (2011–2040) under RCP2.6, RCP4.5, and RCP8.5 [7]. Derived indicators include the number of days above T_{max} thresholds (25 °C, 30 °C, 35 °C), frost or near-frost days in the growing season ($T_{min} \leq -1$ °C), seasonal precipitation and temperature means, evapotranspiration and water-balance indices, and drought indices (SPI, EDDI, SWD).

Topographic derivatives

From the LiDAR-based DEM (aggregated to 10 × 10 m), slope, aspect, elevation, and topographic wetness index (TWI) were computed to support mechanisation feasibility, erosion risk and wetness-related constraints.

Standardisation

Before conducting the multi-criteria evaluation, factor standardisation was required. For each factor and agricultural production type, experts converted the original values into standardised scores from 0 to 100, where 0 indicates unsuitable and 100 indicates most suitable. Standardisation methods included:

(i) continuous membership functions for numerical variables;
(ii) class lookup tables for categorical variables;
(iii) binary constraints $C_j \in \{0,1\}$ for limiting conditions (e.g., flood zone, water body).

Multi-criteria evaluation

Suitability (S) is calculated using the Weighted Linear Combination (WLC):

$$S = \Sigma(w_i X_i) \times \Pi(C_j),$$

where X_i are standardised factor scores (0,100). Weights w_i reflect factor importance and sum to 1 within each model. Standardisation and weighting follow best practice in raster-based MCE [8].

Sector- and crop-specific models

General land-use models include arable land, permanent grassland (cut/pasture variants), intensive orchards and general viticulture. Crop-specific models include maize, cereals (wheat and barley), potato, apple/pear, strawberry, American blueberry, pasture-cut grassland and pasture grassland. For improved classification, arable fields were categorised following Land Capability Classification(LCC) principles [9,10]. Each model defines its own factor set, membership functions, and weights, focusing on natural factors while excluding management-dependent good-practice variables at this stage (Figure 1).

Figure 1. Workflow of the *RajonSI* methodology

RESULTS AND DISCUSSION

In 2025, the factor catalogue (61 candidate variables) and harmonised raster layers for soils, climate indicators and topography were compiled. Draft suitability maps were generated for selected sectors and crops, revealing clear gradients controlled by elevation, slope and thermal regimes, and highlighting flood-prone and frost-prone constraints (Figure 2). Weighting schemes for permanent grassland (mowing vs. pasture) prioritise texture and soil type, followed by precipitation and elevation; mechanisation-related slope thresholds distinguish feasible management zones.

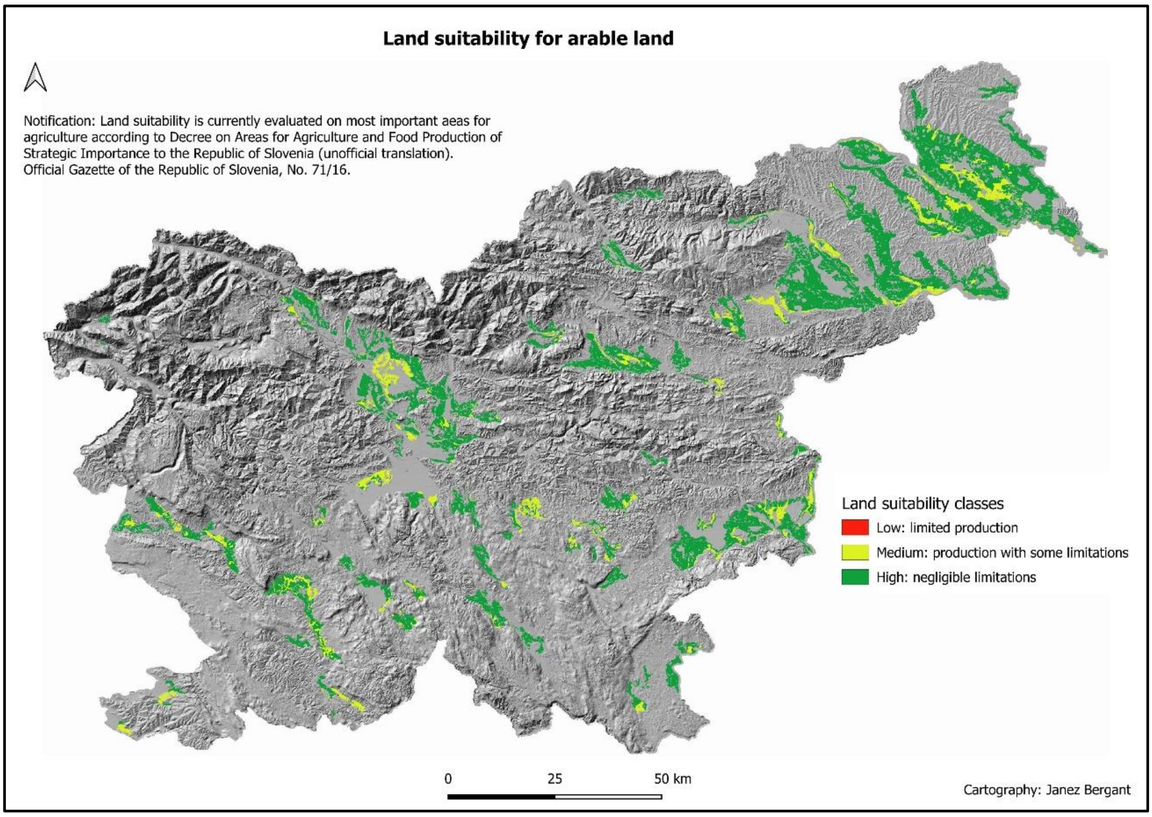

Figure 2. Draft land suitability map for arable land.

The spatial analysis indicates a predominance of areas classified as highly suitable for arable land, accounting for 84% of the evaluated agricultural area (171,243 ha) (Figure 3). These areas are characterised by negligible limitations to crop production and form the core of Slovenia's strategically important land for food production. Their spatial distribution largely follows lowland plains, valley bottoms and gently undulating terrain, where favourable soil properties, topography and accessibility support stable and intensive agricultural use.

Low-suitability areas represent 16% of the assessed area (33,416 ha) (Figure 3). These zones are spatially fragmented and primarily associated with more complex terrain, transitional relief or locally unfavourable soil conditions. Limitations in these areas are likely linked to factors such as slope, shallow or heterogeneous soils, drainage constraints or increased erosion risk, which restrict productive arable use and increase management requirements.

The strong dominance of highly suitable land highlights the overall favourable natural conditions for arable agriculture within the designated strategic areas. At the same time, the presence of low-suitability zones underscores the need for site-specific land management, where alternative land uses, reduced cropping intensity or targeted soil-conservation measures may be more appropriate. From a planning and policy perspective, the results support prioritising the protection of high-suitability land, while recognising low-suitability areas as more vulnerable and need of careful management to prevent land degradation.

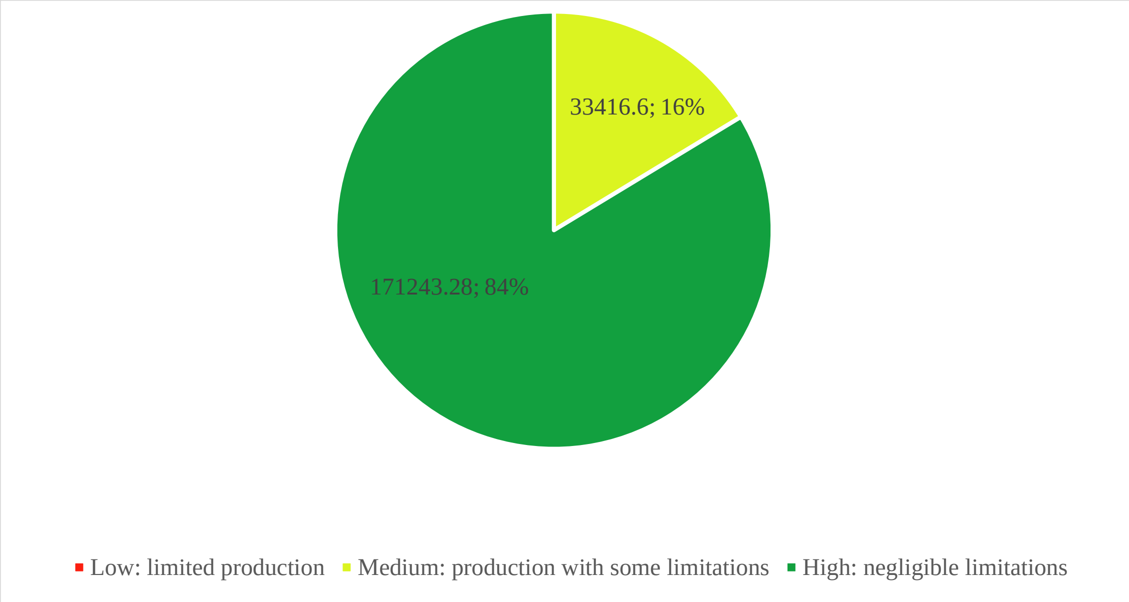

Figure 3. Distribution of land suitability classes.

CONCLUSION

Project RajonSI establishes a reproducible, transparent GIS framework for producing crop-specific land-suitability maps and creating agricultural zones in Slovenia. The harmonised data stack and WLC-based models enable cross-sector suitability assessments under current and future climates. Next steps include accessing land-suitability maps for future climate scenarios using EURO-CORDEX climate data, model calibration with expert knowledge, refinement of membership functions and weights, publication of national suitability layers, and deployment via a web GIS viewer to support Ministry of Agriculture, Forestry and Food (MAFF) and farm-level decisions.

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