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Geospatial investigation of land multi-degradation in Europe (Investigarea geospațială a multi-degradării terenurilor din Europa)

Remus PRĂVĂLIE

- ***General objective***: *exploring the geospatial convergence/incidence of multiple land degradation processes (multi-degradation) in European agricultural environments;*

- ***Structure:***
  - *the methodological approach of land multi-degradation in Europe;*
  - *the geospatial results of multiple land degradation processes in Europe;*
  - *conclusions;*
  - *references;*
  - *published results (scientific deliverables).*

Land degradation concept:

- ***land degradation***: *reduction or loss of biological or economic productivity of lands, due to many degradation processes, such as water/eolian soil erosion, physical/ chemical/biological/economic land deterioration, or long-term loss of vegetation (UNCCD, 1994);*
- *a prolonged decline of ecosystem functions and services of land systems (soils, vegetation, water resources) (Prăvălie, 2016, 2021);*
- *land degradation =* ***desertification*** *if it occurs in dryland systems (except for hyper-arid areas) (UNCCD, 1994; Reynolds et al., 2007; Prăvălie, 2016, 2021) (Fig. 1);*
- *most / all land degradation processes – so far* ***analyzed in a singular manner (the "uni-degradation" perspective)*** *across the globe.*

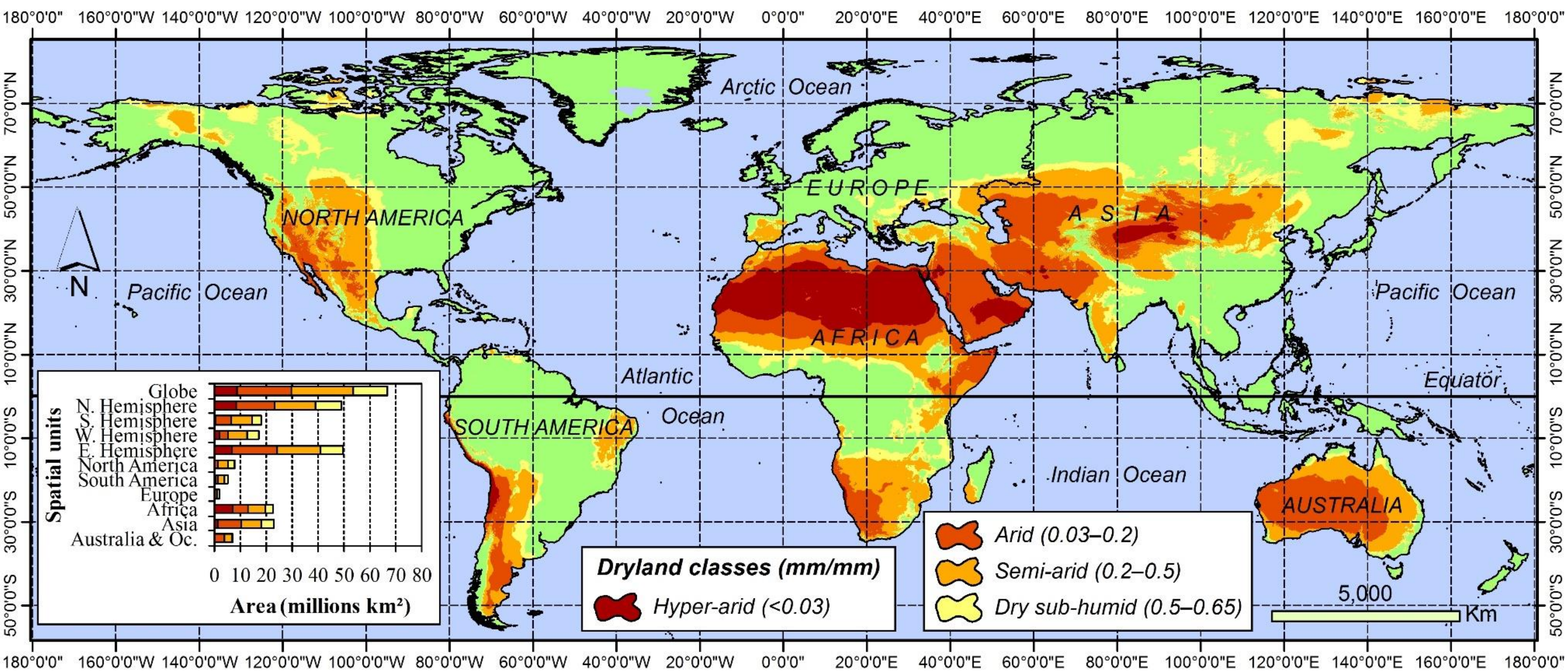


Fig. 1. Spatial representation of the global dryland systems (after Prăvălie, 2016).

❑ *Land multi-degradation concept:*

- ***land multi-degradation*** *(land degradation by multiple convergent processes) – studied for the first time at the planetary level in Prăvălie et al. (2021a);*
- *the simultaneous presence of two degradation processes – the major form of arable land multi-degradation across the world (Figs. 2, 3);*

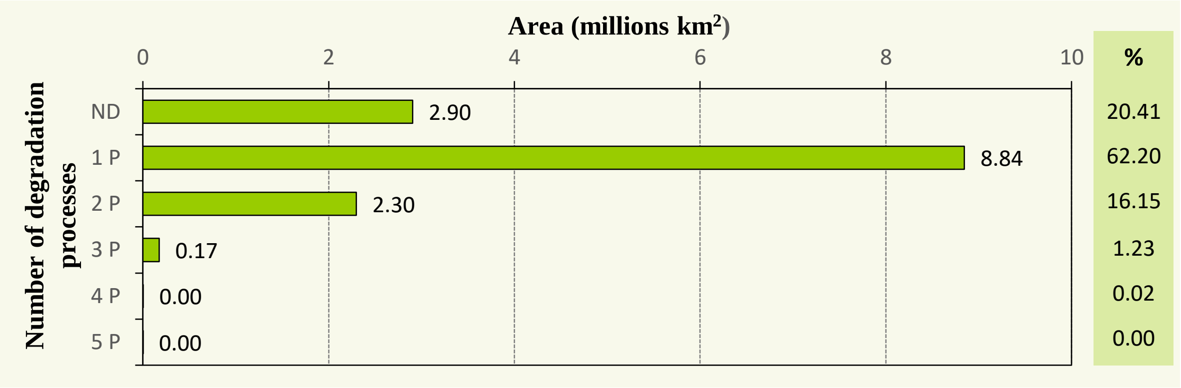


Fig. 3. *Areas (in km^2/%) covered by various numbers of land degradation processes in global arable lands (after Prăvălie et al., 2021a).*

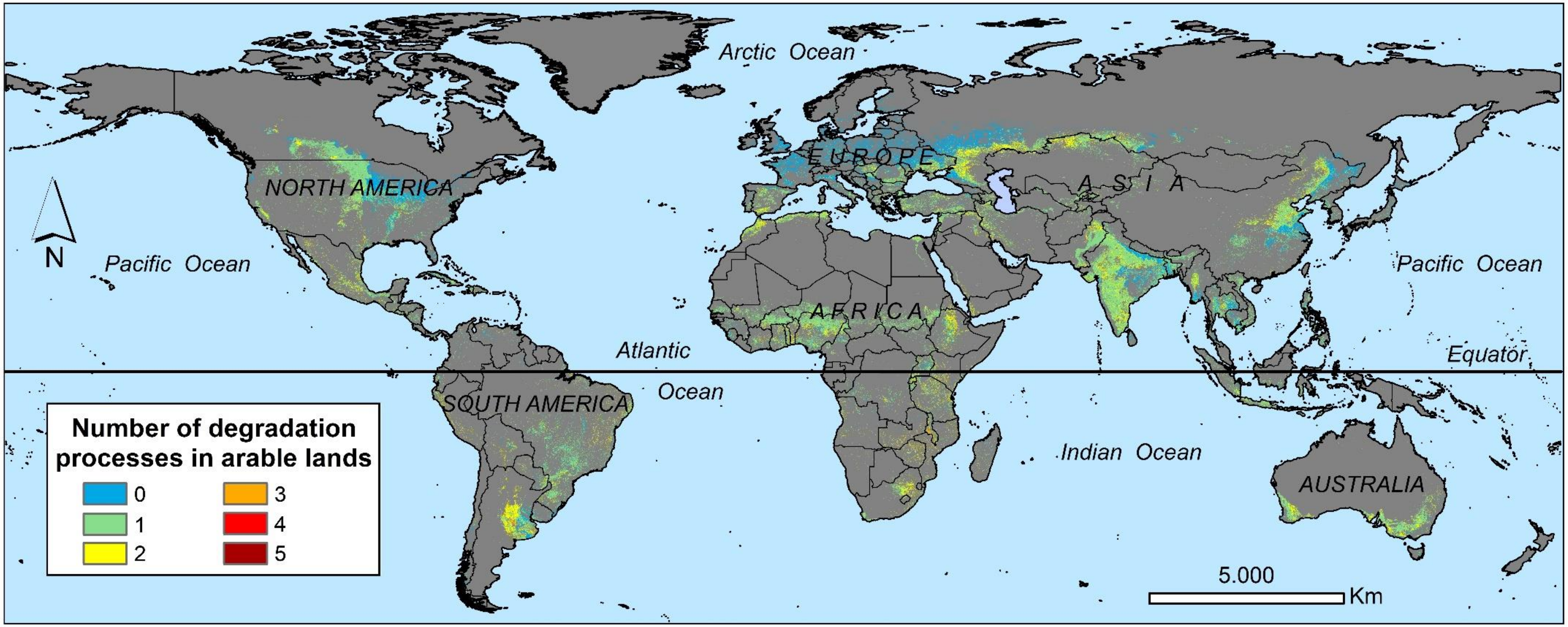


Fig. 2. *Global spatial representation of the number of land degradation processes in arable systems (after Prăvălie et al., 2021a).*

- *aridity (A) – the global dominant vector of arable land uni-degradation (Figs. 11, 12);*
- *soil erosion (E) – also a notable form of uni-degradation globally (Figs. 4, 5);*
- *aridity and soil erosion – the dominant pathways of multi-degradation in arable systems (Figs. 4, 5).*

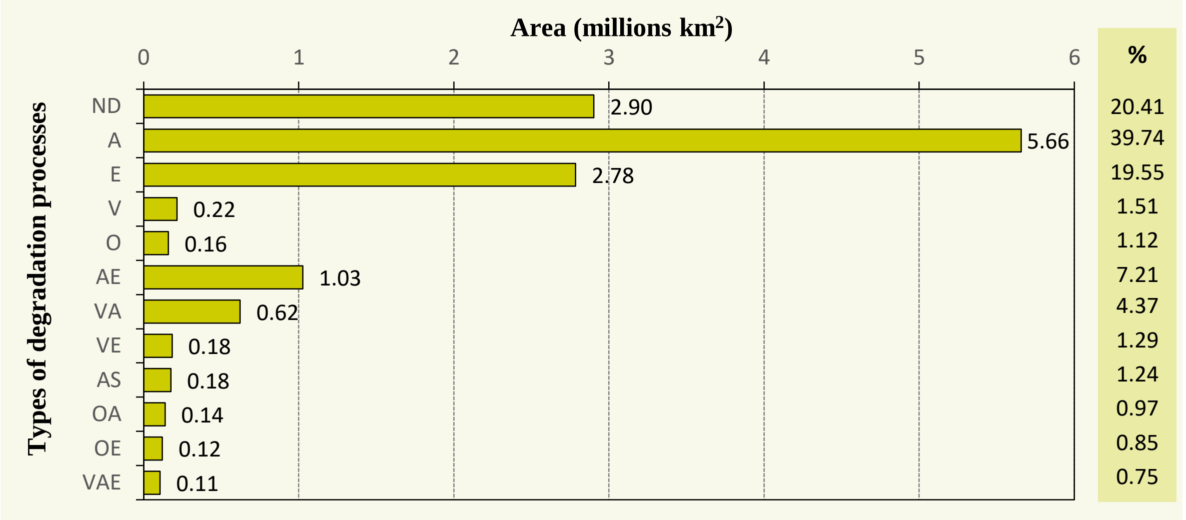


Fig. 5. *Areas (in km²/%) covered by the type of land degradation processes in global arable lands (after Prăvălie et al., 2021a).*

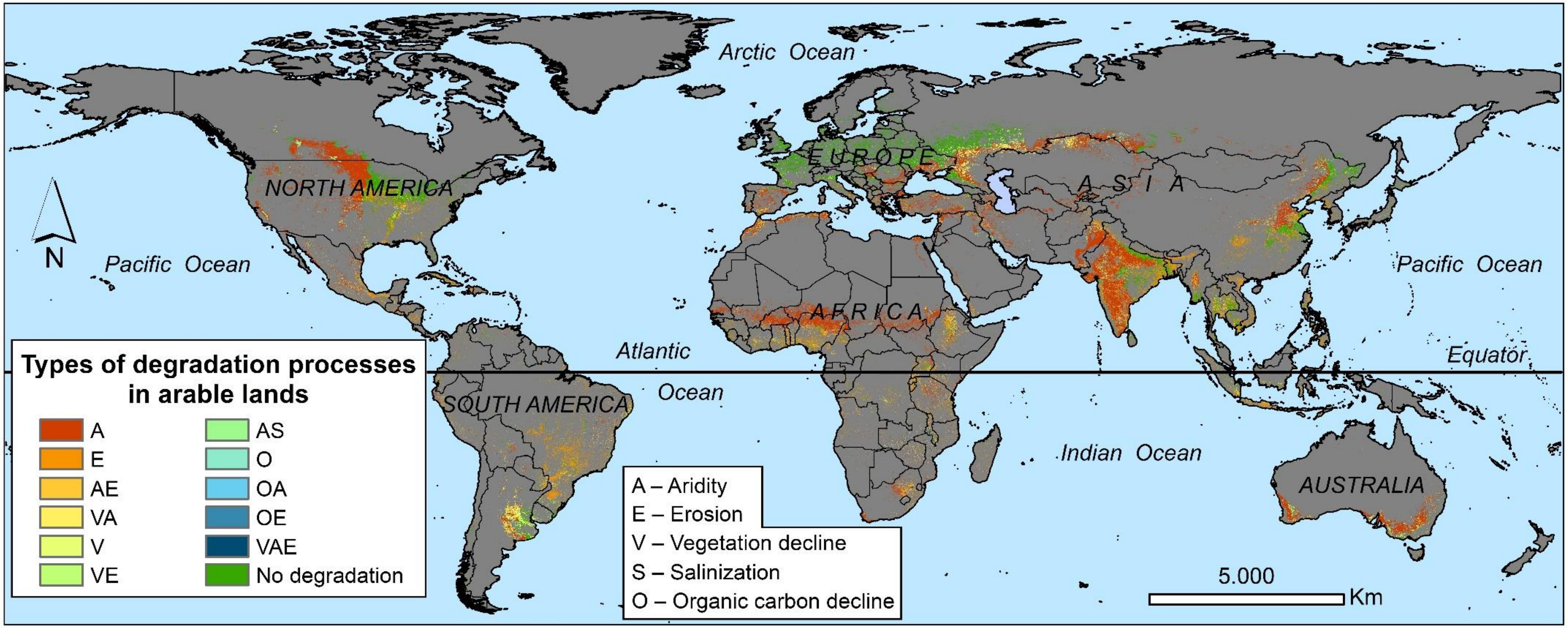


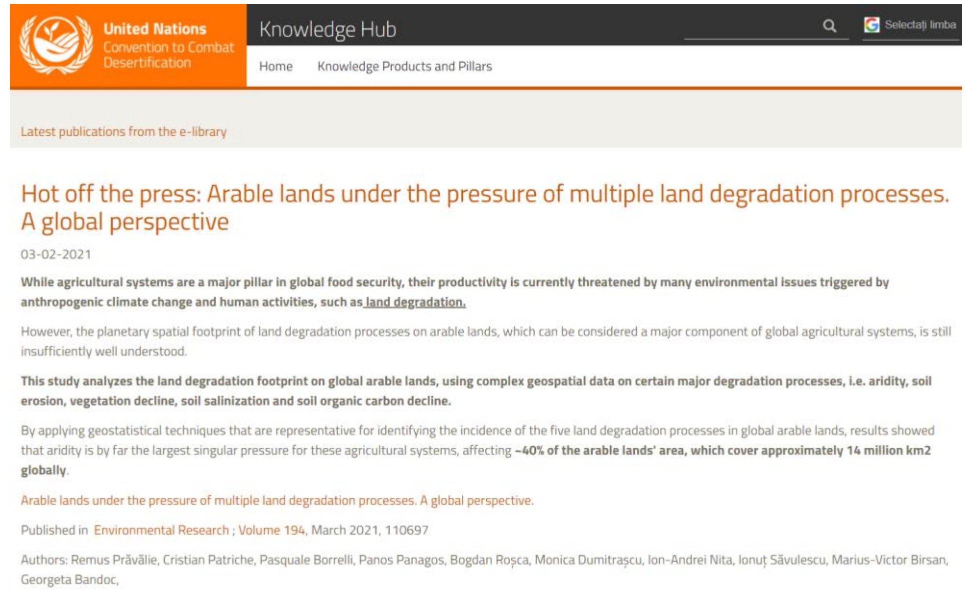
Fig. 4. *Global spatial representation of the types of land degradation processes in arable systems (after Prăvălie et al., 2021a).*

- *the land multi-degradation approach ([Prăvălie et al., 2021a]) – **a wide interest** for the international community, namely for **the UNCCD and the European Commission** (the screenshots below);*

- *this scientific approach is important for some key land degradation control policies:*
  - *Land Degradation Neutrality (LDN) (Cowie et al., 2018);*
  - *the 2030 Agenda for Sustainable Development (Wunder et al., 2018);*
  - *Paris Agreement (Rumpel et al., 2018);*

- *the results of this project, focused on **land multi-degradation in Europe**, could generate **a similar international impact;***

- *the continental results – essential for the key policies above, applied in Europe.*



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Hot off the press: Arable lands under the pressure of multiple land degradation processes. A global perspective

03-02-2021

While agricultural systems are a major pillar in global food security, their productivity is currently threatened by many environmental issues triggered by anthropogenic climate change and human activities, such as land degradation.

However, the planetary spatial footprint of land degradation processes on arable lands, which can be considered a major component of global agricultural systems, is still insufficiently well understood.

This study analyzes the land degradation footprint on global arable lands, using complex geospatial data on certain major degradation processes, i.e. aridity, soil erosion, vegetation decline, soil salinization and soil organic carbon decline.

By applying geostatistical techniques that are representative for identifying the incidence of the five land degradation processes in global arable lands, results showed that aridity is by far the largest singular pressure for these agricultural systems, affecting **~40% of the arable lands' area, which cover approximately 14 million km2 globally**.

Arable lands under the pressure of multiple land degradation processes. A global perspective.

Published in Environmental Research ; Volume 194, March 2021, 110697

Authors: Remus Prăvălie, Cristian Patriche, Pasquale Borrelli, Panos Panagos, Bogdan Roșca, Monica Dumitrașcu, Ion-Andrei Nita, Ionuț Săvulescu, Marius-Victor Birsan, Georgeta Bandoc,

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Land degradation in global arable lands

Analysis of the spatial footprint of the multiple forms of land degradation in global arable lands. This includes 5 land degradation processes: aridity, soil erosion, vegetation decline, soil salinization and soil organic carbon decline. Data are at global scale.

Resource Type: Datasets, Soil Threats Data

Year: 2021

Language: en

Registration is requested: Yes

Description Request Form

Metadata

Title: Land degradation in global arable lands.

Description: Land degradation is a global environmental issue that affects the world's arable lands on a large scale, thus threatening global food production systems. This study analyzes the land degradation footprint on global arable lands, using complex geospatial data on certain major degradation processes, i.e. aridity, soil erosion, vegetation decline, soil salinization and soil organic carbon decline. By applying geostatistical techniques that are representative for identifying the incidence of the five land degradation processes in global arable lands, results showed that aridity is by far the largest singular pressure for these agricultural systems, affecting ~40% of the arable lands' area, which cover approximately 14 million km^2 globally. Therefore, the world's arable lands are particularly vulnerable to uni-degradation (the incidence of a single degradation process), through large-scale aridity conditions. Also, it was found that soil erosion is another major degradation process, the unilateral impact of which affects ~20% of global arable systems.

Resolution: 1km

Time Reference: 2012

Format: GeoTIFF

Projection: Equal-area Mollweide

Input data: Aridity, soil erosion, vegetation decline, soil salinization and soil organic carbon decline.

Reference of source (Citations) :

Prăvălie, R., Patriche, C., Borrelli, P., Panagos, P., Roșca, B., Dumitrașcu, M., Nita, I.A., Săvulescu, I., Birsan, M.V. and Bandoc, G. 2021. Arable lands under the pressure of multiple land degradation processes. A global perspective. *Environmental Research*, **194**, art no .110697.

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Arable lands under the pressure of multiple land degradation processes. A global perspective

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❑ *The methodological approach of land multi-degradation in Europe:*

- *this project focuses on modelling 12 processes in Europe – **water erosion, wind erosion, soil organic carbon loss, soil salinization, soil acidification, soil compaction, soil nutrient imbalances, soil pollution via pesticides, soil pollution via heavy metals, vegetation degradation, groundwater decline** and **aridity**) (Table 1);*
- *these land degradation processes are highly relevant for highlighting the agricultural land degradation in Europe and worldwide (Table 1).*

Table 1. *The 12 processes selected for this project, considering the general negative ecological effects for agricultural land productivity (after Prăvălie et al., 2023).*

No.	Land degradation processes	Examples of negative effects on agricultural land productivity
1	Water erosion	*Degrading soil structure, reducing soil depth or decreasing / losing the soil nutrient content*
2	Wind erosion	*Accelerating dust emission, damaging crops by abrasion or reducing the organic matter content*
3	Soil organic carbon loss	*Disrupting structural stability and water holding capacity of soils or decreasing soil fertility*
4	Soil salinization	*Limiting plant growth due to phytotoxicity, water uptake difficulty or soil organic carbon losses*
5	Soil acidification	*Threatening soil bacterial diversity, increasing toxicity for plants or limiting soil nutrient availability*
6	Soil compaction	*Reducing soil porosity, shrinking oxygen and water supply to plants or restricting root penetration*
7	Soil nutrient imbalances	*Amplifying acidity and micronutrient deficiencies in soils, due to N or P excess, or inhibiting plant growth, due to N or P deficit*
8	Soil pollution via pesticides	*Exerting stress on soil health via toxicity and decline in microbial community or earthworm activity*
9	Soil pollution via heavy metals	*Poisoning the soil, injuring plants via chlorosis and necrosis or hindering root growth and crop yields*
10	Vegetation degradation	*Decreasing soil productivity via soil organic carbon losses or through increased land exposure to water and wind erosion*
11	Groundwater decline	*Depleting groundwater resources, inducing soil water stress or inhibiting plant development*
12	Aridity	*Generating surface low water availability and constant soil water deficit or triggering desertification*

- *6 databases available internationally were directly used – water erosion (Borrelli et al., 2017), soil organic carbon (SOC) loss (Prăvălie et al., 2021b), soil salinization (Toth et al., 2008), soil acidification (Ballabio et al., 2019), soil compaction (EC, 2008) and soil pollution via pesticides (Tang et al., 2021) (Fig. 6);*

- *for the other layers (wind erosion, soil nutrient imbalances, soil pollution via heavy metals, vegetation degradation, groundwater decline and aridity), various pre-existent data from other sources were collected, in order to model the geospatial data for the remaining 6 processes (Prăvălie et al., 2023) (Table 2, Fig. 6);*

- *the 12 rasters, with various features (Table 2), were structured into **2 classes – Critical** and Non-critical (Fig. 6);*

- *by intersecting the Critical classes of the 12 datasets, **Land Multi-degradation Index (LMI)** was obtained.*

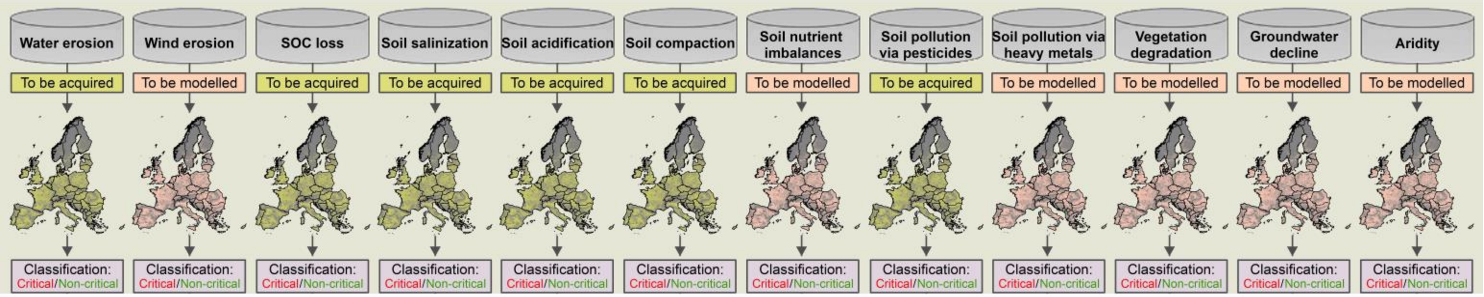

Fig. 6. *Processing of geospatial databases in Europe, in line with the objectives of this project.*

Table 2. *Characteristics of land degradation data that were used in this project (after Prăvălie et al., 2023).*

No.	LD data	Original resolution [a]	Time period	Metric
1	Water erosion	250 × 250 m	2012	t ha^{-1} yr^{-1}
2	Wind erosion	500 × 500 m	2001–2021	t ha^{-1} yr^{-1}
3	SOC loss	1 × 1 km	2001–2015	t C km^2 yr^{-1}
4	Soil salinization	1 × 1 km	2008	%
5	Soil acidification	500 × 500 m	2019	pH units
6	Soil compaction	1 × 1 km	2008	Susceptibility
7	Soil nutrient imbalances	1 × 1 km (N) 100 ×100 m (P)	2010–2019	kg/ha (N) mg/kg (P)
8	Soil pollution via pesticides	10 × 10 km	2015	Risk score
9	Soil pollution via heavy metals	1 × 1 km (As, Cd, Cr, Co, Pb, Sb, Ni) 500 × 500 m (Cu) 250 × 250 m (Hg)	2009	mg/kg
10	Vegetation degradation	500 × 500 m	2000–2015	NDVI units
11	Groundwater decline	1 × 1 km	2004–2013	GTD (m yr^{-1})
12	Aridity	1 × 1 km	1981–2018	AI (mm/mm)

Notes: m – meter, km – kilometer, ha – hectare, t – ton, C – carbon, N – Nitrogen, P – Phosphorous; NDVI – Normalized Difference Vegetation Index; GTD – Groundwater Table Depth; AI – Aridity Index; As – Arsenic; Cd – Cadmium; Cr – Chrome; Co – Cobalt; Pb – Lead; Sb – Antimony; Ni – Nickel; Cu – Copper; Hg – Mercury; a – spatial resolution of the originally collected data, which will be processed in this project at an intermediate resolution of 500 × 500 m.

❑ *The geospatial results of multiple land degradation processes in Europe:*

- *different spatial patterns of land (uni-) degradation processes across Europe (Fig. 7);*
- *each driver of degradation – examined according to some specific critical thresholds (red class) (Figs. 7, 8);*

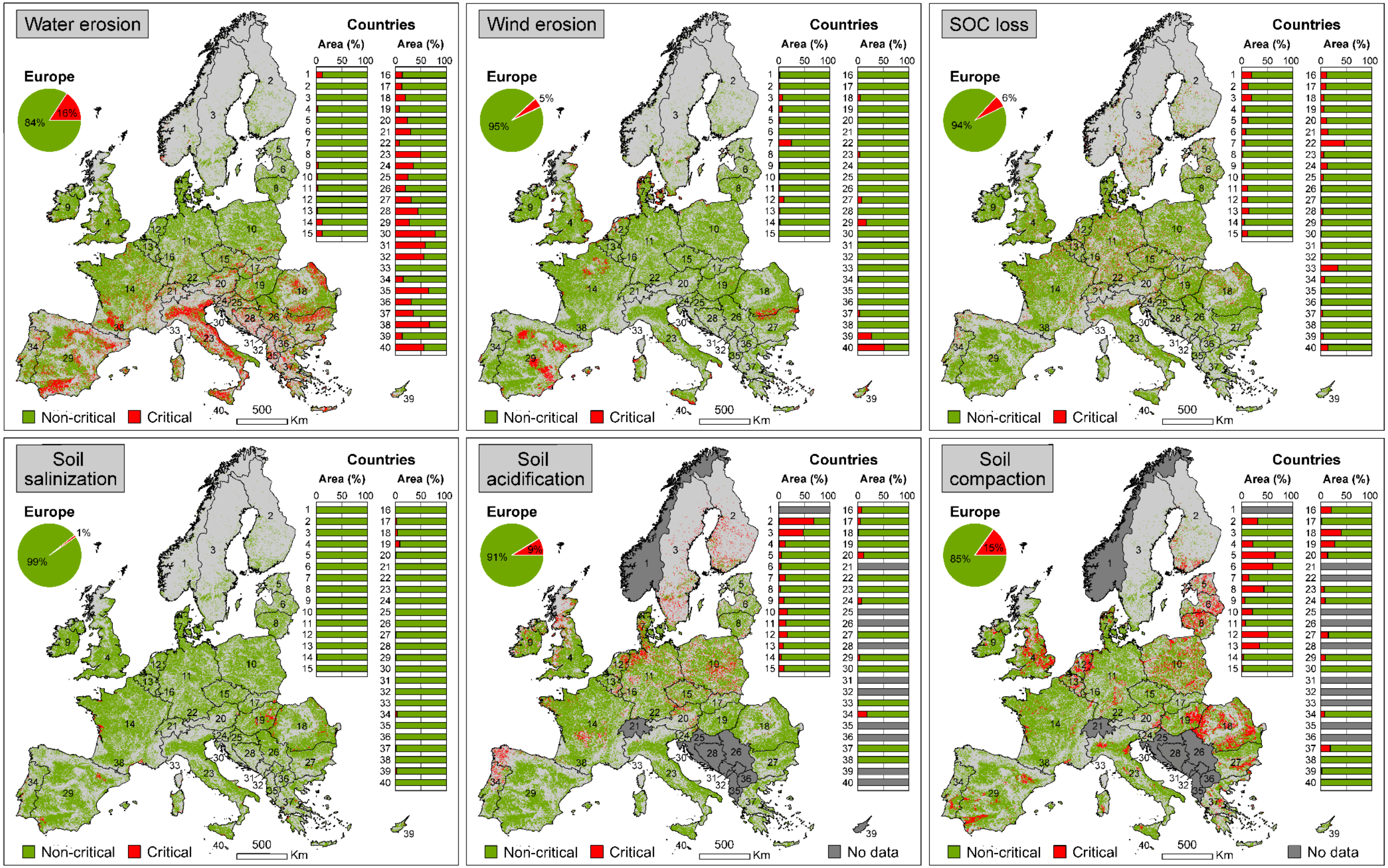

Fig. 7. *Mapping of water erosion, wind erosion, SOC loss, soil salinization, soil acidification and soil compaction in European agricultural areas.*

- *soil pollution via pesticides – the largest spatial footprint at continental level (52% of the cumulated agricultural area of the 40 investigated countries) (Fig. 8);*
- *followed by soil nutrient imbalances (39%), soil pollution via heavy metals (31%) and aridity (26%) (Fig. 8);*

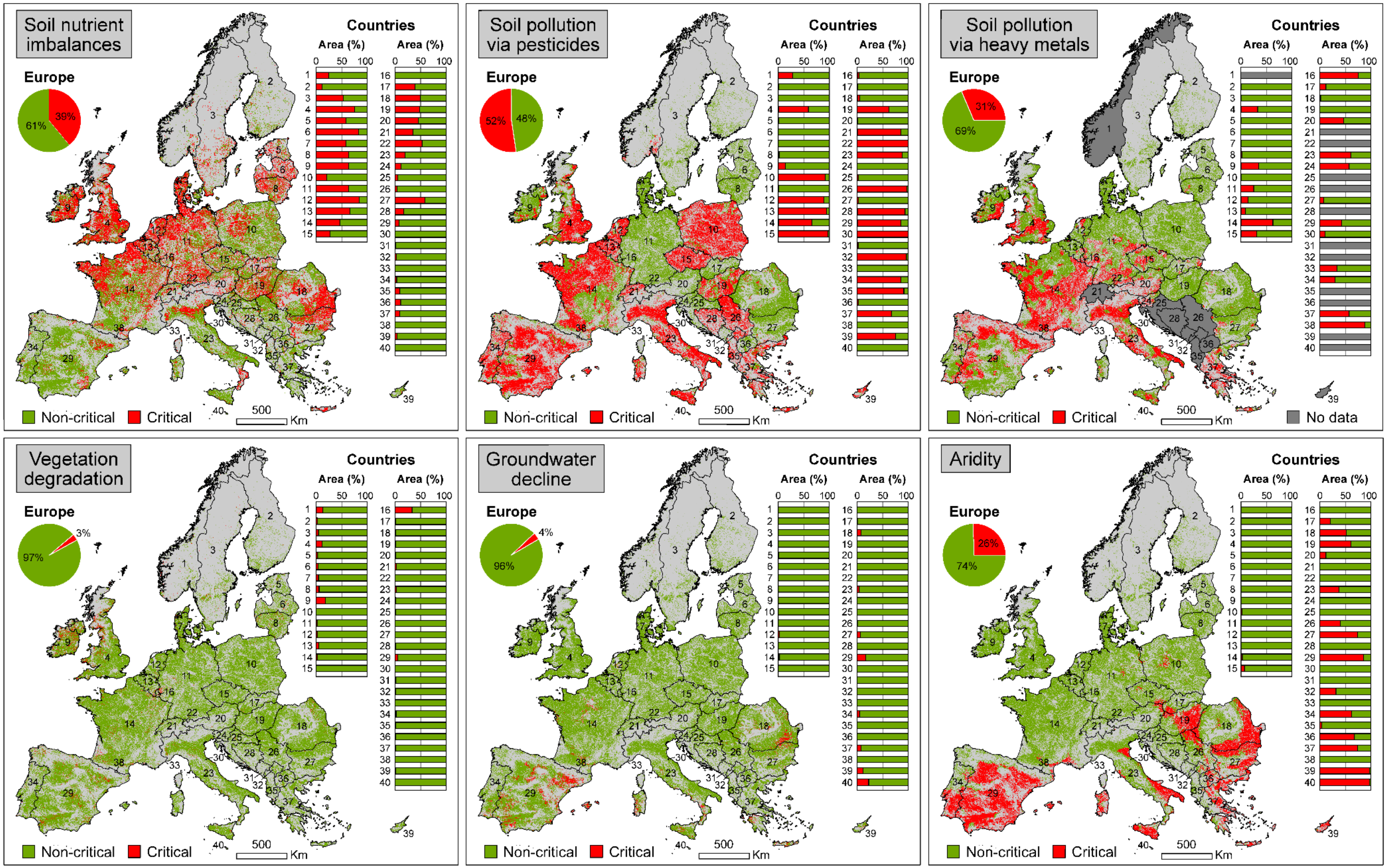

Fig. 8. *Mapping of soil nutrient imbalances, soil pollution via pesticides, soil pollution via heavy metals, vegetation degradation, groundwater decline and aridity in European agricultural areas.*

- *Land Multi-degradation Index (LMI) – obtained by fusing the 12 land degradation databases (Fig. 9);*
- *LMI revealed between one and ten converging (co-occurring) processes in Europe (Fig. 9);*
- *~10% of agricultural/arable lands are cumulatively affected by 4 and ≥ 5 concurrent processes (Table 3);*

Table 3. *Spatial extent (in km² and %) of LMI classes in agricultural/arable environments of Europe (after Prăvălie et al., 2023).*

No.	LMI classes (number of co-occurring processes)	Agricultural lands		Arable lands	
		km²	%	km²	%
1	No degradation (0)	143,626	6.84	71,196	6.23
2	Very low degradation (1)	577,279	27.50	304,105	26.60
3	Low degradation (2)	727,147	34.65	395,940	34.64
4	Medium degradation (3)	451,213	21.50	249,178	21.80
5	High degradation (4)	156,170	7.44	95,169	8.33
6	Very high degradation (≥ 5)	43,473	2.07	27,562	2.40

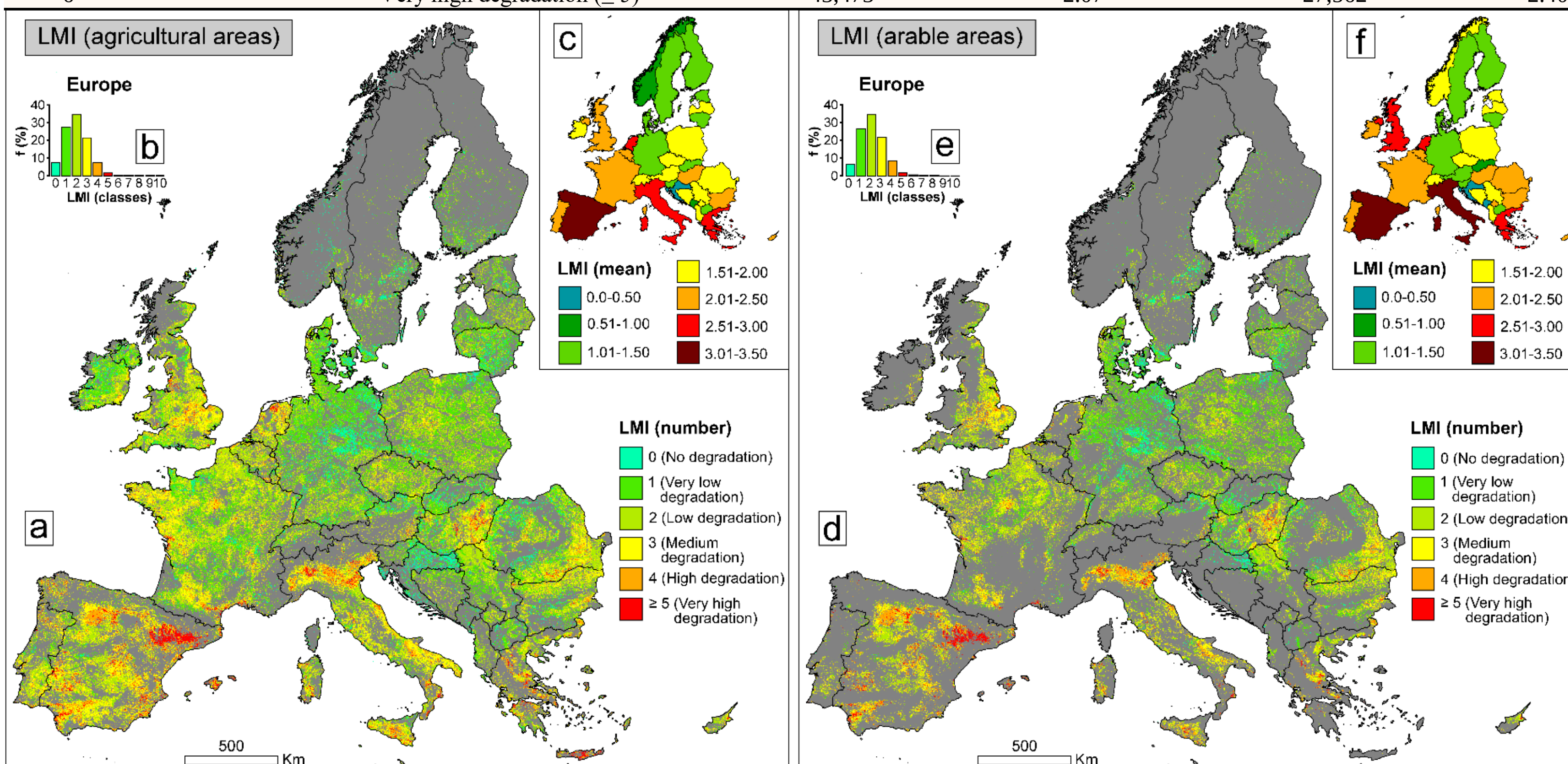

Fig. 9. *Land multi-degradation (LMI) in Europe.* ***a,d*** *Spatial distribution of LMI values in agricultural / arable landscapes.* ***b,e*** *Histogram of LMI values for European agricultural /arable lands.* ***c,f*** *Average number of co-occurring processes in agricultural / arable environments of Europe.*

- *in terms of* ***process combinations*** *– a complex pattern of interacting land degradation pathways (Figs. 10, 11);*
- *the Mediterranean countries – the main hotspots of four and five process combinations (Figs. 10, 11).*

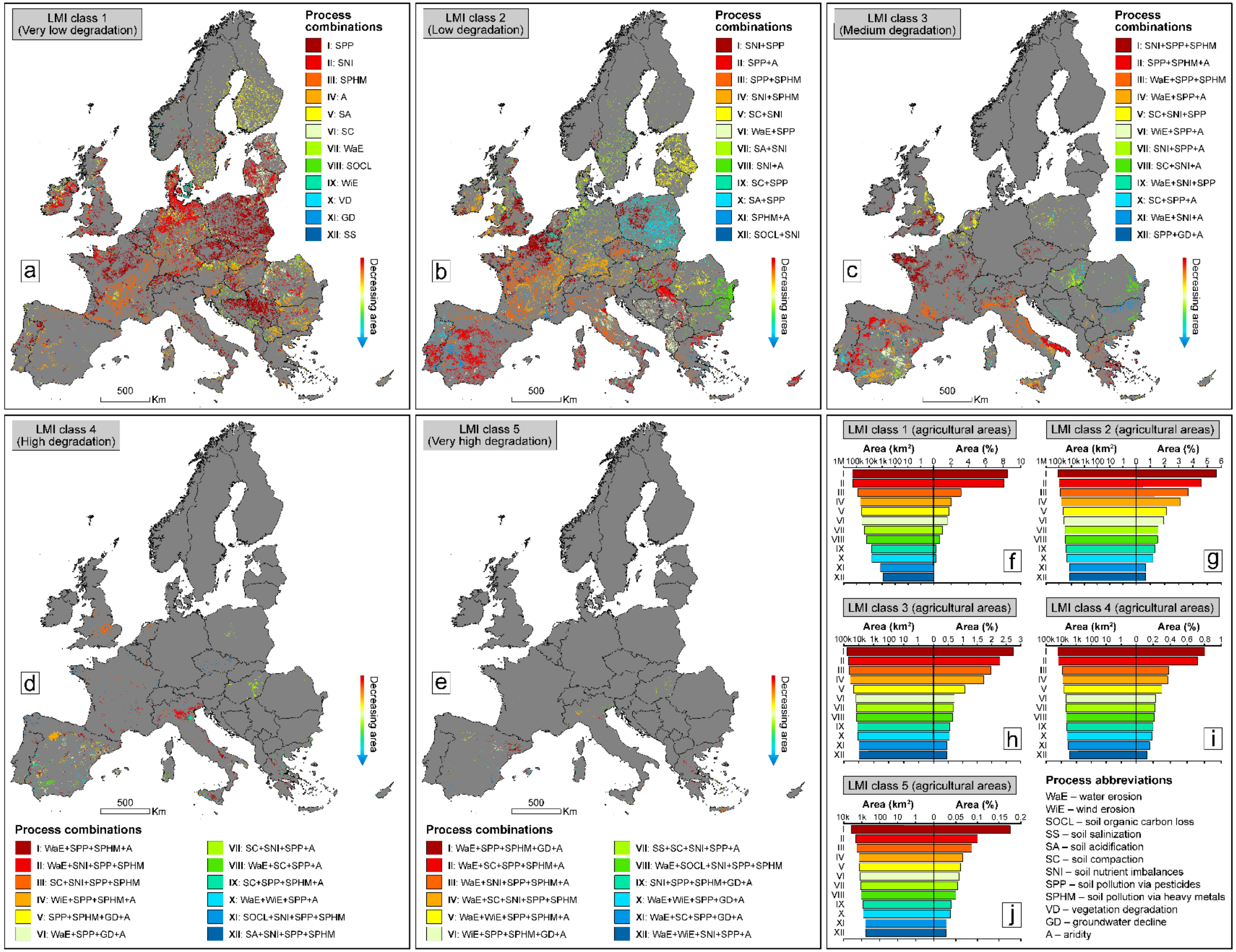

Fig. 10. *Spatial pattern of interacting convergent processes in agricultural environments of Europe.* ***a–e****, Spatial distribution of the dominant co-occurring process combinations in LMI agricultural classes 1 (a), 2 (b), 3 (c), 4 (d) and 5 (e).* ***f–j****, Absolute and percentage-based (% of the total continental agricultural lands) spatial footprint of the dominant co-occurring process types in LMI agricultural classes 1 (f), 2 (g), 3 (h), 4 (i) and 5 (j).*

Notes: process abbreviations: WaE – water erosion, WiE – wind erosion, SOCL – soil organic carbon loss, SS – soil salinization, SA – soil acidification, SC – soil compaction, SNI – soil nutrient imbalances, SPP – soil pollution via pesticides, SPHM – soil pollution via heavy metals, VD – vegetation degradation, GD – groundwater decline, A – aridity.

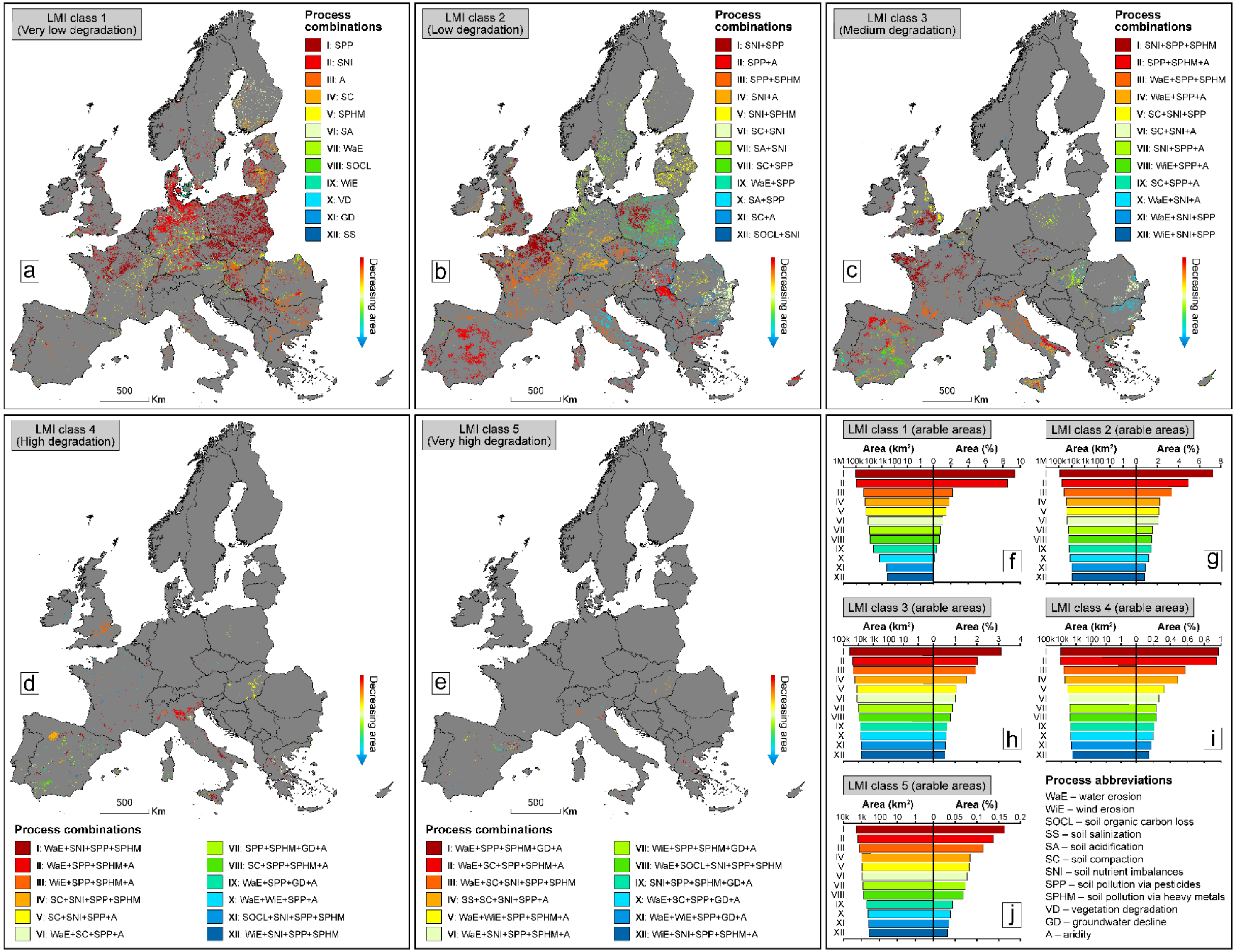

Fig. 11. *Spatial pattern of interacting convergent processes in arable environments of Europe.* ***a–e****, Spatial distribution of the dominant co-occurring process combinations in LMI arable classes 1 (a), 2 (b), 3 (c), 4 (d) and 5 (e).* ***f–j****, Absolute and percentage-based (% of the total continental arable lands) spatial footprint of the dominant co-occurring process types in LMI arable classes 1 (f), 2 (g), 3 (h), 4 (i) and 5 (j).*

Notes: process abbreviations: WaE – water erosion, WiE – wind erosion, SOCL – soil organic carbon loss, SS – soil salinization, SA – soil acidification, SC – soil compaction, SNI – soil nutrient imbalances, SPP – soil pollution via pesticides, SPHM – soil pollution via heavy metals, VD – vegetation degradation, GD – groundwater decline, A – aridity.

❑ *Conclusions:*

- ✓ *all project objectives were successfully achieved, according to the project proposal;*
- ✓ *all detailed results, produced in accordance with the 5 objectives of the project, are available in the paper submitted for publication;*
- ✓ *the results of the project have been submitted for publication in the prestigious **Nature Communications** journal.*

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Manuscript #	NCOMMS-23-14179
Current Revision #	0
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Title	A unifying modelling of multiple land degradation pathways in Europe
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Collection	N/A
Corresponding Author	Mr Remus Prăvălie (pravalie_remus@yahoo.com) (University of Bucharest)
Contributing Authors	Professor Pasquale Borrelli , Dr Panos Panagos , Dr Emanuele Lugato , Professor Adrian Chappell , Dr Gonzalo Miguez-Macho , Professor Federico Maggi , Dr Jian Peng , Mr Mihai Niculiță , Mr Bogdan Roșca , Cristian Patriche , Ms Monica Dumitrașcu , Dr Marius-Victor Birsan , Georgeta Bandoc , Mr Ion-Andrei Nita
Authorship	Yes
Abstract	Land degradation (LD) is a complex socio-environmental threat, which generally occurs as multiple concurrent pathways that remain largely unexplored in Europe. Here we present an unprecedented analysis of land multi-degradation in 40 continental countries, using for the first time twelve dataset-based processes that were modelled as LD convergence and combination pathways in Europe's agricultural (and arable) environments. Using a Land Multi-degradation Index, we found that about 27%, 35% and 22% of continental agricultural (>2 million km2) and arable (>1.1 million km2) lands are currently threatened by one, two and three drivers of degradation, while ~10% of pan-European agricultural/arable landscapes are cumulatively affected by four and at least five concurrent processes. We also investigated the complex pattern of spatially interacting processes, emphasizing the major combinations of LD pathways across continental and national boundaries. Our results will enable policy makers to develop knowledge-based strategies for LD mitigation and other critical European sustainable development goals.

***Prăvălie R.**, Borrelli P., Panagos P., Lugato E., Chappell A., Miguez-Macho G., Maggi F., Peng J., Niculiță M., Roșca B., Patriche C., Dumitrașcu M., Birsan M.V., Bandoc G., Nita I.A., 2023. A unifying modelling of multiple land degradation pathways in Europe. **Nature Communications** (under evaluation).*

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- ***Published results (scientific deliverables) – 4 scientific articles*** *(with results directly or indirectly related to the project topic, land degradation) published / under publication in* ***highly prestigious journals****, with a* ***cumulative impact factor of 38.2****:*

- ***Prăvălie R.****, Sîrodoev I., Ruiz-Arias J., Dumitrașcu M., 2022. Using renewable (solar) energy as a sustainable management pathway of lands highly sensitive to degradation in Romania. A countrywide analysis based on exploring the geographical and technical solar potentials.* ***Renewable Energy****, 193, https://doi.org/10.1016/j.renene.2022.05.059 – Q1 (red zone) in Web of Science,* ***Impact factor 8.7****;*

- ***Prăvălie R.****, Niculiță M., Roșca B., Patriche C., Dumitrașcu M., Marin G., Nita I.A., Bandoc G., Birsan M.V., 2023. Modelling forest biomass dynamics in relation to climate change in Romania using complex data and machine learning algorithms.* ***Stochastic Environmental Research and Risk Assessment****, 37, 1669–1695, FI 3.8, Q1 (red zone) in Web of Science,* ***Impact factor 4.2****;*

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Using renewable (solar) energy as a sustainable management pathway of lands highly sensitive to degradation in Romania. A countrywide analysis based on exploring the geographical and technical solar potentials

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ORIGINAL PAPER

Modelling forest biomass dynamics in relation to climate change in Romania using complex data and machine learning algorithms

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Abstract

Forest biomass controls climate stability, many ecological processes and various ecosystem services. This study analyzes for the first time the recent changes (1987–2018) of forest above-ground live biomass (AGB) in Romania, based on a complex volume of remote sensing and forest inventory data that were modelled yearly using a series of sophisticated statistical algorithms. Subsequently, after modelling interannual AGB data, yearly raster values (~ 2 billion total pixel values) were explored as trends over the 32 years, using the *Sen's slope* estimator and Mann–Kendall test. A large volume of climate data was also processed in this study, in order to detect possible statistical relationships between climate and forest biomass, after 1987. Results showed a mean multiannual value of forest biomass of ~ 185 t/ha and a total AGB amount (stock) of about 1.25 billion tons (~ 1249 million tons or megatonnes/Mt) across Romania. Regarding forest biomass changes, findings revealed increasing and decreasing AGB trends that account for ~ 70% and 30%, respectively, of the countrywide forest biomass changes. However, it was found that about half (~ 48%) of all positive AGB trends are statistically significant, while negative AGB trends have a statistical confidence on only one-fifth (~ 21%) of their spatial footprint in Romania. Overall, upon averaging and summing up all statistically significant values of positive and negative trends, an average AGB increase of ~ 3 t/ha/yr and a total forest biomass gain of ~ 205 Mt were found in Romania, over the entire 1987–2018 period. The various regional statistics highlight a more complex picture of AGB changes across the country. The analysis of interannual eco-climate data indicated a low to moderate climate signal in AGB changes, revealing that climate change is not a major driving force of AGB dynamics, at least according to the data and methodology applied in this study. The results can be useful to governmental forestry, climate and sustainable development policies in Romania.

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Research article

Machine learning-based prediction and assessment of recent dynamics of forest net primary productivity in Romania

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Dear Mr Prăvălie,

Thank you again for submitting your manuscript "A unifying modelling of multiple land degradation pathways in Europe" to Nature Communications. We have now received reports from 2 reviewers and, after careful consideration, we have decided to invite a major revision of the manuscript.

As you will see from the reports copied below, the reviewers raise important concerns. We find that these concerns limit the strength of the study, and therefore we ask you to address them with additional work. Without substantial revisions, we will be unlikely to send the paper back to review. In particular, both referees appreciate the potential value of your work. However, they also raised major concerns about the methodology and the potential uncertainties, which editorially we think should be seriously addressed. Please also expand the discussion regarding how the methodology used compares to other type of methods since they assign equal importance to each individual LD process in LMI. You can also expand the Methods section to provide as much detail as necessary..

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