A GLOBAL EXAMINATION OF ARABLE LAND MULTI-DEGRADATION

PRĂVĂLIE Remus [1,2], BORRELLI Pasquale [3,4], PANAGOS Panos [5], BANDOC Georgeta [1,2]

[1] University of Bucharest, Faculty of Geography, 1 Nicolae Bălcescu Street, 010041, Bucharest, Romania
[2] Academy of Romanian Scientists, 54 Splaiul Independenței Street, 050094, Bucharest, Romania
[3] Department of Environmental Sciences, Environmental Geosciences, University of Basel, Basel, Switzerland
[4] Department of Science, Roma Tre University, Rome, Italy
[5] European Commission, Joint Research Centre (JRC), Ispra, Italy

1. CONTEXT AND OBJECTIVE

◊ **Context:** *agricultural lands provide 99% of the global food production (Prăvălie et al., 2021a; Halpern et al., 2022), thus currently having an astonishing contribution to the world's food security; however, the progressive and multidimensional degradation of arable lands (the most important agricultural systems by far) has become a major environmental challenge for world food security (Cherlet et al., 2018; Sartori et al., 2019) and, generally, for other critical land (soil) functions and ecosystem services, such as carbon sequestration, climate regulation, water purification, nutrient cycling and others (Greiner et al., 2017; Baveye et al., 2020); the collapse of land functions is all the more intense as land degradation (LD) occurs through multiple concurrent processes, a state called land multi-degradation (Prăvălie et al., 2024) that is not well understood at the level of global arable systems.*

◊ **Objective:** *exploring arable land multi-degradation by analyzing the geospatial convergence (incidence) of five major processes in global arable environments.*

2. DATA AND METHODS

○ 2.1 Selection of land degradation data:

- *five LD processes were selected, from a wide spectrum of potential processes (Fig. 1) (Prăvălie, 2021), for modelling arable land multi-degradation across the globe;*
- *the selection of processes was made according to certain relevant criteria, such as global spatial footprint, data availability or impact on arable systems (Prăvălie et al., 2021a).*

○ 2.2 Arable land data:

- *derived from the MODIS MCD12Q1 Land Cover Type and modified by Borrelli et al. (2017);*
- *the arable data – representative for 2012 and collected globally (Fig. 2a) from Borrelli et al. (2017).*

○ 2.3 Aridity data:

- *sourced from the CGIAR Consortium for Spatial Information (Trabucco and Zomer, 2009) and downloaded as a global Aridity Index (AI) (Fig. 2b);*
- *the AI (in mm/mm) – computed as a multiannual ratio (1950–2000) between precipitation and potential evapotranspiration;*
- *the index defines 4 types of drylands – dry sub-humid (0.65–0.5 mm/mm), semi-arid (0.5–0.2 mm/mm), arid (0.2–0.03 mm/mm) and hyper-arid (<0.03 mm/mm);*
- *aridity – both a cause and a pathway of LD, through constant dryness or climate-induced desertification.*

○ 2.4 Vegetation decline (degradation) data:

- *collected from a global vegetation trend database, produced for the 1982–2011 period (Ivits et al., 2014);*
- *vegetation decline data – derived by correlating FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) anomalies with the negative values of SPEI (Standardized Precipitation and Evaporation Index) (Ivits et al., 2016);*
- *FAPAR is a reliable indicator of plant productivity, while SPEI is a suggestive tool of drought events;*
- *the negative statistically significant trends resulting from the correlations indicated degradation/decline of crop biomass in drought-affected areas (Fig. 2c).*

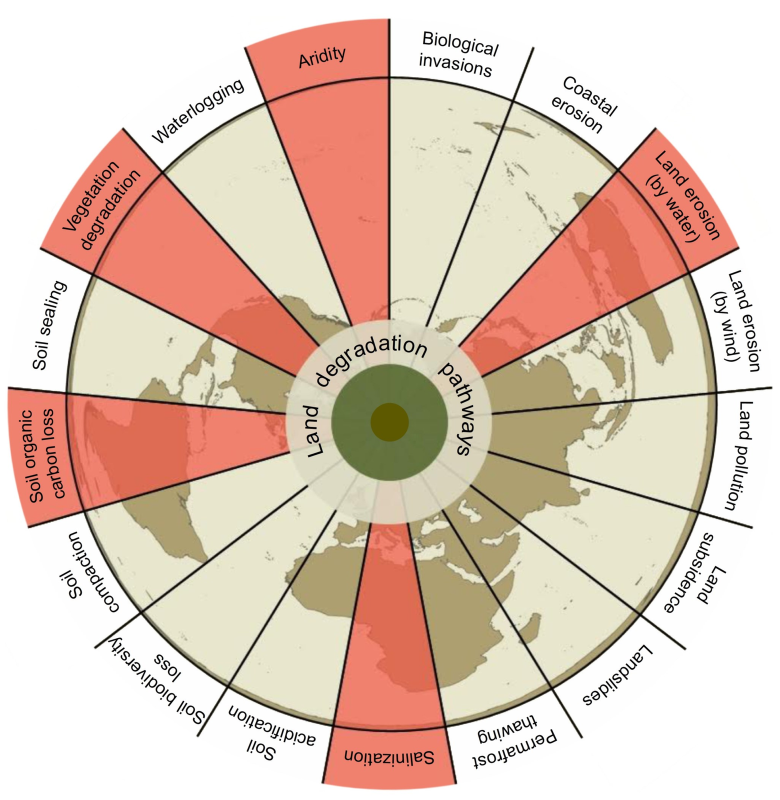

Fig. 1. Schematic approach to LD pathways currently occurring globally. Note: sections in red indicate LD pathways (processes) that were considered to be major in this global analysis, according to some relevant criteria like global spatial footprint, data availability or impact on arable systems (after Prăvălie, 2021).

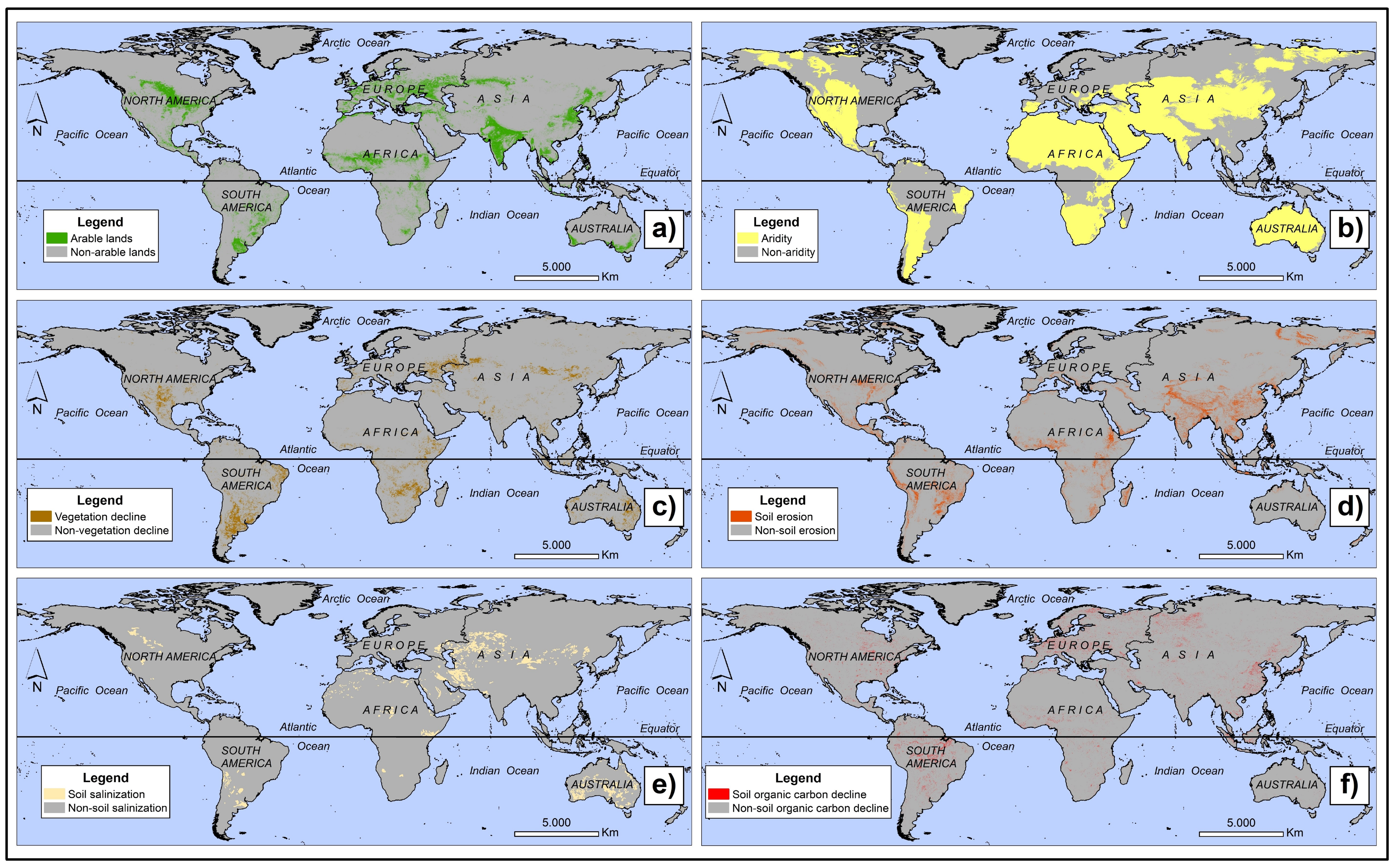

Fig. 2. Global spatial representation of arable lands (a) and of the analyzed LD processes, i.e. aridity (AI values < 0.65 mm/mm) (data processing after Trabucco and Zomer, 2009) (b), vegetation decline (negative trends of biomass in areas exposed to drought conditions) (data processing after Ivits et al., 2014) (c), soil erosion by water (>10 t ha^{-1} yr^{-1}) (data processing after Borrelli et al., 2017) (d), soil salinization (Solonchaks, Solonetzs and salt-covered areas)(data processing after FAO, 2014) (e) and soil organic carbon decline (negative trends of the soil organic carbon stock) (data processing after Prăvălie et al., 2021b) (f). Note: while all spatial data of the 5 LD processes are displayed in these maps at the entire global scale, their incidence (co-occurrence) was analyzed strictly within the world's arable land boundaries (a).

○ 2.5 Soil erosion data:

- *developed via RUSLE-based model (soil erosion due to inter-rill and rill erosion) and collected from Borrelli et al. (2017);*
- *water erosion data – extracted based on the threshold >10 t ha^{-1} yr^{-1}, which indicates severe erosion rates (Fig. 2d).*

○ 2.6 Soil salinization data:

- *acquired from the FAO-UNESCO Soil Map of the World – Digital Soil Map of the World, 2007, version 3.6 (FAO, 2014);*
- *Solonchaks, Solonetzs and salt-covered areas – extracted for highlighting soil salinization (Fig. 2e), as a major form of LD.*

○ 2.7 Soil organic carbon decline data:

- *processed using multitemporal gridded datasets (2001–2015) of soil organic carbon (SOC) stock (in kg/m^2, converted to tons/km^2) (Wheeler and Hengl, 2018) and collected from the SOC trend database developed by Prăvălie et al. (2021b);*
- *SOC decline data – modelled globally based on negative statistically significant trends of SOC stock (Fig. 2f);*
- *SOC losses detected – decreases in soil fertility and productivity and, implicitly, a worsening of LD.*

○ 2.8 Data processing:

- *for modelling the convergence / co-occurrence of multiple LD processes, only the critical classes (the colored ones in Fig. 2b-f) of the five processes were considered;*
- *all LD processes (critical classes) were superimposed / intersected across arable zones (each LD factor having an equal contribution), using GIS (Geographic Information Systems) techniques;*
- *all data were processed (in terms of the number, types and area of LD processes' convergence in arable landscapes) at a common spatial resolution of 1 km;*
- *the entire modelling was performed across 193 United Nations (UN) member states and three other states with different UN statuses (Kosovo, Palestine and Taiwan), the combined arable surfaces of which total ~14.2 million km^2, or almost 10% of the Earth's terrestrial area.*

Table 1. LD processes' extent in absolute and relative values at global and continental arable area.

Land degradation process/Spatial unit		km^2	%[a]
Aridity	Globe	7,786,636.6	54.7
	North and Central America	1,061,755.3	49.4
	South America	458,717.2	30.6
	Europe	681,330.6	34.6
	Africa	2,105,755.5	74.6
	Asia	3,034,356.2	57.3
	Australia and Oceania	444,721.7	89.8
Vegetation decline	Globe	1,192,191.5	8.4
	North and Central America	101,137.5	4.7
	South America	341,333.5	22.8
	Europe	243,179.5	12.4
	Africa	214,793.6	7.6
	Asia	232,763.5	4.4
	Australia and Oceania	58,983.8	11.9
Soil erosion	Globe	4,256,374.9	29.9
	North and Central America	577,871.0	26.9
	South America	811,495.6	54.2
	Europe	75,405.5	3.8
	Africa	1,069,740.6	37.9
	Asia	1,705,988.7	32.2
	Australia and Oceania	15,873.4	3.2
Soil salinization	Globe	266,784.6	1.9
	North and Central America	34,564.0	1.6
	South America	65,123.9	4.3
	Europe	11,573.2	0.6
	Africa	14,102.6	0.5
	Asia	82,979.2	1.6
	Australia and Oceania	58,441.7	11.8
SOC decline	Globe	472,377.9	3.3
	North and Central America	42,717.1	2.0
	South America	66,316.9	4.4
	Europe	103,290.2	5.2
	Africa	59,529.0	2.1
	Asia	196,406.0	3.7
	Australia and Oceania	4118.7	0.8

Note: a – percentages of absolute area of LD processes in relation to the global (14,234,399.4 km^2) /continental (North and Central America – 2,150,691.4 km^2; South America – 1,497,907.8 km^2; Europe – 1,968,805.7 km^2; Africa – 2,824,027.6 km^2; Asia – 5,297,469.1 km^2; Australia and Oceania – 495,497.8 km^2) arable area; these data were extracted through the individual (separate) intersection of LD processes with arable areas.

3. RESULTS

○ 3.1 Number of spatially interacting processes across the globe:

- *the separate investigation (without a synergistic / convergent approach) of LD factors highlights aridity and soil erosion as dominant processes affecting global arable landscapes (Table 1);*
- *the analysis of intersected processes shows multi-degradation conditions (between 2 and 5 degradative factors acting simultaneously) on ~17% of global arable lands (Figs. 3, 4);*
- *the same intersecting procedure revealed that most of the world's arable environments (~62%) are affected by a single LD process (uni-degradation) (Figs. 3, 4).*

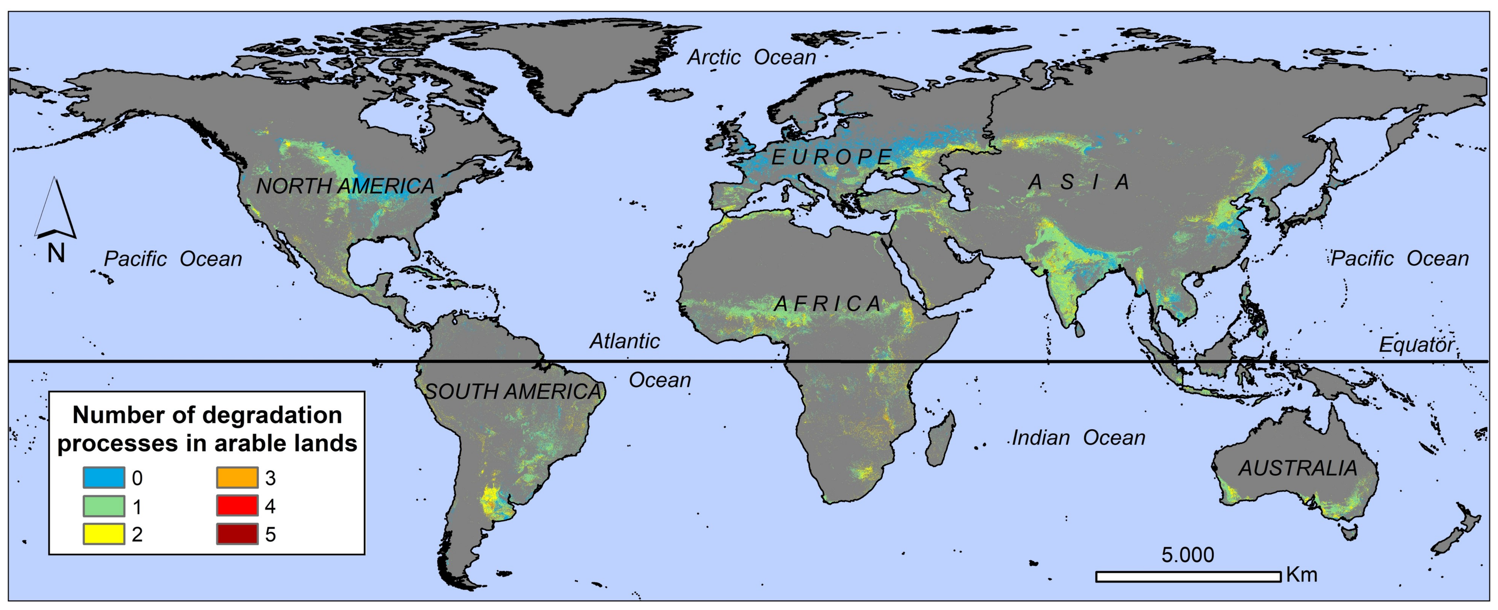

Fig. 3. Global spatial representation of the number of LD processes in arable systems. Note: in this map the value 0 indicates the absence of any degradation process, 1 indicates the presence of a single degradation process, and the following values indicate the simultaneous presence of 2, 3, 4 and 5 LD processes in arable lands.

○ 3.2 Types of spatially interacting processes across the globe:

- *aridity (A) – the global dominant vector of arable land uni-degradation (affecting ~40% of the world's total arable surface) (Figs. 5, 6);*
- *soil erosion (E) – also a major form (~20%) of arable uni-degradation across the planet (Figs. 5, 6);*
- *A and E – the dominant pathways (~7%) of global multi-degradation of arable systems (Figs. 5, 6).*

○ 3.3 Number and types of spatially interacting processes across the world's countries:

- *India, the United States, China, Brazil, Argentina, Russia and Australia – countries most vulnerable to arable land uni-degradation / multi-degradation, in terms of absolute data (Figs. 7, 8);*
- *African countries – generally the most affected by arable land uni-degradation / multi-degradation, in terms of percentages (Figs. 7, 8).*

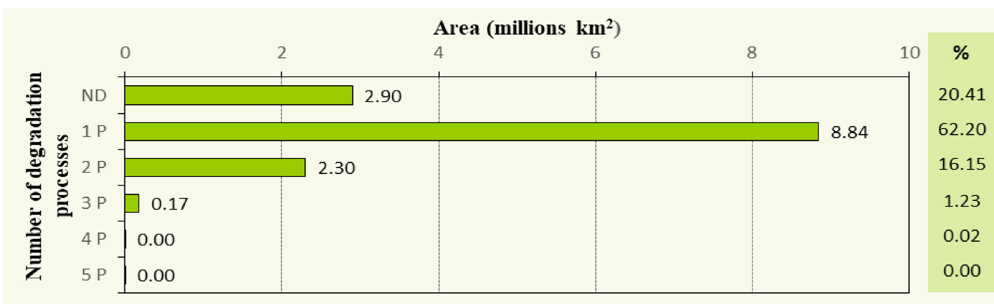

Fig. 4. Areas (in km^2 / %) covered by the number of LD processes in global arable lands.

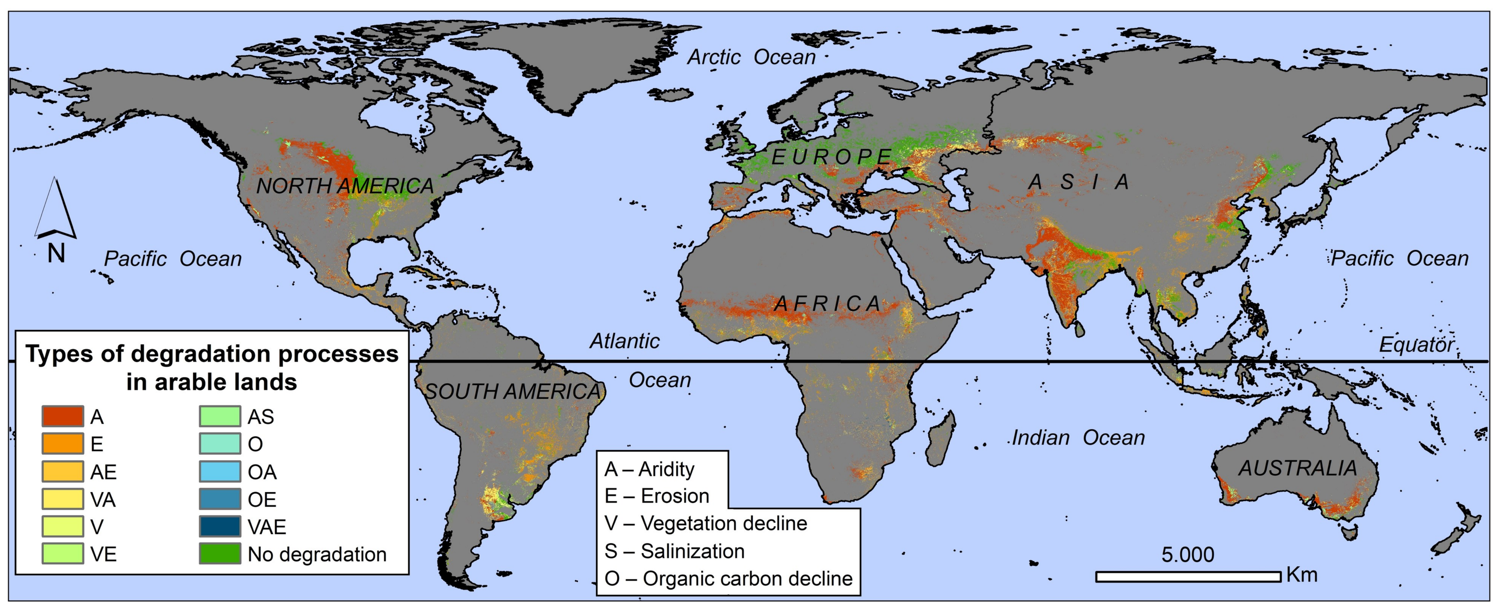

Fig. 5. Global spatial representation of the types of LD processes in arable systems. Note: in this map one-letter acronyms indicate the presence of a single process, while more acronyms show the combinations of LD processes in arable lands.

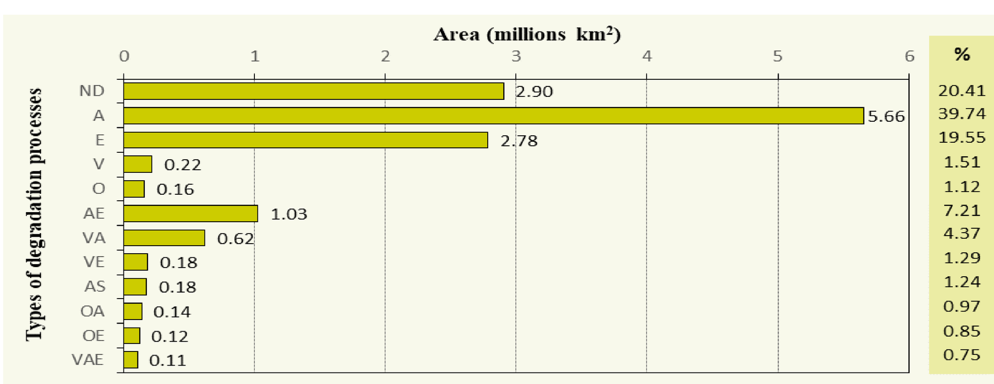

Fig. 6. Areas (in km^2 / %) covered by the types of LD processes in global arable lands.

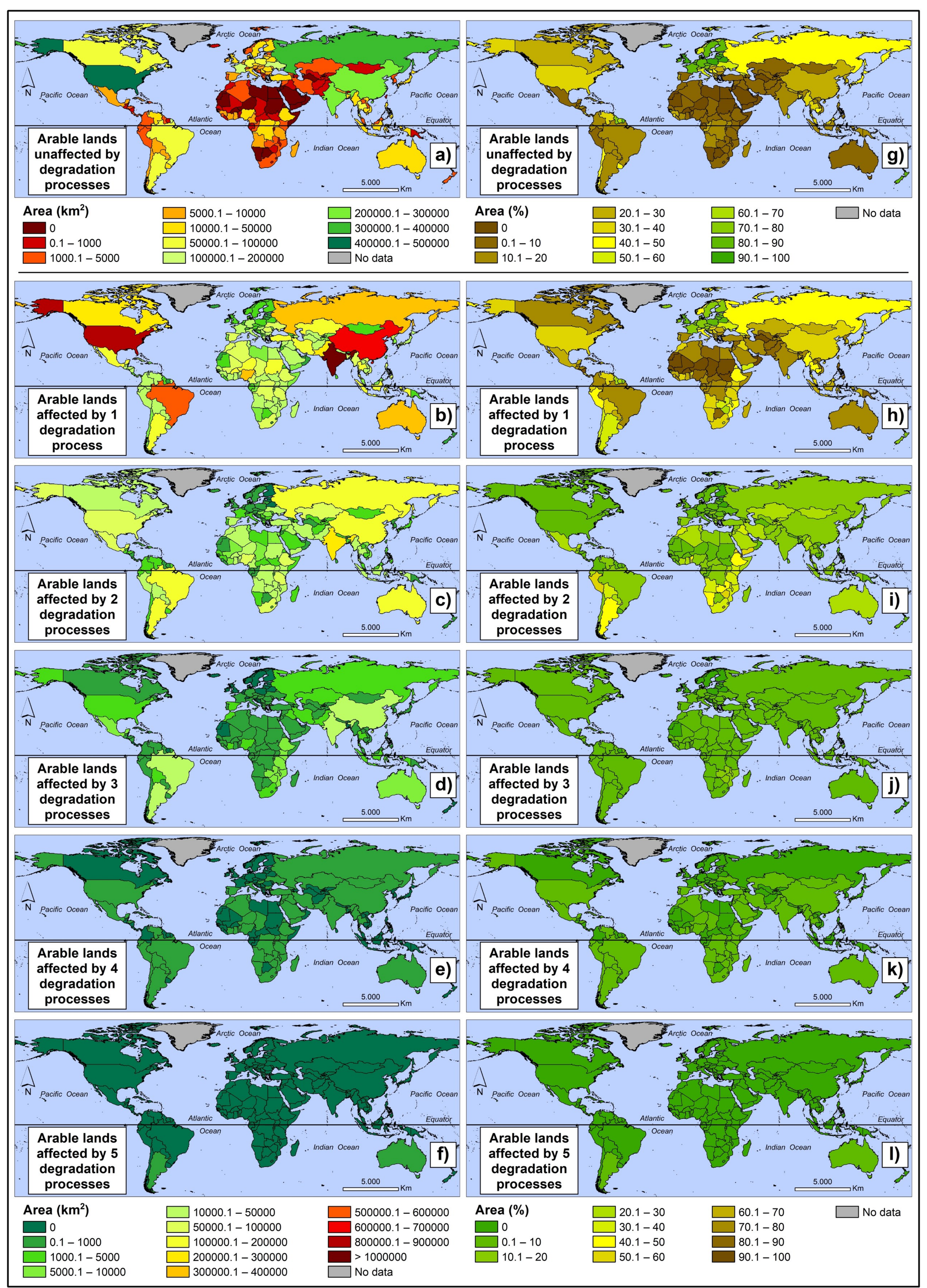

Fig. 7. Global spatial representation of absolute (a–f) and percentage-based (g–l) arable areas that are unaffected / affected by different numbers of occurrences of LD processes nationally. Note: in the case of arable lands that are unaffected by degradation processes (a, g), the low (red / brown) values indicate limited / non-existent areas nationally in which arable systems are not affected by degradation (i.e. countries that hold arable lands that are in fact affected by one or more degradation processes); percentage-based data featured on the figure's right side are percentages of absolute LD processes area in relation to the arable state area.

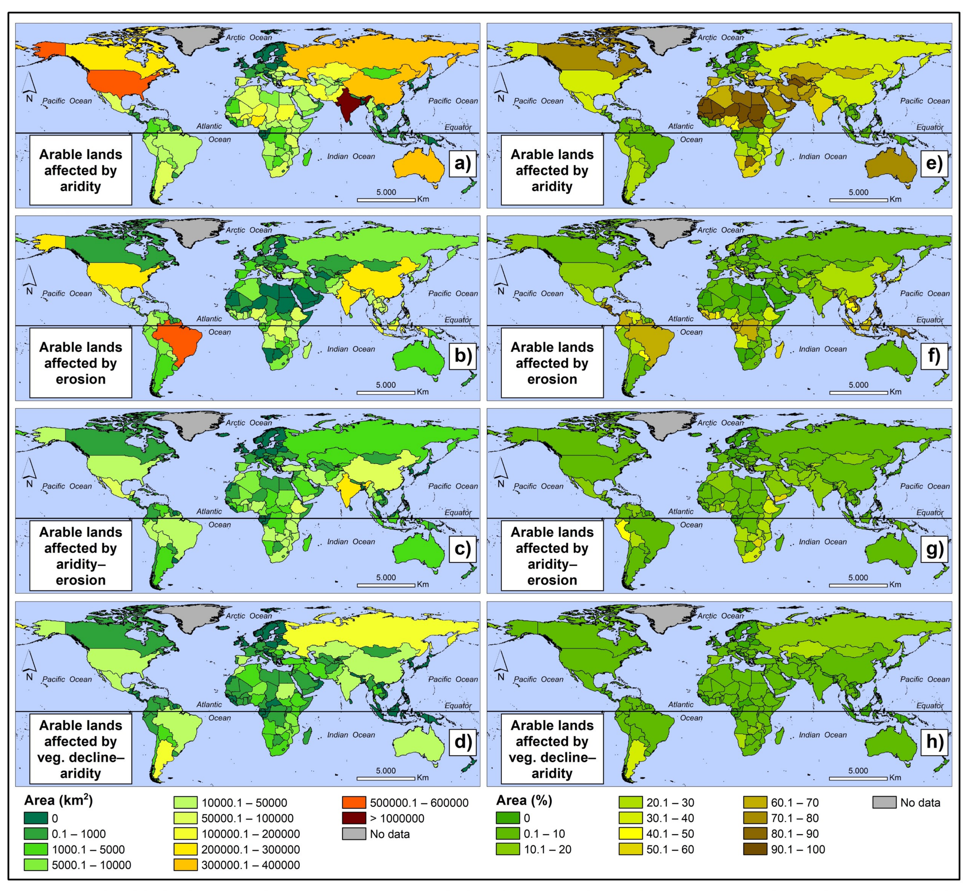

Fig. 8. Global spatial representation of absolute (a–d) and percentage-based (e–h) arable areas that are affected by major types of LD processes nationally.

4. CONCLUSIONS

◊ *global arable systems – under the pressure of various LD processes, which were addressed simultaneously in this research;*

◊ *aridity – the largest singular pressure for agricultural systems, affecting ~40% of global arable lands;*

◊ *soil erosion – another major degradation process, the unilateral impact of which affects ~20% of global arable systems;*

◊ *the two LD processes simultaneously affect (as land multi-degradation) an additional ~7% of the arable lands of the planet.*

5. REFERENCES

- Baveye, P.C., Schnee, L.S., Boivin, P., et al., 2020. *Soil organic matter research and climate change: Merely re-storing carbon versus restoring soil functions*. Front. Environ. Sci. 8, https://doi.org/10.3389/fenvs.2020.579904.
- Borrelli, P., Robinson, D.A., Fleischer, L.R., et al., 2017. *An assessment of the global impact of 21st century land use change on soil erosion*. Nat. Commun. 8, https://doi.org/10.1038/s41467-017-02142-7.
- Cherlet, M., Hutchinson, C., Reynolds, J., et al., (Eds.), 2018. *World Atlas of Desertification (WAD), Third Edition*. Publication Office of the European Union, Luxembourg, Luxembourg.
- FAO, 2014. *World Reference Base for Soil Resources 2014*. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps, Update 2015.
- Greiner, L., Keller, A., Grêg-Regamey, A., et al., 2017. *Soil function assessment: review of methods for quantifying the contributions of soils to ecosystem services*. Land Use Policy 69, https://doi.org/10.1016/j.landusepol.2017.06.025.
- Halpern, B.S., Frazier, M., Verstaen, J., et al., 2022. *The environmental footprint of global food production*. Nat. Sustain. 5, 1027–1039.
- Ivits, E., Horion, S., Fensholt, R., et al., 2014. *Global ecosystem response types derived from the Standardized Precipitation Evapotranspiration Index and FPAR3g series*. Remote Sens. 6, 4266–4288.
- Ivits, E., Horion, S., Erhard, M., et al., 2016. *Assessing European ecosystem stability to drought in the vegetation growing season*. Glob. Ecol. Biogeogr. 25, 1131–1143.
- Prăvălie, R., Patriche, C., Borrelli, P., et al., 2021a. *Arable lands under the pressure of multiple land degradation processes. A global perspective*. Environ. Res. 194, https://doi.org/10.1016/j.envres.2020.110697.
- Prăvălie, R., Nita, I.A., Patriche, C., et al., 2021b. *Global changes in soil organic carbon and implications for land degradation neutrality and climate stability*. Environ. Res. 201, https://doi.org/10.1016/j.envres.2021.111580.
- Prăvălie, R., 2021. *Exploring the multiple land degradation pathways across the planet*. Earth Sci. Rev. 220, https://doi.org/10.1016/j.earscirev.2021.103689.
- Prăvălie, R., Borrelli, P., Panagos, P., et al., 2024. *A unifying modelling of multiple land degradation pathways in Europe*. Nat. Commun. 15, https://doi.org/10.1038/s41467-024-48252-x.
- Sartori, M., Philippidis, G., Ferrari, E., et al., 2019. *A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion*. Land Use Policy 86, 299–312.
- Trabucco, A., Zomer, R.J., 2009. *Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Database v1*, https://csidotinfo.wordpress.com/data/global-aridity-and-pet-database/.
- Wheeler, I., Hengl, T., 2018. *Soil organic carbon stock (0–30 cm) in kg/m^2 time-series 2001–2015 based on the land cover changes*, https://zenodo.org/records/2529721.

ACKNOWLEDGEMENTS

This work was funded by the EU's NextGenerationEU instrument through the National Recovery and Resilience Plan of Romania – Pillar III-C9-2022-I8, managed by the Ministry of Research, Innovation and Digitalization, within the project entitled "Complex modelling of multiple land degradation processes in Europe. Towards an integrative scientific framework for sustainable land management across the continent", contract no. 760051/23.05.2023, code CF 216/29.11.2022.

Finanțat de Uniunea Europeană NextGenerationEU

Planul Național de Redresare și Reziliență

Program website address: https://mfe.gov.ro/pnrr/ **Facebook page:** https://www.facebook.com/