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NATURAL RESOURCE MANAGEMENT INVOLVING TECHNOLOGICAL APPROACH (ARTIFICIAL INTELLIGENCE) TO SEQUESTER CARBON, LIMIT GLOBAL WARMING TO WELL BELOW 2°C AND ACHIEVING LAND DEGRADATION NEUTRALITY IN REPUBLIC OF MOLDOVA

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Current Trends in Natural Sciences

Abstract
The Republic of Moldova is part of the region with a major risk of the ecological state, characterized by the super intensive use of agricultural landscapes. In the last decades, many eco-pedological problems have worsened considerably in connection with the degradation of the potential of soil resources, the decrease in the efficiency of ecological control and, as a result, the reduction of people's standard of living. It is possible to prevent the intensification of negative processes through a detailed assessment of determining factors. The use of artificial intelligence allows us to quickly and effectively identify and assess the main forms of soil degradation, evaluate the degree of their severity, develop measures to stop and combat them in order to improve the ecosystem situation.
Given the results of the research, the analysis reveals that the "Land Use/Land Cover Data Collection Methodology", an innovative approach using geostatistical modeling combined with satellite imagery, has been developed. The concept for "Methodology of data collection for the potential indicator of land productivity and soil carbon stocks" was also developed. The scientific approach based on geospatial analysis and Artificial Intelligence (AI) enables the automation of information in an efficient, fast, and cost-effective way for documenting and systematizing baseline data for land degradation neutrality that will enable advanced and evidence-based operational decisions, including the development of sustainable land use strategies. Methodologies provide time-efficient means with minimal expense to identify the best areas for a given crop based on multifactor analysis and they have an impact on increasing the operational capacities of decision-making, planning, evaluation, monitoring and control for central and local public authorities and agricultural producers with a reduction of expenses of up to 50%.

Keywords: artificial intelligence, degradation land, neutrality, methodology, concept.

1. INTRODUCTION

The Republic of Moldova is part of the region with a major risk of the ecological state, characterized by the super intensive use of agricultural landscapes. In the last decades, many eco-pedological problems have worsened considerably in connection with the degradation of the potential of soil resources (Cerbari et al., 2012; Popov and Tofan, 2015; Rusu et al., 2019), the

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decrease in the efficiency of ecological control and, as a result, the reduction of people's standard of living.

Rational use of soil resources and achieving the goal of land degradation neutrality is based on detailed knowledge of the natural and anthropogenic determinants influencing land productivity and quality status.

Preventing the intensification of negative processes and achieving land degradation neutrality is possible by assessing the three basic indicators (land cover, land productivity, soil carbon stock assessment) and the spatial positioning of areas. The use of Artificial Intelligence allows the detection and evaluation of the main forms of soil degradation, the assessment of their degree of manifestation, the development of measures to stop and combat them in order to improve the situation in ecosystems. This article contains the results of the development of the methodological concept for the extrapolation of soil quality data on soils with similar landform characteristics (morphometric and morphological), rainfall conditions, soil types and subtypes. The mentioned methods were conceptualized and obtained as a result of a joint collaboration between experts of the Food and Agriculture Organization of the United Nations (FAO) and the specialists of the IPASP “Nicolae Dimo”. This collaboration took place in the frames of the “Enabling a policy environment for integrated natural resources management and implementation of an integrated approach to achieve land degradation neutrality in Moldova” (FAO, 2023), implemented by FAO and financed by the Global Environment Facility (GEF). This integrated management approach allows the launch of a new tool for evidence-based decision making which can be of service for agricultural producers, as well as for the central public administration, and which will allow the visualization of the main natural risks across the whole country, while at the same time allowing an analysis of the productivity potential and potential agricultural yields of main crops. This graphical system will enable warning, planning and control to highlight the emergence of risks in a given region and the measures that need to be planned or/and undertaken to mitigate the impact of degradation risks.

2. MATERIALS AND METHODS

The research was carried out in the north-eastern part of the Republic of Moldova, including 32 localities/mayoralties as territorial administrative units. The total area of the action territory was 88528 ha.

We have used ArcGis digital software, CORINE 2000 toolkit, orthophoto-maps, Sentinel 2 information data, Copernicus, NDVI.

The research was to develop an automated mechanism for collecting, documenting and systematizing information on Land Degradation Neutrality involving Artificial Intelligence (FAO, 2023).

The GIS datasets and maps will then form the basis for a broader soil quality monitoring system. According to the newly adopted methodology, the Institute of Pedology, Agrochemistry and Soil Protection "Nicolae Dimo" (hereafter Institute) aimed at collecting respective data sets at a scale of 1:10 000, an innovative approach with an accuracy of 1 ha per pixel (Popov, 2022). This will enable smaller farmers to receive objective information to responsibly and efficiently manage natural resources in an integrated way.

According to the methodology developed, LDN indicators have been identified to allow analysis of proposed objectives at regional and local scale:

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- Land Use/Land Cover (LULC),
- Land productivity potential,
- Soil Carbon Stock.

The following deliverables are supplied for;

1) Land Use/Land Cover (LULC):

- Initial GIS dataset for Land Use/Land Cover (LULC) resulting from machine learning/AI algorithms, delivered in RASTER (geotiff) format for the project area, available through download link;
- Final GIS LULC digital dataset for entire project area in form geo-service and downloadable dataset. Web map and RASTER (geotiff) and VECTOR formats are available;
- Final LULC digital datasets for each community within project area delivered as downloadable RASTER (geotiff) and VECTOR format (shapefiles) available through download link.

2) Soil Carbon Stocks:

- GIS Dataset for Soil Carbon Stocks (humus content) for the Project area, delivered via web service/raster/vector formats.

3) Land Productivity Potential – LPPM (see Annex 2):

- Supporting GIS Datasets for Soil, Climate, Topography, Cadastre, Vegetation indices, Satellite imagery for the Project area, delivered as web service/raster/vector formats;

GIS datasets/layers for annual and multiannual crops for 3 scenarios in a multifactor LPPM – Recommended areas for the crop, Acceptable areas for the crop, and Non-recommended areas for the crop. Crops annual/multiannual include: winter wheat, winter barley, peas, corn, sunflower, rapeseed, soybean, lucerne, sparceta, apple, pear, quince, cherry, sour-cherry, plum, apricot, walnut, hazelnuts, technical grapes and table grapes.

Soil sampling was carried out according to standard methods. In the laboratory of the Institute of Pedology, Agrochemistry and Soil Protection "Nicolae Dimo", in the soil was determined the content of Humus, Nitrogen, Phosphorus, Potassium and Carbonates (Rusu et al., 2019; Popov, 2022).

3. RESULTS AND DISCUSSIONS

Developed integrated methodology is a new approach to collect Land Use/Land Cover (LULC) using geostatistical modeling and satellite imagery combined with fieldwork for ground proof. Such methodology implies trained machine learning model (AI) to generate initial LULC GIS dataset and further field work with local cadastral engineers to register new information, apply quality corrections via control procedures and generate final LULC dataset.

The methodology has its final aim to offer automated and reliable data entry and processing mechanism for generating baseline LULC GIS dataset for the Project area in form of vector and raster GIS layers. It is worth mentioning existing LULC resources. Land Use / Land Cover datasets are widely offered internationally with its specific classes and defined methodologies for source data and collection mechanisms. Now in Moldova specialists can rely on number of freely available LULC datasets. Among those is CORINE Land Cover datasets.

Land Use dataset for Corine Land Cover (CLC) covering entire Moldova was produced in 2000. It has relatively low spatial resolution (approx. 25m.) Starting from 2018 Corine Land Cover initiative started to utilize Copernicus Sentinel missions (accuracy 10m.) for its derived CLC datasets.

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Moldova offers some CLC 2018 products in form of WMS geo-services. However, those datasets are only generated for the central part of Moldova and partially cover project area. The CORINE Land Cover (CLC) classes are generalized into 15 classes (fig.1).
The project context requires tailored array of LULC classes with focus on agricultural lands, complete project area coverage and enhanced data accuracy. Thus, it was imperative to use elaborated new approach – a comprehensive methodology as a cost effective and efficient means to collect, process and aggregate LULC dataset.
Therefore, the elaborated comprehensive methodology is a step-by-step mechanism to be used to collect and process LULC geospatial information.

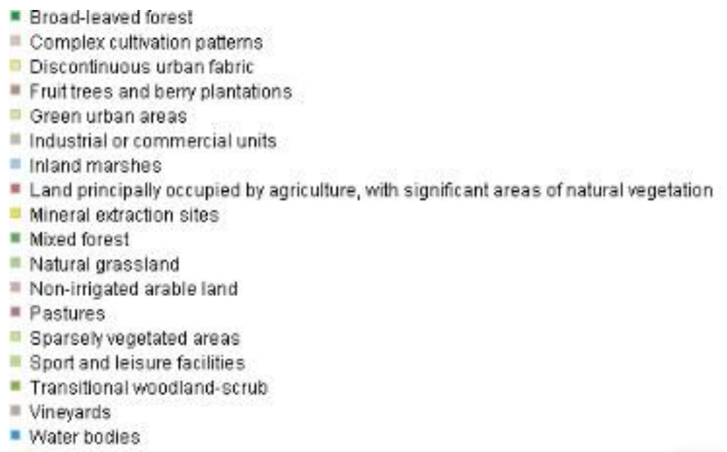
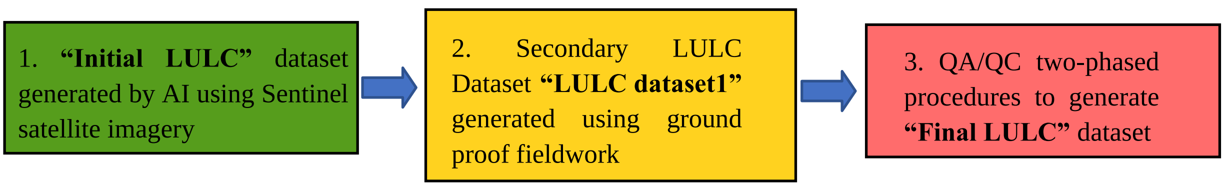


Figure 1. Classes of Land Cover (CLC) indicator

Such methodology offers sound scientific and cost-effective means to produce spatial LULC datasets for the project area featured by high variability (non-regular surface). At the same time, the methodology allows data capture at a larger scale of up to 1:10 000 and includes ground proof data and expertise from local authorities in participating communities.

The methodology implies the following major phases below:



Proposed methodology assumes the use of Sentinel2 (particularly Sentinel-2 Level-2A (1C)) imagery data of Copernicus mission. Sentinel-2 multispectral and multi-temporal atmospherically corrected imagery is a great scientific source to be used in automated land use classification and modelling due to imagery high spatial resolution and rich sensor characteristics (fig. 2).
For the purpose of the task four Sentinel -2A satellite imagery from February, March, April, and May 2021 with low cloud coverage were downloaded from Copernicus data hub. The imagery was pre-processed for modelling and further classification via machine learning methods. Trained and

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tuned machine learning model (or AI model) on Esri geospatial platform was used to work with four Sentinel 2 imagery to perform LULC classification. This geospatial deep learning model allowed automated feature extraction to obtain preliminary LULC GIS layer - "Initial LULC" (tab. 1).

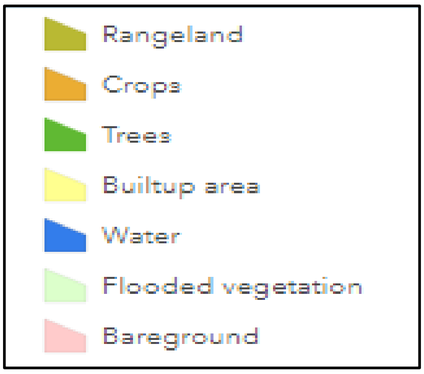

Figure 2. This approach resulted in classified raster with basic Corine Land Cover (CLC) 2018 classe

Table 1. Statistics on AI /machine learning LULC GIS dataset

Class	Area, ha	Objects, nr
Water	1085.7637	102
Trees	15946.688	591
Flooded vegetation	1.8485	15
Crops	66708.6956	808
Buildup area	6621.6376	227
Bareground	87.0334	8
Rangeland	4863.321	1756
SUM	**95315**	**3511**

As per analysis of resulting geodata and statistics it was found that the model had good performance over identifying objects in classes: water, build-up area, forestry (tab. 1). Due to current land management and overall model limitations, it was identified that model has medium to poor performance at rangelands (grassland) and crops. It turns that existing model is not tuned well to discern patters in pastures vs annual crops vs abandoned crops (annual/multi-annual) as well as multi-annual crops (orchards) vs forestry.

Since the major interest for this exercise is set on detailed and updated information for agricultural land and rangeland and its respective state in the context of soil degradation it is important to carefully execute ground proof activities with local expertise within the next phase. It was decided to expand crops classification into three new separate classes: crops annual, crops multi-annual, crops abandoned. These new classes will play essential role in the next step assessment of land productivity potential and further elaboration of sustainable land participatory plans at community level.

"Final LULC" with Integral Quality Control

Integral Quality Control (QC) process is an essential phase to obtain Final LULC dataset. Several steps were executed within this phase. As a first step team of specialists worked on aggregating data of initial and ground-proofed LULC GIS datasets. We used instruments available in ArcGIS desktop application. Automated processing and manual overhead digitalization were used. Some additional expertise from local authorities was required at this stage.

As a second step, many issues were identified with the assistance of FAO Geographic Information Systems expert. These relate to data coherence and consistency. The main issue was overlapping polygons and errors in general topology. To fix those errors we used automated procedures for cleaning LULC dataset using overlay analysis toolset and topological editing. Final overhead digitizing was applied to finalize needed corrections.

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The resulting Final LULC GIS dataset was compared to existing LULC resources particularly partially covering the research area CORINE Land Cover (CLC) for 2018 and Esri 2020 land cover layer. Both were found not consistent and outdated in comparison to collected and verified detailed information. Thus, this data was not used as it was initially offered by the methodology.
At the final phase, separate datasets in vector (shapefile) and raster (geotiff) format were created for each community and uploaded online for further access and download (fig.3). The same shared drive offer access to the entire LULC GIS dataset in vector and raster formats. Please see Annexes for visual representation of the LULC and respective download links.
Below (fig.3) please consult statistics on distribution of areas in hectares for each LULC class for each participating community within "Final LULC" dataset with total identified area of 88528.32 ha.

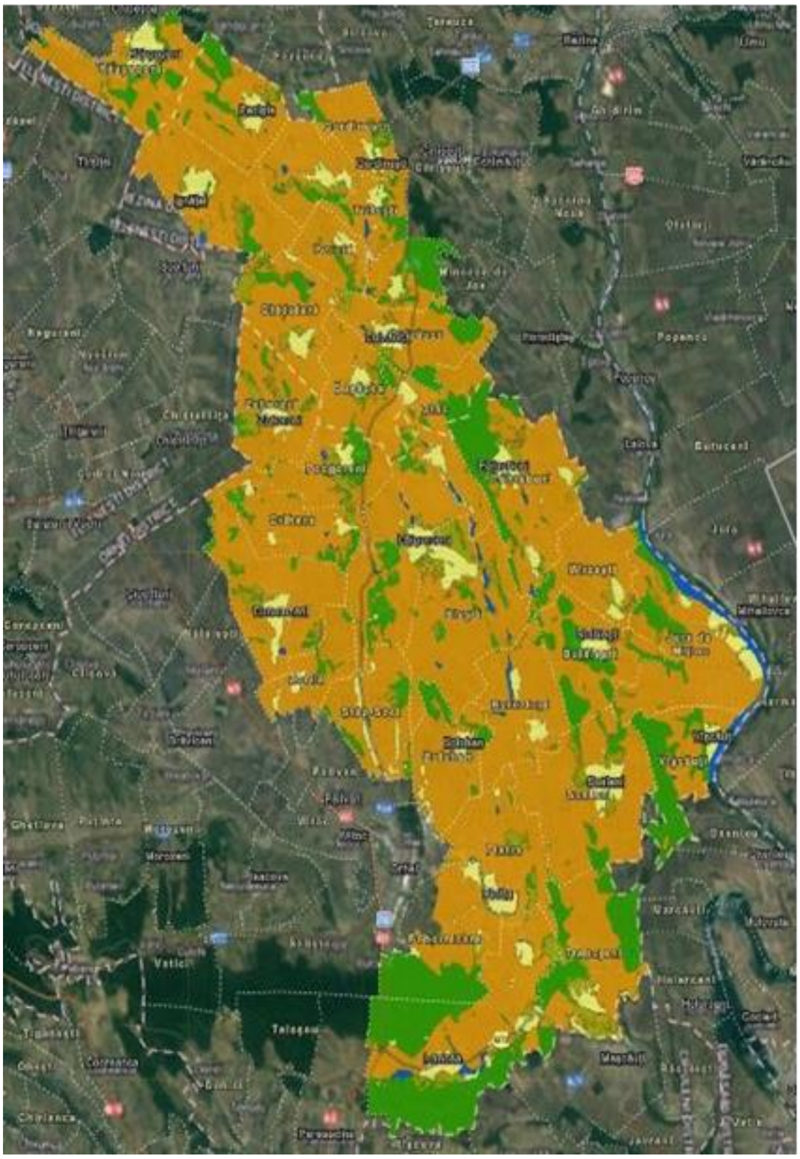

Figure 3. A snapshot of AI/machine learning LULC GIS dataset. 3511 objects were identified

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Methodology to capture and model Soil Carbon Stocks

The developed methodology offers efficient and science-based approach for collecting and modelling of Soil Carbon Stocks data using robust geostatistical methods in a dedicated GIS environment.

Following careful zone-based sampling strategy the goal is to verify proposed strategy, gather soil related information and interpolate it for the project area. Representative sampling model developed is based on such factors as existing soil profiles, DEM and land use to define set of unique series of combinations to produce potential lots for future sampling [1, 4]. Field composite sampling at 30cm depth was executed at those defined locations. Resulting soil data was considered a subject to interpolation grid. The grid that was calculated for entire project area was identified to have factors that accounts for deficiency in the initial assumptions.

Resulting GIS dataset for the Project area are delivered in form of vector and raster GIS layers as well as web map/service and GIS Dashboard.

Representative Soil Sampling Model (RSSM)

While working with uneven soil composition and variate topography within project spatial context (larger scale with more detail on the smaller land spot), it is clear that field soil sampling and appropriate interpolation methods could be considered as a best fit principal approach for Soil Carbon Stocks indicator. In order to perform efficient interpolations for the soil data from known to unknown locations one has to carefully choose area where field sampling is to be done.

Informative soil sampling was done via representative samples (spatially defined sampling). Those locations were identified using the following factors: Soil existing datasets (Soil Type/Texture), DEM (including slope/aspect), Land Cover Land Use (focus on Croplands). Those datasets in form of entry classified spatial grids for mentioned GIS datasets form a spatial model – Representative Soil Sampling Model (RSSM) that uses Map Algebra algorithms (raster functions) with resulting grid where each cell will have unique set of parameters (fig.4).

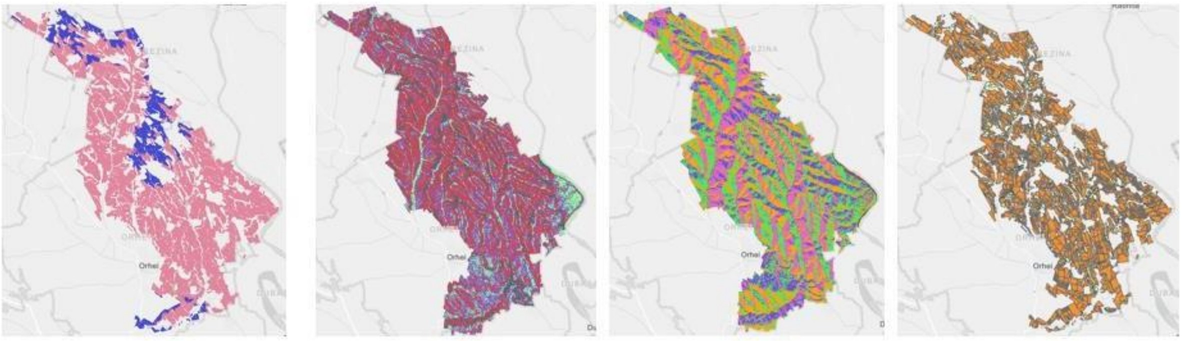

Figure 4. RSSM Model – combination of four factors: LULC + Soil Type/Texture + Slope + Aspect

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For the use of the model it was decided to use the following characteristic for each factor (fig.5). For that reason intial spatial datasets were reclassified and adjusted using ArcGIS Pro + Spatial Analyst software packages.

- Land Use/Land Cover (LULC): Crops annual, Crops multiannual, Crops Abandoned, Grassland (fig.6);
- Soil Type/Texture: Cernoziom, Mocirla, Grey soils;
- Slope: 0-2 degrees, 2-4 degrees, 4-10, degrees, >10 degrees Aspect: Flat, North, South, East, West;

The model (fig. 6) was run and resulted in approx. 200 unique classes for potential soil sampling (covering apprx.70% of the Project area).

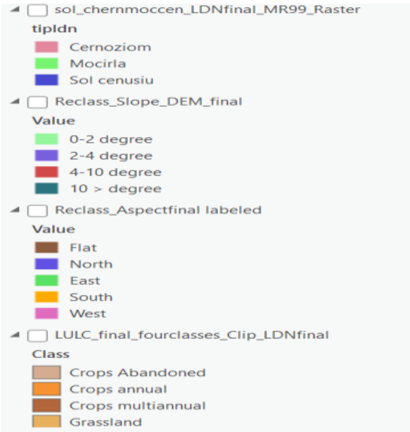

Figura 5. Reclassified datasets and adjusted using ArcGISPro

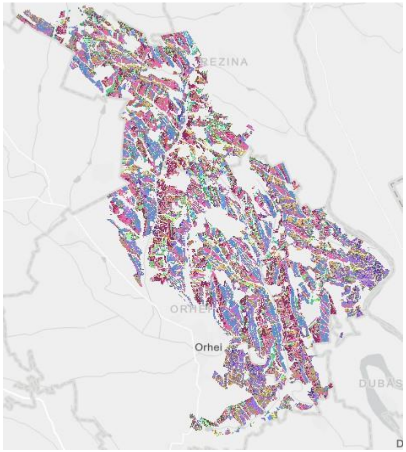

Figura 6. Digital map of distribution of classes to sampling and data collection

Table 2. Out of LULC (crops annual) + All Aspects + Slope (0 ->10°) +Type of Soil (Cernoziom, Grey Soil, Mocirla) totaling 42,647 Ha

Class	Total HA	% of total area of Crops Annual
Cernoziom, (all aspect)		
Crops Annual, Slope 4-10	18,583	43.57%
Crops Annual, Slope 2-4	11,892	27.88%
Crops Annual, Slope 0-2	4,984	11.69%
Crops Annual, Slope >10	843	2%
Subtotal:	**36,302**	**85.14%**
Grey soils, (all aspect)		
Crops Annual, Slope 4-10	2,873	6.74%
Crops Annual, Slope 2-4	2,080	4.88%
Crops Annual, Slope 0-2	1,145	2.68%
Crops Annual, Slope >10	207	0.5%
Subtotal:	**6,305**	**14.8%**
Mocirla (all aspect)		
Crops Annual, Slope 4-10	22	0.05%
Crops Annual, Slope 2-4	15	0.04%
Crops Annual, Slope 0-2	2	0.004%
Crops Annual, Slope >10	1	0.002%
Subtotal:	**40**	**0.096%**

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Considering above statistics (tab. 2), field sampling within 4 most representative classes with maximum coverage were prioritized. Those were combination of all Aspects for Crops annual and Cernoziom for the slope of 4-10 degrees.

Soil Sampling in the Field

Next step was to execute Soil sampling at the indicated areas. Chosen area of 9 599 ha became subject to 168 composite samples with majority being in the central area (com. Biesti and com. Chiperceni) and 2 control areas in southern and northern communities of the project with distinctive spatial distance to ensure statistical significance (fig. 7). Sampling was done across all Aspects' values. Those areas fall into expected by initial methodology 10-20% of the total areas covered by particular class (Crops annual) of approx. 47 000 ha.

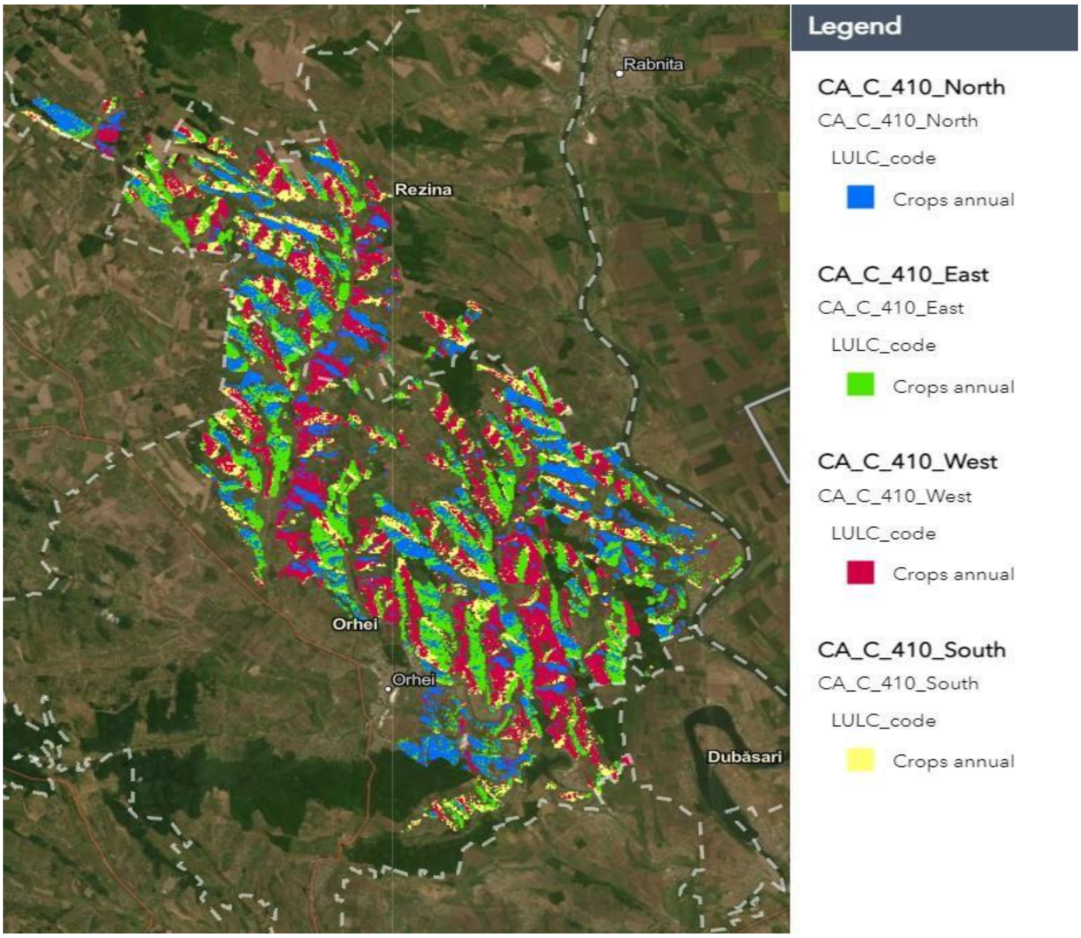

Figure 7. Digital map of distribution of soil sampling points

The methodology for taking soil samples at a depth of 30 cm consists in dividing the entire study area into small plots of 5 ha each. The mixed sample is formed from repeated sampling at different points distributed on the diagonal line of the 5 ha surface. The mixed sample includes the structural variety of the soil with the subsequent presentation of the results regarding the general quality

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indicators (humus, nitrogen, phosphorus, potassium, carbonates) as a response to the impact of the technological action and the consumption of nutrients to obtain a plant production unit. Later, these data are included in the soil passport with the mention of agricultural tenure. All together allow reading the evolution of soil quality in time, space and crop rotation.
Upon careful analysis of the resulting data it was identified that due to high variability in the field data within selected LULC type (Crops annual) and Slope (4-10 grades) land Aspect is considered minor determinant factor for further interpolations. The major findings comply with many studies that Soil Type/Soil texture is the main predictor for Humus content.

Soil Data Interpolation

At this stage the complete Research area prediction grid for Soil Carbon Stocks was generated using interpolation geospatial methods considering Soil Type/Soil texture dataset.
Upon further analysis, an interpolated grid was set up against field data. Four verification GIS datasets were generated showing clearly that final Soils Carbon Stocks dataset has high correlation with SoilType/Soil Texture (Cernoziom having high values of Humus content 3-5- 5.2 and uniform at all land aspects) (fig.8).

Figure 8. Digital map of Soils Carbon Stocks dataset correlation with SoilType/Soil Texture

During analysis, it was identified that captured field data in comparison to empirical interpolation Final Carbon Stocks grid delivers similar range values for humus content but with irregular

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diminishing factor. The assumption here is that exist number of explanatory reasons/variables that initially were not taken into consideration – primarily could be crop rotation history, current agricultural practices and fertilizer intake. Those were not estimated or investigated within current assignment.
Respective Annex is offering access to the Soil Carbon Stocks dataset in a web service and raw data (vector\raster) formats.
All precedent models serve a basic for further Land Productivity Potential models. The models described below are part of forthcoming research.

Methodology for Land Productivity Potential
Land Productivity Potential Model (LPPM) using suitability geospatial algorithms is a proposed method of modelling land productivity potential as a baseline LDN dataset. Such a model is seen as a combination of many factors in form of merging and overlaying different GIS datasets for targeted area including data on major soil properties, topographic maps and other supporting GIS datasets. LPPM would enable beneficiaries to deduct the production potential of various zones for particular crop within the project pilot areas. For that reason, Regional LPPM and LPPM tailored to the crop were developed. Offered model featured by suitability GIS analysis principals will offer greater flexibility in identifying best land candidates for particular location and for the crop of interest using multifactor analysis.
Land Productivity Potential Model – Regional level
Regional Land Productivity Potential Model is defined using several major factors represented by number of GIS datasets. For the initial analytics major factors have even impact (weight) for the model. GIS datasets for majority of the categories were processed using Kriging interpolation geospatial instruments (Soil, climate) as well as existing GIS services from the project partners were utilized.

4. CONCLUSIONS
1. The main deliverables in the form of GIS datasets, maps and applications were successfully elaborated under given assignment. Respective annexes reference each deliverable for 3 LDN indicators: **Land Use Land Cover, Land Productivity Potential** and **Soil Carbon Stocks** for the Project area.
2. The documentation and systematization of the baseline data for Land Degradation Neutrality indicators will enable advanced and evidence-based decision making, including the development of the land use strategies for the pilot area and the participatory land use planning activities that will take place at the local level according to FAO guidelines.
3. Project team assisted by FAO experts developed an innovative methodology for modelling and collecting LDN indicators data at local level. Scientific approach based on geospatial analysis and Artificial Intelligence (AI) enabled automation of information in an efficient, fast and cost-effective way. The collection of 1:10 000 scale datasets will permit smaller farmers and local authorities to benefit from essential data on land and soil and to responsibly and efficiently manage natural resources to achieve land degradation neutrality.
4. The developed Land Productivity Potential Model (LPPM) that uses GIS suitability methods offers efficient means to identify best areas for particular crop based on multifactor analysis. LPPM,

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as a model both in regional context and crop tailored, has potential to further evolve within the framework of a broader soil quality monitoring system.

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