Spatial analysis of land degradation sensitivity in Romania using the multi-criteria MEDALUS methodology
– Final scientific report 2020 –

Throughout the project's duration (2018–2020), the scientific activities were conducted in accordance with the project's general objective, i.e. an interdisciplinary/multi-criteria analysis of land sensitivity to degradation in Romania based on the complex MEDALUS methodology. Additionally, all of the project's scientific activities were conducted in accordance with the five concrete objectives mentioned in the project's funding application (Table 1).

Table 1. The research activity planning, according to the 5 concrete objectives set for the project

Yr	Objectives		Specific activities	Deliverables
2018	**1**	Identification/acquisition of all geographical data sets (pedological, climatic, hydrologic, biotic) deemed necessary for the MEDALUS model implementation, in accordance with the regional/national specificities of this environmental process.	1.1. Detailed theoretical research based on international specialized literature regarding the entire implementation procedure for the MEDALUS methodology; 1.2. Identification of datasets (pedologic, climatic, hydrologic, biotic) required by the methodology; 1.3. Acquisition of datasets from online databases and specialized institutions in Romania.	No deliverables during the first 8 months of the project, when the MEDALUS method was documented theoretically and when the data needed to apply this model in Romania was collected.
2019 / 2020	**2**	Processing the data to obtain the main biophysical indicators that are driving forces of land degradation, which will help generate the final index of land susceptibility to degradation.	2.1. Calibration of acquired datasets; 2.2. Organizing and processing datasets as raster-type data; 2.3. Obtaining the main biophysical indicators CQI, SQI, VQI, MQI and WQI; 2.4. Obtaining the final product – LDSI.	2 internal conferences (achieved).
	3	Mapping/statistical analysis of all national lands with different degrees of sensitivity to this process, based on the final index of land susceptibility to degradation.	3.1. Mapping lands that are prone to degradation by generating a national map with LDSI sensitivity classes; 3.2. Geographically-based statistical analysis of sensitivity classes (landforms); 3.3. Administratively-based statistical analysis of sensitivity classes (development regions, counties, administrative-territorial units).	1 ISI-indexed paper; 2 international conferences; 1 internal conference (achieved).
	4	Validation of the final sensitivity model with field investigations.	4.1. Regular fieldwork and observations in key sectors indicated by the LDSI (areas that are highly-prone to degradation); 4.2. Establishing the relationship between field observations and the LDSI using statistical analyses (the ROC curve procedure).	1 ISI-indexed paper; 1 international conference; 1 internal conference (achieved, 1 ISI-indexed paper in press).
	5	Raising awareness on the importance of a multi-criteria/interdisciplinary analysis of this environmental issue in Romania's scientific/political spheres by disseminating the study's results.	5.1. Performing research activities corresponding to the first four objectives; 5.2. Participating at relevant international and national conferences; 5.3. Publishing results in prestigious journals (ISI-indexed) that are at least classed on the yellow list (first half of the scientific domain).	International conferences; Internal conferences; ISI-indexed papers; Project web page (achieved).

This final activity report focuses on two main parts, namely **1) synthetically resuming the results obtained in the previous two phases (May 2018 – December 2019)**, and **2) presenting the results obtained from early 2020 to date (January – April 2020)**. The two parts will be presented below in terms of relevant cartographic and statistical results obtained nationally within the project.

In the first part (1), according to the 2018 and 2019 scientific reports, previously prepared for this research project, in the first 20 months of the project (the first eight months of 2018 and the 12 months of 2019) almost all activities specific to the five concrete project objectives (mentioned above) were completed (Table 1). As a very brief presentation of results obtained by early 2020, all data necessary for applying the MEDALUS methodology in Romania were obtained (the quality indicators Climate Quality Index, Soil Quality Index, Vegetation Quality Index, Water Quality Index, Management Quality Index, initially included in the project proposal, but also two additional quality indicators applied subsequently, for the first time nationally and internationally, namely Geomorphological Quality Index and Anthropic Quality Index). In the same period, following the data collection and processing phases that resulted in the seven quality indicators (Fig. 1), the final product of the project, Land Degradation Sensitivity Index (LDSI), was obtained and validated through field investigations conducted nationally.

A brief analysis of the scientific results obtained in the first part will however be kept in this final report, even though it was presented in the previous reports. Thus, applying the MEDALUS methodology in Romania showed, for the first time, that lands that are critically susceptible to degradation (>1.38, on the LDSI scale, which indicates the areas that are already highly degraded, characterized by a strong decline of land economic and ecological productivity) are mainly located in Romania's extra-Carpathian region, especially in the Romanian Plain, Dobrogea Plateau and Moldavia Plateau landforms, but also in the Inner-Carpathian region, especially in the Western Plain and, in part, in Transylvania Plateau (Fig. 2).

Statistically, it was found that areas critically sensitive to degradation (*Critical 1*, *Critical 2* and *Critical 3* classes of LDSI) total in Romania ~68,600 km^2 or 29% of the national territory (Table 2). Moreover, it was noticed that lands with a fragile ecological state (the 1.23–1.38 interval on the LDSI scale, which indicates areas on the verge of degradation, in which any perturbation of the fragile balance between environment and anthropogenic activities can lead to rapid land degradation) also cover extensive areas across Romania, generally in extra-Carpathian areas of the country (Fig. 2, Table 2).

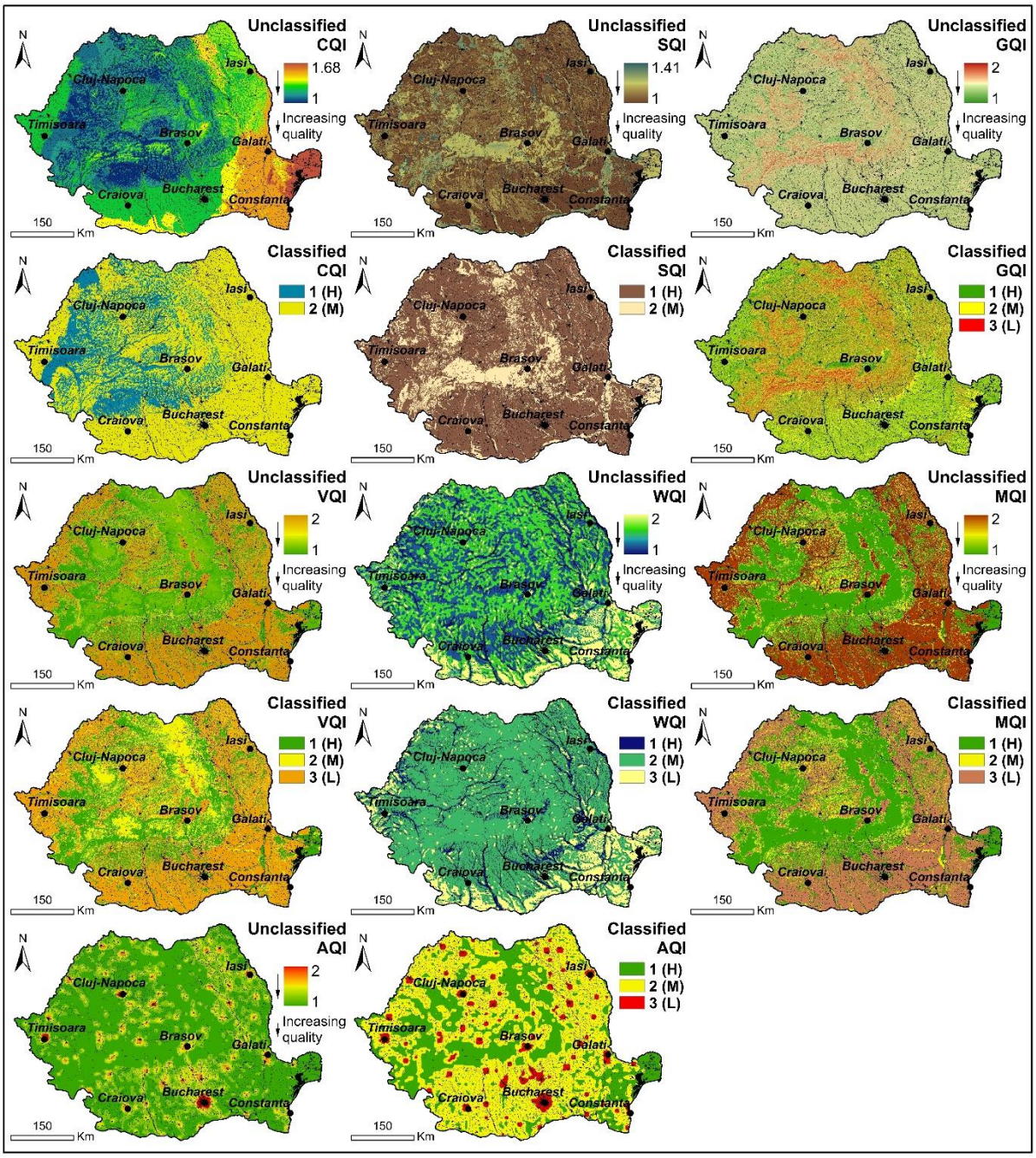

Fig. 1. Spatial representation of Climate Quality Index (CQI), Soil Quality Index (SQI), Geomorphological Quality Index (GQI), Vegetation Quality Index (VQI), Water Quality Index (WQI), Management Quality Index (MQI) and Anthropic Quality Index (AQI), in unclassified and classified forms in Romania. Note: the 7 quality indicators were obtained based on 24 constituting sub-indicators/parameters (selected according to the particular environmental conditions that influence land susceptibility to degradation in Romania) and were classified according to the information featured in Prăvălie et al. (2020a); letters H, M and L between brackets (in the classified maps) are abbreviations for high, moderate and low quality classes, according to the information featured in Prăvălie et al. (2020a); more details about obtaining these quality indicators can be consulted in the paper published in the Catena journal (Prăvălie et al., 2020a).

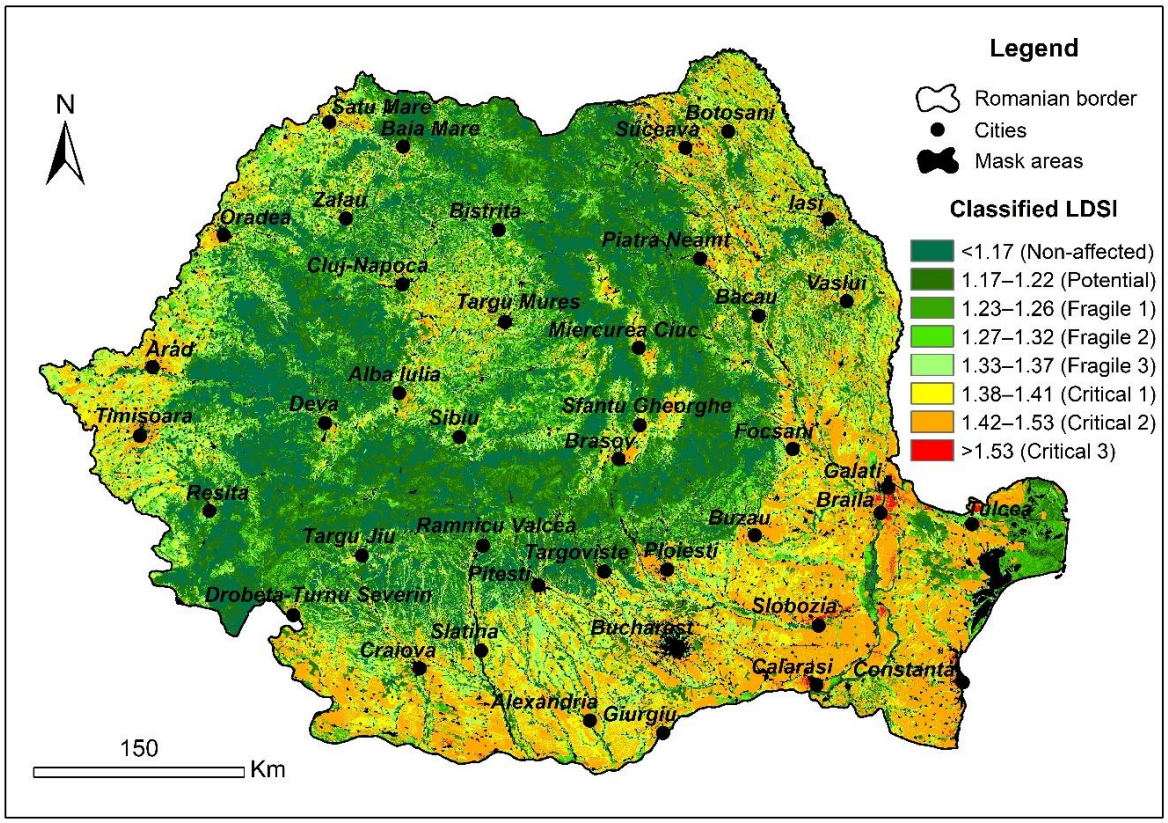

Fig. 2. Spatial representation of classified Land Degradation Sensitivity Index (LDSI) in Romania (in 2018), obtained based on the 7 quality indicators; more details about LDSI can be consulted in the paper published in the Catena journal (Prăvălie et al., 2020a).

Table 2. The area, expressed in absolute and percentage-based (% of the total country area) values, which corresponds to the sensitivity classes of the final LDSI in Romania.

Class	Sub-class	Score range	Total area (km^2)	Total area (%)
Non-affected	N	<1.17	43031.31	18.18
Potential	P	1.17–1.22	38431.71	16.23
Fragile	F1	1.23–1.26	20191.73	8.53
	F2	1.27–1.32	24339.37	10.28
	F3	1.33–1.37	25608.12	10.82
Critical	C1	1.38–1.41	29487.09	12.45
	C2	1.42–1.53	38658.65	16.33
	C3	>1.53	446.36	0.19
Mask areas (artificial and aquatic areas)			16555.00	6.99

Countrywide field observations, especially in the areas critically sensitive to degradation, revealed that, indeed, extensive critical areas (C1, C2, C3) are already highly degraded in reality (Fig. 3), being therefore affected by a strong decline in economic and ecological land productivity. In situ observations confirmed that areas that are highly susceptible to degradation are affected by multiple degradation processes, which directly or indirectly generate a decrease in the lands' biological and agro-ecological productivity – from various forms of erosion to salinization or degradation of vegetation (Fig. 3). The validation of LDSI results revealed that the data presented in figure 2 and table 2 are indeed reliable.

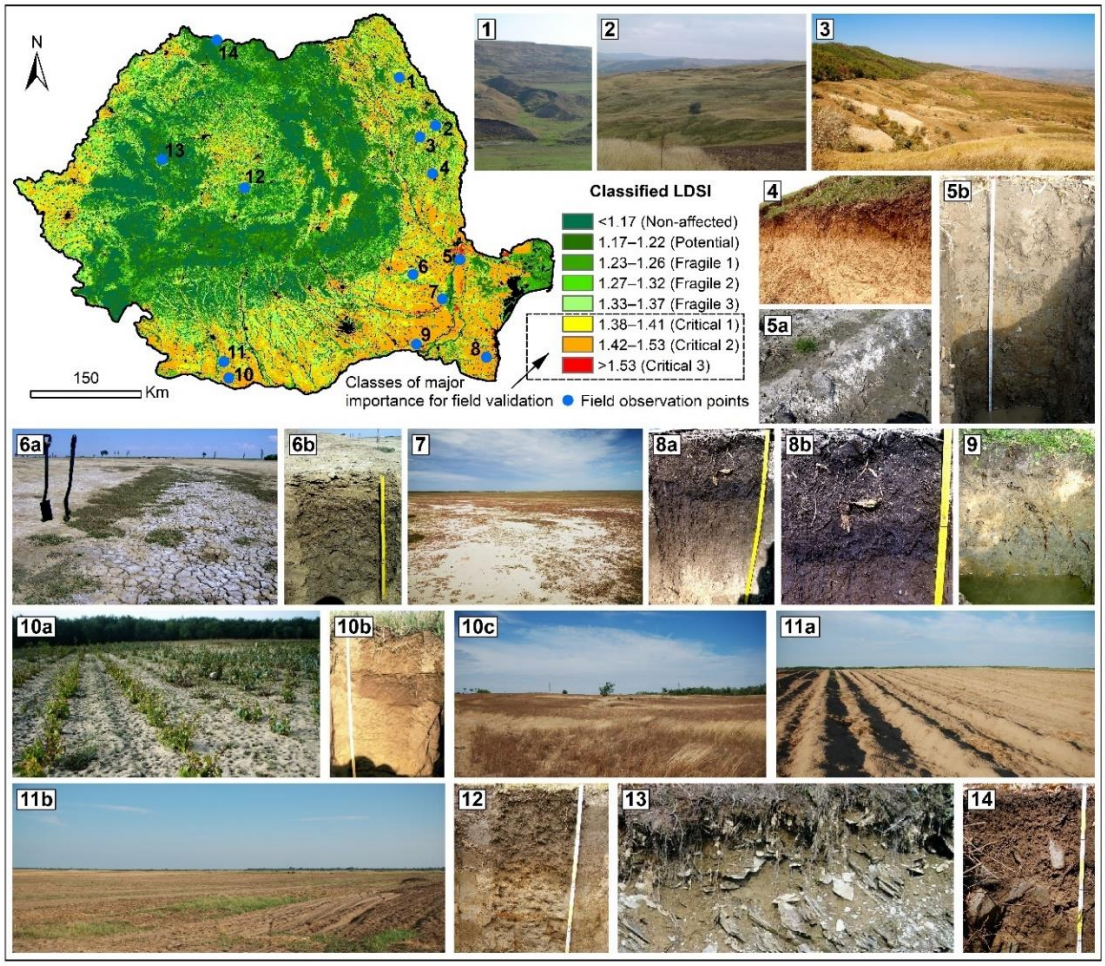

Fig. 3. Examples of local land degradation pathways based on field investigations carried out especially in the areas critically sensitive to degradation in Romania. Note: most field observations were made in areas Critical 1, 2 and 3, except for several cases where observations were made in classes Fragile 1, 2 and 3; all photographs highlight various forms of local land degradation, which directly or indirectly generate a decrease in the lands' biological and agro-ecological productivity – active landslides, gullies, rill and inter-rill erosion (photos 1, 2, 4), gleization and secondary salinization processes (photos 5a, 5b, 6a, 6b, 7, 9, 12), granular structure degradation processes (photos 8a, 8b), presence of sandy soils with poor textural characteristics (photos 10a, 10b, 11a, 11b), presence of underdegraded pastures and withered underdeveloped vegetation (photos 3, 10c), partially developed soils (with low morphological thickness) (photo 13) and soils with high skeletal content and low edaphic volume (photo 14); more details about the LDSI validation based on field investigations can be consulted in the paper published in the Catena journal (Prăvălie et al., 2020a).

In the context of proven data reliability, other more complex geostatistical results were extracted for Romania's geographic and administrative spatial units (Fig. 4). Geographically, the results indicated that the extra-Carpathian region is by far the country's most heavily affected geographic area, as it is highly exposed to degradation especially in the Romanian Plain (Fig. 4). Administratively, the observations showed that the south and south-east development regions (NUTS 2) are the most vulnerable to degradation, while the counties (NUTS 3) making up these development regions are generally the most heavily affected nationally (Fig. 4). This final geostatistical data can be useful primarily to policymakers that

can implement concrete actions for fighting land degradation and desertification in these hotspot areas marked by high land degradative conditions.

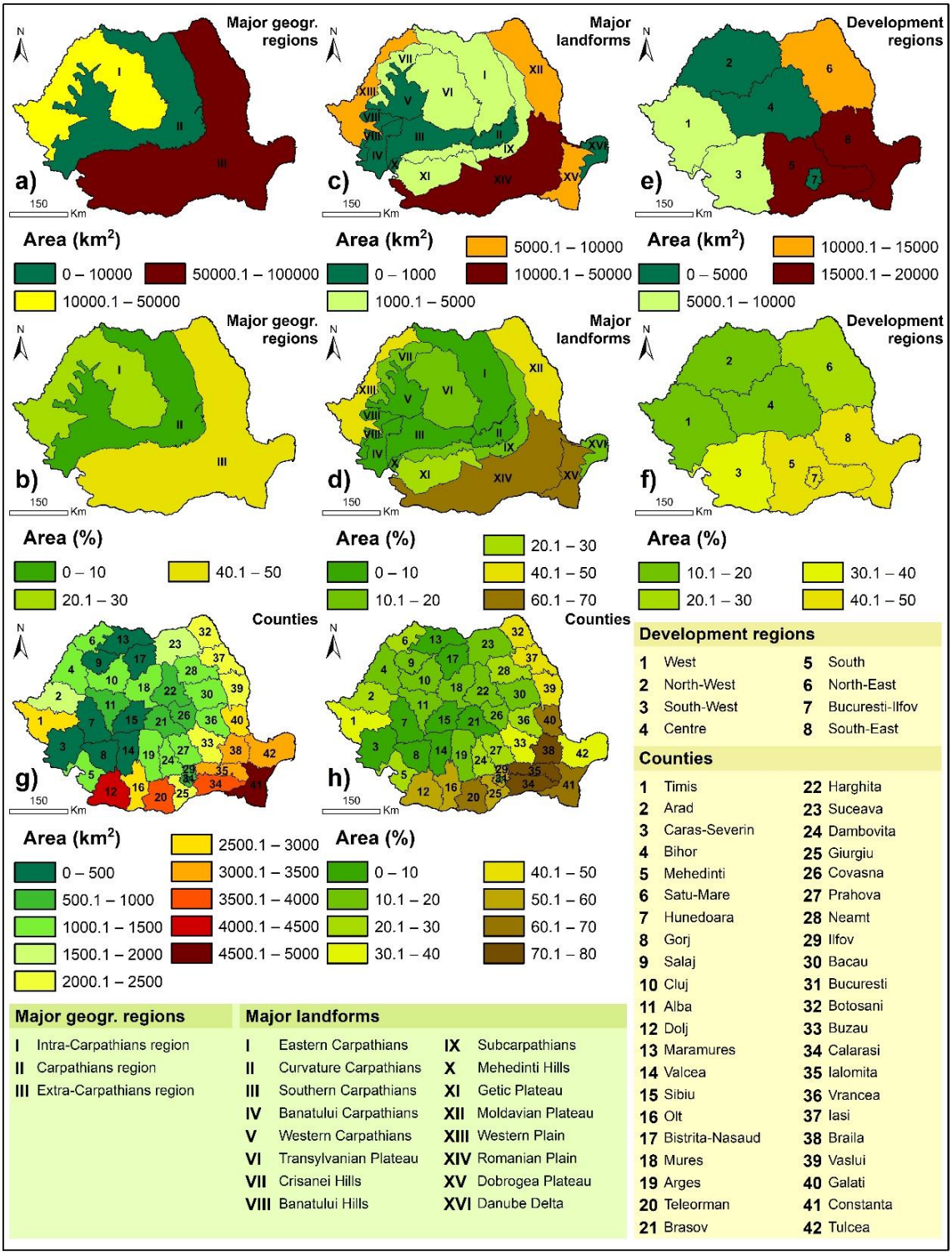

Fig. 4. Geostatistical representation of areas (absolute and percentage-based) of critical LDSI classes (*Critical 1*, *Critical 2* and *Critical 3*) in Romania, in terms of major geographic (geogr.) regions (a, b), major landforms (c, d), development regions (e, f) and counties (g, h). Note: percentage data were computed by relating absolute areas to the total areas of reference spatial units; the in-map numbering was made from west to east, based on increasing longitude coordinate values of the spatial units' western boundaries; more details about the geographic and administrative statistical status of LDSI critical classes can be consulted in the paper published in the Catena journal (Prăvălie et al., 2020a).

The second part of this report (2) presents the results obtained since early 2020 (on the dynamics of the LDSI between 1990 and 2018), which are currently undergoing publication. In other words, while so far results on the static (current) state of LDSI (in 2018) were presented, a temporal perspective on LDSI dynamics in Romania after 1990 (a recent period known to have been marked nationally by considerable changes in climate and anthropic driving forces of land degradation) will be presented below.

By applying the MEDALUS methodology for 1990, using representative data for this year (based on which the LDSI was obtained in 1990), and by performing a comparative analysis against present LDSI data (2018), the results showed significant recent changes in land degradation potential in Romania (Fig. 5, Table 3). Essentially, the detailed geostatistical observations indicated an expansion of ~1,300 km^2 (<1% of Romania's territory) of LDSI classes critically sensitive to degradation (C1, C2 and C3 classes), which in 1990 totalled ~67,300 km^2 (28.4%) across Romania, vs ~68,600 km^2 (29%) in 2018 (Table 3). Although this net expansion of lands critically sensitive to degradation does not seem to be exceedingly high, the findings are still alarming considering the high spatial differences of the exacerbation of land degradative conditions across the country.

The most significant such territorial discrepancies were observed in Romania's extra-Carpathian regions, which, after 1990, have become the most sensitive to degradation nationally (Fig. 5), due to intense climate change (amplification of aridity conditions) and anthropogenic changes (various changes in land use/cover classes, alongside other unsustainable anthropogenic activities). All these findings (presented briefly in this report, but in much more detail in Prăvălie et al., 2020b) are alarming, considering, first and foremost, the dominant presence of arable systems in these regions of the country. In this context, it is expected a major potential decline in the agro-ecosystems productivity located especially in the country's extra-Carpathians region, if trends in land susceptibility to degradation continue to show increases in the coming years.

In the face of this environmental threat, the results of this project require the urgent implementation of solutions to fight land degradation in Romania. Some examples of effective actions in this respect include restoring irrigation systems, afforestation, planting of forest shelterbelts, the conservation of water resources, applying anti-erosion measures, promoting agricultural crops that are resilient to water scarcity or the rational use of agricultural land resources. The implementation of these measures, by central (e.g. the Ministry of Agriculture and Rural Development), regional (e.g. agricultural departments) or local (city halls) policymakers, should mitigate / reverse the future trends of land degradation in Romania.

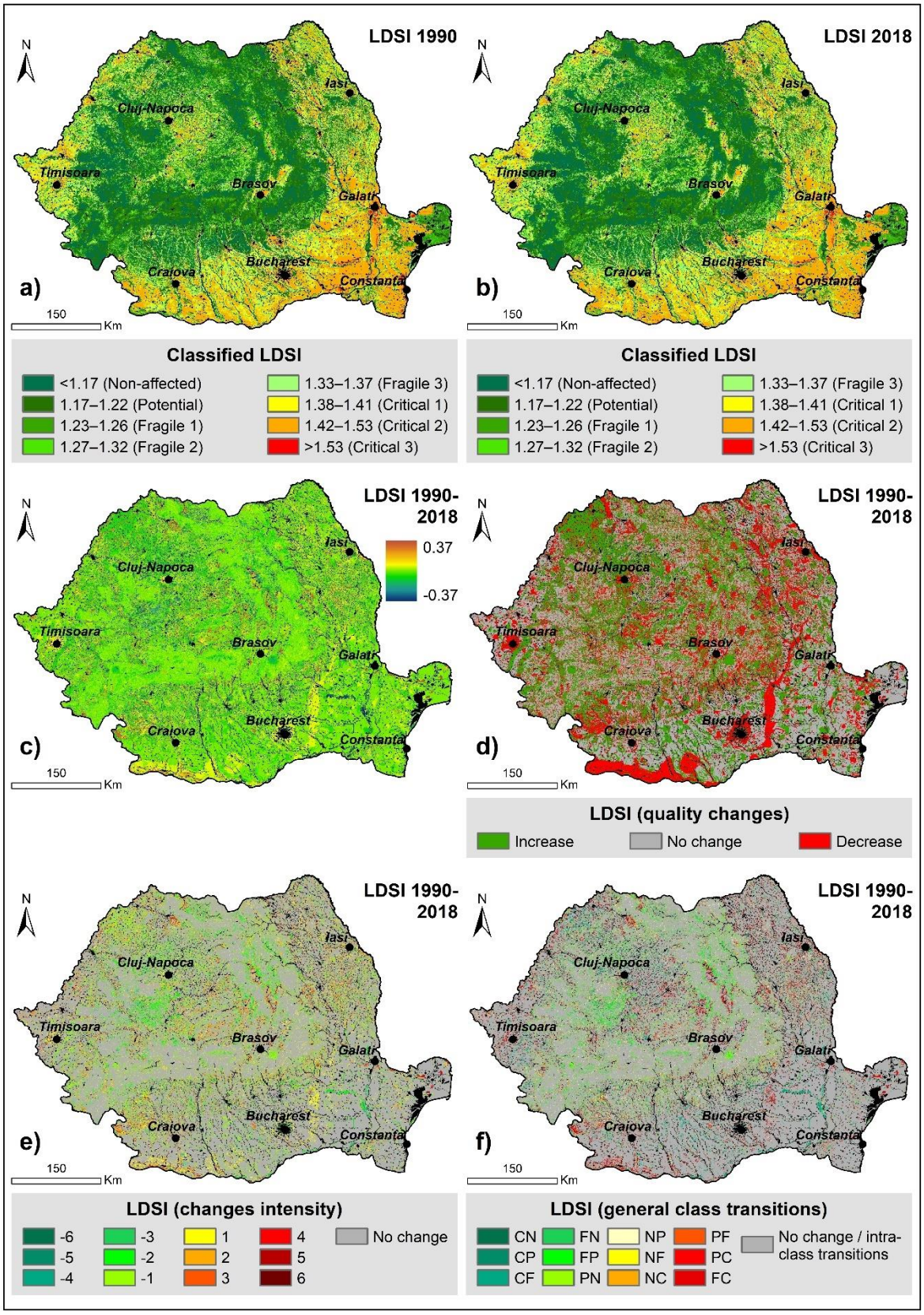

Fig. 5. Spatial representation of LDSI in 1990 (a) and in 2018 (b), and of differences between the two indicators in the two analyzed years (c–f). Note: the 1990 LDSI (a) was obtained in the paper authored by Prăvălie et al. (2020b), while the 2018 LDSI was sourced from Prăvălie et al. (2020a); differences between the two final indices were processed as changes from 1990 in 2018, based on unclassified values (c, where, for instance, the peak positive value of changes indicates a land sensitivity to

degradation that is with 0.37 units higher in 2018 compared to 1990) and values grouped into three general classes (d; green – increases in land quality in 2018 compared to 1990, highlighted by lower LDSI values in 2018 compared to 1990; red – decreases in land quality in 2018 compared to 1990, highlighted by higher LDSI values in 2018 compared to 1990; grey – areas with no changes); changes in intensity (e) indicate the magnitude of class transition (from 1990 to 2018) using the number of modified classes (negative values indicate the transition towards higher quality classes, while positive values indicate a transition towards lower quality classes; e.g. -3 can mean a transition from Critical 1 to Fragile 1, while 4 can mean a transition from Fragile 2 to Critical 3; grey – areas with no changes); the types of transitions (f) indicate changes in general LDSI classes (N – *Non-affected*, P – *Potential*, F – *Fragile*, C – *Critical*), from 1990 to 2018 (green shades – transitions towards higher quality classes; e.g. CF represents the transition from the *Critical* class in 1990 to the *Fragile* class in 2018; yellow-red shades – transitions towards lower quality classes; e.g. PF represents the transition from the *Potential* class in 1990 to the *Fragile* class in 2018; grey – areas with no changes or with changes between detailed inside Critical or Fragile classes); areas in black represent the general mask applied across Romania, in which land sensitivity to degradation was not analyzed; more details about the LDSI changes from 1990 to 2018 can be consulted in the paper currently undergoing publication (Prăvălie et al., 2020b).

Table 3. Land Degradation Sensitivity Index (LDSI) classes extent in absolute and relative values, in 1990, 2018 and differences between these two years, for the entire Romanian territory.

No.	Class	Sub-class	Score range	LDSI 1990		LDSI 2018		Difference between LDSI 1990 and LDSI 2018	
				km^2	%	km^2	%	km^2	%
1	Non-affected	N	<1.17	41264.79	17.43	43031.31	18.18	+1766.52	+0.75
2	Potential	P	1.17–1.22	40215.53	16.99	38431.71	16.23	-1783.82	-0.75
3	Fragile	F1	1.23–1.26	21745.27	9.18	20191.73	8.53	-1553.54	-0.66
		F2	1.27–1.32	25709.51	10.86	24339.37	10.28	-1370.14	-0.58
		F3	1.33–1.37	23980.89	10.13	25608.12	10.82	+1627.23	+0.69
4	Fragile (total)	F	1.23–1.37	71435.67	30.17	70139.22	29.63	-1296.45	-0.55
5	Critical	C1	1.38–1.41	28814.24	12.17	29487.09	12.45	+672.85	+0.28
		C2	1.42–1.53	38014.18	16.06	38658.65	16.33	+644.47	+0.27
		C3	>1.53	449.94	0.19	446.36	0.19	-3.58	-0.00
6	Critical (total)	C	>1.38	67278.36	28.42	68592.10	28.97	+1313.74	+0.55
7	Mask areas			16555.00	6.99	16555.00	6.99	0.00	0.00

Note: the mask areas (artificial and aquatic areas) were not analyzed in Romania in terms of land sensitivity to degradation; the absolute LDSI class data were extracted by applying mask areas (artificial and aquatic areas) across Romania, while percentage-based data were obtained by relating the extracted absolute data to the total national area; positive values indicate an expansion of LDSI classes in 2018 compared to 1990, while negative values represent a compression of LDSI classes in 2018, compared to 1990; the statistical differences between the two years are reliable, since the MEDALUS model has been successfully tested (applied and validated) in Romania (Prăvălie et al., 2020a); furthermore, the application of the Chi-squared test on the 1990 and 2018 datasets confirmed that the area differences are statistically significant at the 5% threshold; more details about the LDSI changes from 1990 to 2018 can be consulted in the paper currently undergoing publication (Prăvălie et al., 2020b).

Finally, it must be mentioned that **these results presented in this final report**, but also certain contextual results, related to climate change impact (intensification of global aridity) on land degradation worldwide (including in Romania), **were published or are currently undergoing publication in three prestigious Q1 journals (red zone)**. The articles, which are directly connected to this project's results (other deliverables, set in the project and completed during the 24 months of scientific activity, can be consulted on the website https://cccpm.unibuc.ro/postdoctoral-project/), are:

- **Prăvălie R.**, Bandoc G., Patriche C., Sternberg T., 2019. *Recent changes in global drylands: Evidences from two major aridity databases*. Catena 178, 209–231;
- **Prăvălie R.**, Patriche C., Săvulescu I., Sîrodoev I., Bandoc G., Sfîcă L., 2020a. *Spatial assessment of land sensitivity to degradation across Romania. A quantitative approach based on the modified MEDALUS methodology*. Catena, doi.org/10.1016/j.catena.2019.104407;
- **Prăvălie R.**, Patriche C., Tişcovschi A., Dumitraşcu M., Săvulescu I., Sîrodoev I., Bandoc G., 2020b. *Recent spatio-temporal changes of land sensitivity to degradation in Romania due to climate change and human activities: An approach based on multiple environmental quality indicators*. Ecological Indicators (in press).

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