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Research Article

Geospatial data for sustainable development goals monitoring: A case study of forest cover dynamics in Romania

Andreea Florentina MARIN, Marius BUDILEANU*

*University of Bucharest, Faculty of Geography, Bucharest, Romania; andreea.marin@geo.unibuc.ro; marius.budileanu@geo.unibuc.ro (*corresponding author)*

Abstract

Monitoring, evaluating, and implementing the Sustainable Development Goals (SDGs), as defined by the United Nations' 2030 Agenda - require the integration of high-quality, up-to-date datasets with a spatial component. Among the indicators in this group is SDG 15.1.1, which measures "Forest area as a proportion of total land area". In this study, we demonstrate how open-source geospatial datasets (such as those provided by the Copernicus Land Monitoring Services) can be combined with long-term national statistical data from the National Institute of Statistics (INS) to gain insights into forest cover dynamics between 1990 and 2023. Statistical and spatial analyses were conducted on time-series data to map the evolution of forest cover across all Romanian counties (NUTS 3), as well on the national level and by local administrative unit (LAU). The dataset comprises 34 annual records, enabling both the analysis of macro-level trends and the identification of annual anomalies. Our analysis reveals a stable national average forest cover, but with pronounced heterogeneity at the county level. Certain counties recorded notable increases or losses in forest area, some exhibiting abrupt year-to-year reversals or near-static forest levels over decades. Our analysis also highlights inconsistencies in national forest cover reporting across different sources. Comparing information from different sources – INS, Food and Agriculture Organization (FAO) and Copernicus Land High Resolution Layer (HRL) – shows that varying reporting methods and dataset structures lead to different results, depending on the data used. These findings highlight the necessity of integrating diverse data sources and geospatial approaches to ensure accurate and scalable assessments of forest dynamics in support of sustainable development objectives.

Keywords: geospatial, forest, SDG, visualization, maps, Romania

Introduction

Forests play a crucial role in maintaining ecological balance, biodiversity, climate regulation, and human well-being (FAO, 2020; IPBES, 2019). In 2015, during the Sustainable Development Summit, the foundation for the 17 Sustainable Development Goals (SDGs) was laid, and the 2030 Agenda was adopted. Among these 17 SDGs, Goal 15 – Life on Land – is the central focus of this study. Romania, characterized by diverse topography and environment, with extensive forest areas, provides a compelling case study for assessing forest dynamics (Niță *et al.*, 2018) in relation to SDG 15.1.1. Throughout history, Romania's forests have been subjected to varying degrees of exploitation (Vasile, 2020), conservation policies (Knorn *et al.*, 2012), and

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management practices (Popa *et al.*, 2019), influenced by a range of socio-economic and political factors (Davidescu and Buzogány, 2021; Albulescu *et al.*, 2022; Giurcă and Dima, 2022). After 2007, significant emphasis has been placed on environmental protection policies, driven by both national initiatives and international commitments, including European Union directives and global climate agreements (Vasile and Iordăchescu, 2022). Romania's accession to the European Union in 2007 intensified international environmental NGO activities and pressures on national authorities regarding illegal logging, while simultaneously requiring the adoption of stringent regulations and surveillance mechanisms such as the SUMAL system (Vasile and Iordăchescu, 2022). Among the 231 globally recognized SDG indicators (Guo, 2024), Indicator 15.1.1, which measures forest area as a proportion of total land area (FAO, 2020; Labohm *et al.*, 2025) is highly significant for understanding forest dynamics and the sustainability of land use. The continuous dynamics of land cover, combined with the heterogeneity of existing data (Bhunia *et al.*, 2020), make tracking the implementation of sustainable development goals challenging (See *et al.*, 2018; Salhab and Basiri, 2020; Giuliani, 2024). Heterogeneous, tabular, traditional datasets do not provide a sufficiently detailed spatial picture to offer nuanced insights. Open geospatial datasets including Copernicus High-Resolution Layers (HRL) and other, now enable a comprehensive approach within a harmonized (Estoque, 2020) geospatial framework (Giuliani *et al.*, 2020; Andries *et al.*, 2022).

This study adopts an integrated analytical perspective that combines statistical methods, advanced geospatial analyses, and visualization techniques. Using datasets provided by the National Institute of Statistics (AGR301A dataset) and supplemented with HRL, this study evaluates changes in forest cover at national, regional, and local scales from 1990 to 2023. By identifying trends, anomalies, and spatial patterns, the study aims to provide insights into the evolution of forest-covered areas in Romania. Our approach aligns with recent UN-GGIM Europe recommendations particularly regarding the operationalization of Tier I (those indicators that have a clear methodology and data gathered to support them) through geospatial data (UN-GGIM Europe, 2019). By demonstrating how open-source data and tools can be effectively utilized for SDG analysis, this study seeks to promote geospatial approaches in the analysis and monitoring of Sustainable Development Goals implementation.

Methodology

One of the objectives of the study was to establish a robust, reproducible methodological framework based on open-source data, capable of evaluating SDG Indicator 15.1.1 at both county and national scales over a continuous 34-year period (1990-2023).

Data sources

Four main data sources were selected for integration, each fulfilling specific analytical objectives.

Statistical data from **the National Institute of Statistics of Romania** (**INS**): This dataset provided annual forest area data at the county level, expressed in thousands of hectares, alongside the total county areas. From this data, we derived forest cover percentages. The INS dataset represents the official national statistical record, offering historical continuity covering the period from 1990 to 2023. Forest areas are specifically defined as land parcels of at least 0.25 hectares, covered with trees capable of reaching a minimum height of 5 meters at maturity under normal growing conditions (INS, 2024).

Copernicus High-Resolution Layers (HRL) Forest Type (2018): This high-resolution raster dataset (with a spatial resolution of 10 meters) enabled detailed comparisons with statistics derived from INS and facilitated large-scale spatial analyses at the level of LAU. The HRL data served as an independent verification tool, allowing comparisons with information provided by other institutions such as INS or FAO. The High-Resolution Layer provides a comprehensive understanding of forest cover across Europe through a suite of

three interconnected layers: tree cover density, dominant leaf type and forest type. These layers are fundamental for assessing forest extent, species composition, and their crucial role within the broader environment. The forest type (FTY) layer delineates areas classified as forest based on the definition provided by the Food and Agriculture Organization (FAO) (CLMS, 2024). In terms of quality, HRL has demonstrated high accuracy in comparisons with national forest inventories (NFI) (Zaczek *et al.*, 2023). This definition incorporates specific criteria related to minimum tree cover density, minimum mapping unit – 0.5 ha (CLMS, 2024) and the exclusion of trees located predominantly within agricultural or urban land use contexts. Given that this dataset meets FAO requirements regarding forests, we consider it highly suitable for the analysis of SDG 15.1.1.

Statistical data from the **Food and Agriculture Organization (FAO)** were extracted from the country report prepared in 2020. Until 2010, the reported figures were based on data provided by the National Institute of Statistics (INS), while after 2015, the data originated from the most recent National Forest Inventory (NFI) conducted in 2018 (NFI, 2025; FAO, 2020). After 2015, FAO data for Romania have been classified as Tier 4 – indicating very high quality – based on the data source, namely multiple National Forest Inventories (Nesha *et al.*, 2021). According to FAO definitions, forests must cover a minimum area of 0.5 hectares, have a canopy cover of at least 10%, and trees must be capable of reaching a minimum height of 5 meters at maturity (Johnson *et al.*, 2023).

Vector administrative boundaries: Obtained from ANCPI, these data provided delineations of county and local administrative unit boundaries. These boundaries served as the spatial framework for all analyses conducted.

Data Processing

The preprocessing phase involved steps aimed at harmonizing and standardizing data formats, ensuring consistency and spatial alignment. Statistical data were assigned to vector data using a tabular join function.

The HRL raster data were treated as a whole, despite featuring two forest classes: deciduous and coniferous. For the purposes of this study, given the objectives addressed, any pixel representing forest classes was considered part of the forest body. Within the same vector layer used for the join, forest areas were calculated at the county level.

Statistical and Spatial Analysis

Given the extensive dataset spanning 34 years and reported for each county individually, a wide range of statistical indicators could be calculated. However, within the article, basic statistical parameters were used to provide an overview of the evolution of forest-covered areas in relation to SDG 15.1.1., which focuses on the protection, restoration, and promotion of sustainable land use. Among the indicators calculated were: 1) annual and multi-year averages, which provided insights into both short-term and long-term trends in forest cover; 2) year-to-year rates of change; 3) comparisons between extreme years and 4) differences between values from different datasets for the same period.

Results

The analyses applied in this study revealed extensive information about the dynamics of forest cover in Romania between 1990 and 2023. The presented results highlight national trends, regional variations, detailed analyses at the county and local administrative unit levels, as well as temporal anomalies.

National forest cover trends

At the national level, forest cover exhibited moderate stability over the 34-year period, fluctuating within a narrow range from 24.74% (1999 and 2000) to 25.68% (2023). Linear regression analysis identified a

slight upward trend, with an increase of approximately +0.026% per year. Nationally, forest cover exceeding 25% (Figure 1) has been notable since 2007. Although modest, this trend may be correlated with environmental policies, the establishment of new protected areas, or European directives protecting forests and reforestation initiatives.

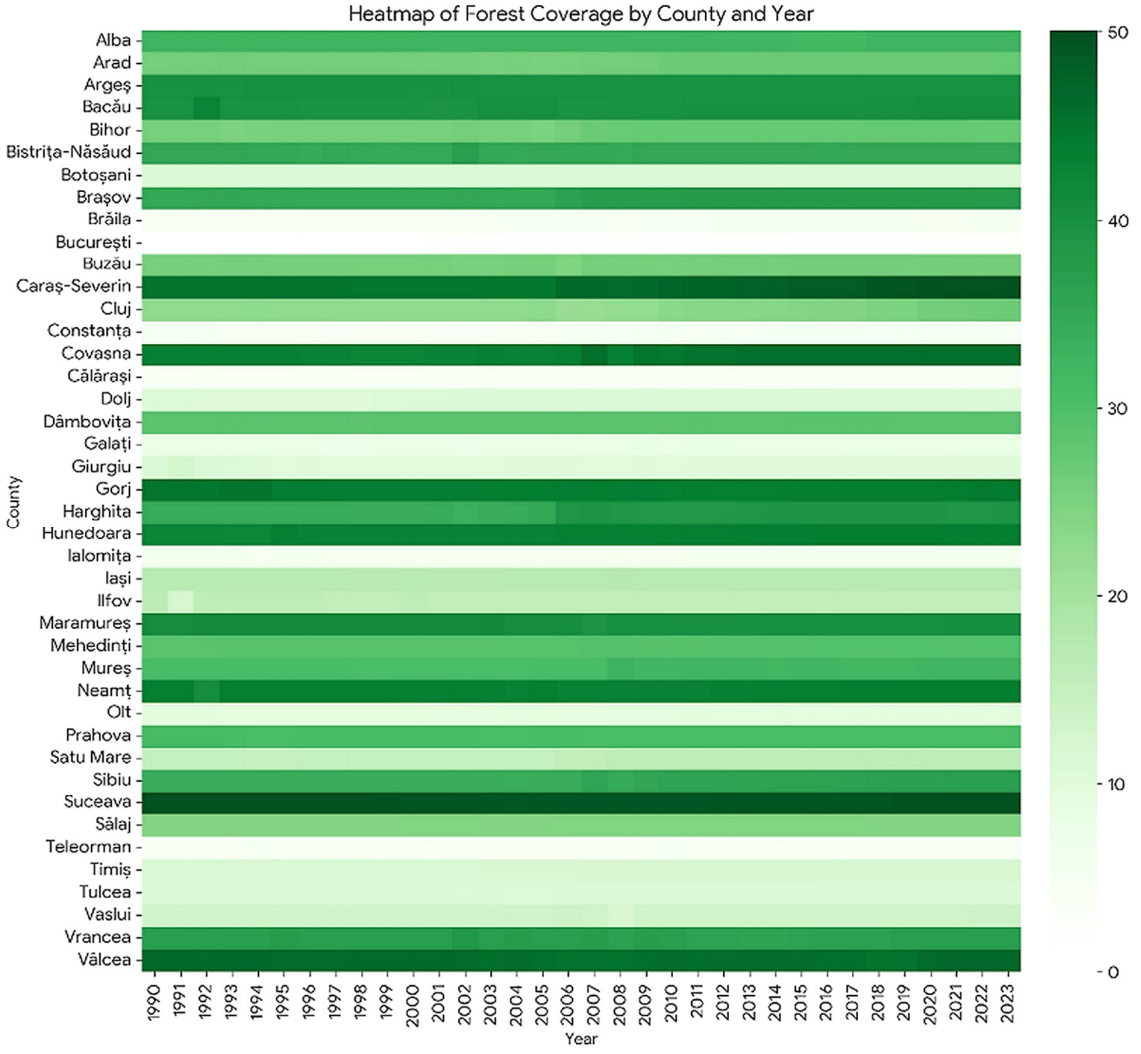

Figure 1. County heatmap forest cover percent by year

Substantial regional disparities were identified, with a clear spatial differentiation in the distribution of forest cover. Counties located in the Carpathian region, particularly Suceava, Maramureș, and Harghita, consistently exhibited the highest forest cover percentages. In contrast, regions surrounding major urban areas, especially Ilfov and Bucharest, recorded significantly lower forest cover, often below 5% as shown in Figure 2.

Regarding the average evolution over the entire analysed period, a uniform distribution is observed between counties with very large forest areas, located in the Carpathians, and those in the southeast of the country. On average, the most forested counties are Suceava, Caraș-Severin, and Neamț, while the lowest percentages, below 5%, are Călărași, Teleorman, Constanța and Buzău.

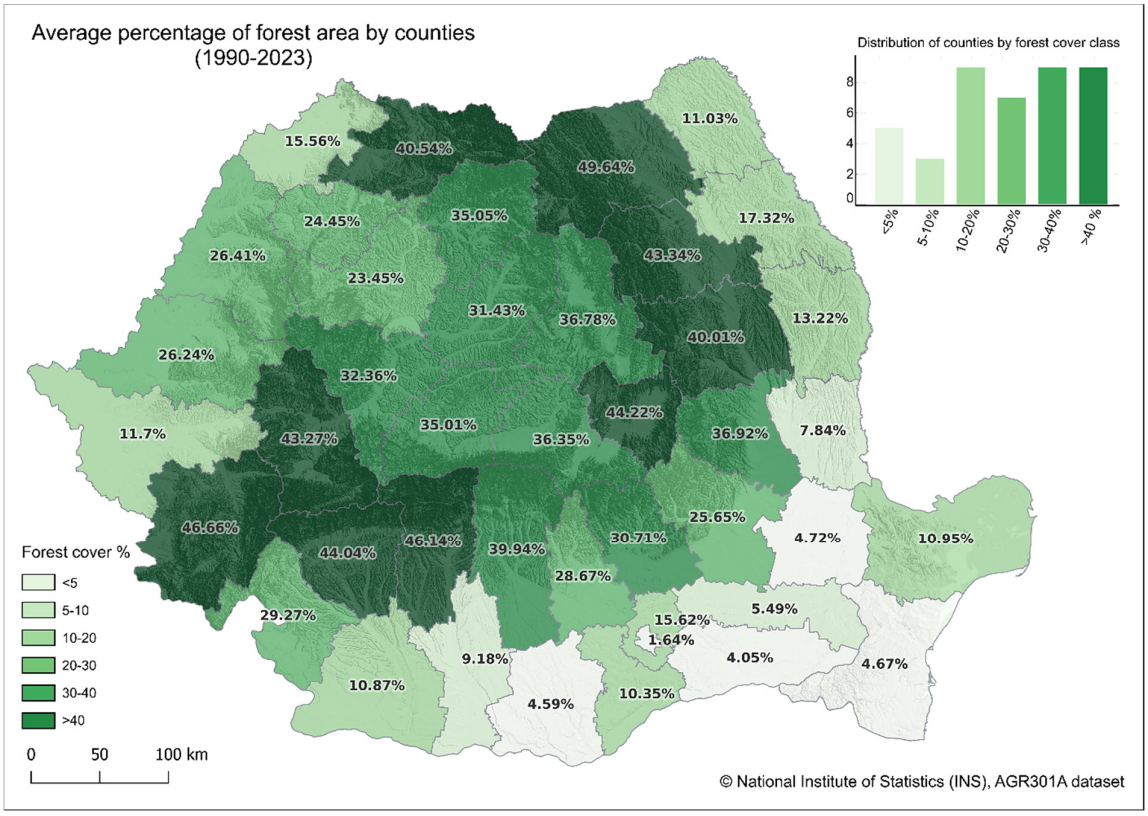

Figure 2. Forest cover evolution and percent average by county (1990-2023)

A detailed temporal analysis revealed several counties with abnormal fluctuations in forest cover, characterized by sharp and significant year-to-year reversals exceeding ±3%. Counties such as Bacău, Covasna, and Ilfov showed notable inconsistencies, suggesting potential inaccuracies in data reporting or local events involving deforestation and reforestation (Figure 3). These anomalies underscore the need for rigorous validation mechanisms. County specific analyses indicated that 30 counties recorded net increases in forest cover between 1990 and 2023.

Considering the FAO data from the latest official report in 2020 regarding Romania, all counties were analysed in relation to this benchmark across the entire dataset. It is noted that 14 counties exceed the average of 30.02%, 19 are below the average (red dotted line in Figure 3) and 9 are approximately at the 30% average. Although some counties show increases (e.g., Cluj), no county has experienced a significant change in which the forest cover percentage crossed above or fell below the average over the 34 years examined. When combined with the absolute difference in forest areas between the extreme years of the evaluate interval, it can be observed that forest areas in Romania have increased since 1990.

In Figure 4, 30 counties were identified where the area covered by forest vegetation increased, cumulatively, by 2235 km^2. At the same time, an area of only 158 square kilometres of forest no longer exists across 9 counties. In absolute terms, between 1990 and 2023, Romania has gained over 2000 square kilometres of forest - an area larger than the entire Ilfov County.

A particularly interesting situation arises in Bistrița-Năsăud, Dâmbovița, and Iași counties, where the forest-covered areas are identical in 1990 and 2023. Additionally, when examining the graph of the evolution of forested areas for these three counties (Figure 3), a rather linear trend with small fluctuations is observed over the 34-year study period.

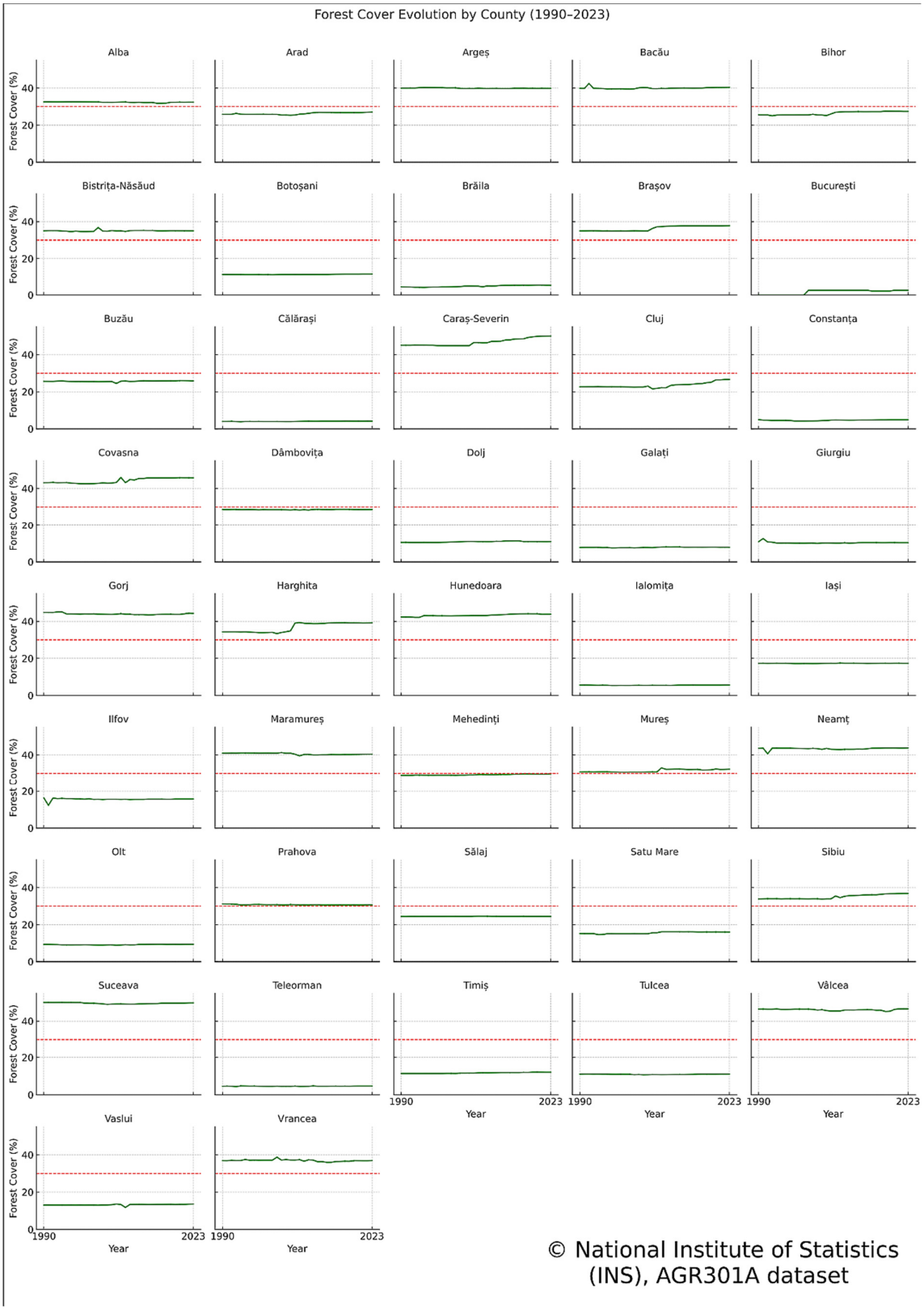

Figure 3. Forest cover percent average by county (1990-2023)

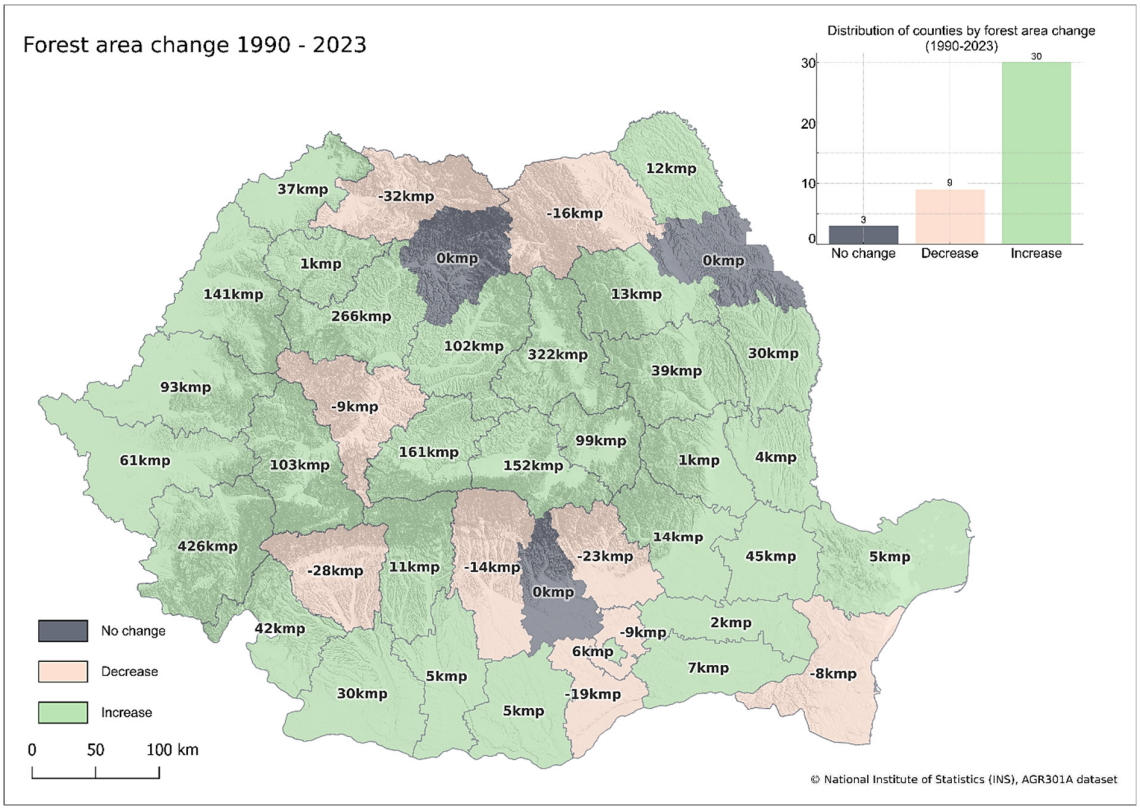

Figure 4. Forest area changes (1990-2023)

The calculated average annual rate of change is approximately 0% for all three counties, indicating no significant long-term trend in forest cover increase or decrease. Additionally, the coefficient of variation remains below 1%, demonstrating minimal inter-annual fluctuations relative to the mean forest cover values. These results collectively suggest that, from a statistical standpoint, forest cover has remained stable across the three counties over the past three decades.

The time series presents one isolated anomaly for Bistrița-Năsăud., which does not affect the general stationary behaviour (full records regarding Bistrița-Năsăud, Dâmbovița and Iași are in Table A1 in Annex A). A temporary increase is observed in 2002, where forest cover rises to 36.81% compared to the surrounding years (typically around 35.0%).

Despite minor year-to-year variations and isolated outliers, the proportion of forested land in the three counties has remained unchanged between 1990 and 2023. One way to quickly address this uncertainty is to cross-check the results with the values provided by the Global Forest Watch (GFW) project (Potapov *et al.*, 2022). This project monitors forests worldwide via satellite, starting from the year 2000. Although there is a 10-year gap between the start of data collection by INS and GFW, the analysis conducted can be replicated using INS data between 2000 and 2020 (Table 1).

Table 1. Net gains between 2000 and 2020

Data provider	County and area		
	Bistrița-Năsăud	Dâmbovița	Iași
INS	19 km^2	7 km^2	6 km^2
GFW	17.1 km^2	28.9 km^2	22.3 km^2

If between 1990 and 2023 these three counties report exactly the same forest areas, during the period from 2000 to 2023, all three counties show increases in forest-covered areas in both analysed datasets. However, even after these analyses, a clear conclusion cannot be drawn, as the growth areas differ significantly between the two sources. Although the growth values for Bistrița-Năsăud County are relatively close, for the other two counties, the values are very different.

For this additional reason, we believe it would be very useful to conduct a further analysis starting with the examples of these three counties, which could subsequently be extended to the entire country.

Comparative analysis: HRL vs INS

The comparative analysis between the statistical data derived from INS and the HRL for the year 2018 revealed discrepancies within the studied datasets. Differences in coverage percentages should be regarded as absolute differences, with negative values indicating a larger forest area reported by INS, and positive values indicating a larger forest area reported by HRL. If the difference was calculated in reverse, only the category would change - negative to positive or positive to negative - while the absolute values would remain identical. Extreme values exceed 4% in both categories. INS reports higher forest area values in 9 counties, with a maximum of 9.6% in Suceava county, while HRL shows higher percentages in all the other 33 counties, with maximums of 4.3% in Maramureș and 5.8% in Sălaj. It is notable that the largest number of counties are within a difference range of 0% to -2%, a value observed in 12 counties (Figure 5). Considering their spatial distribution, one of the reasons for such significant differences, especially in heavily forested counties, could be an overestimation of forest areas in the HRL data.

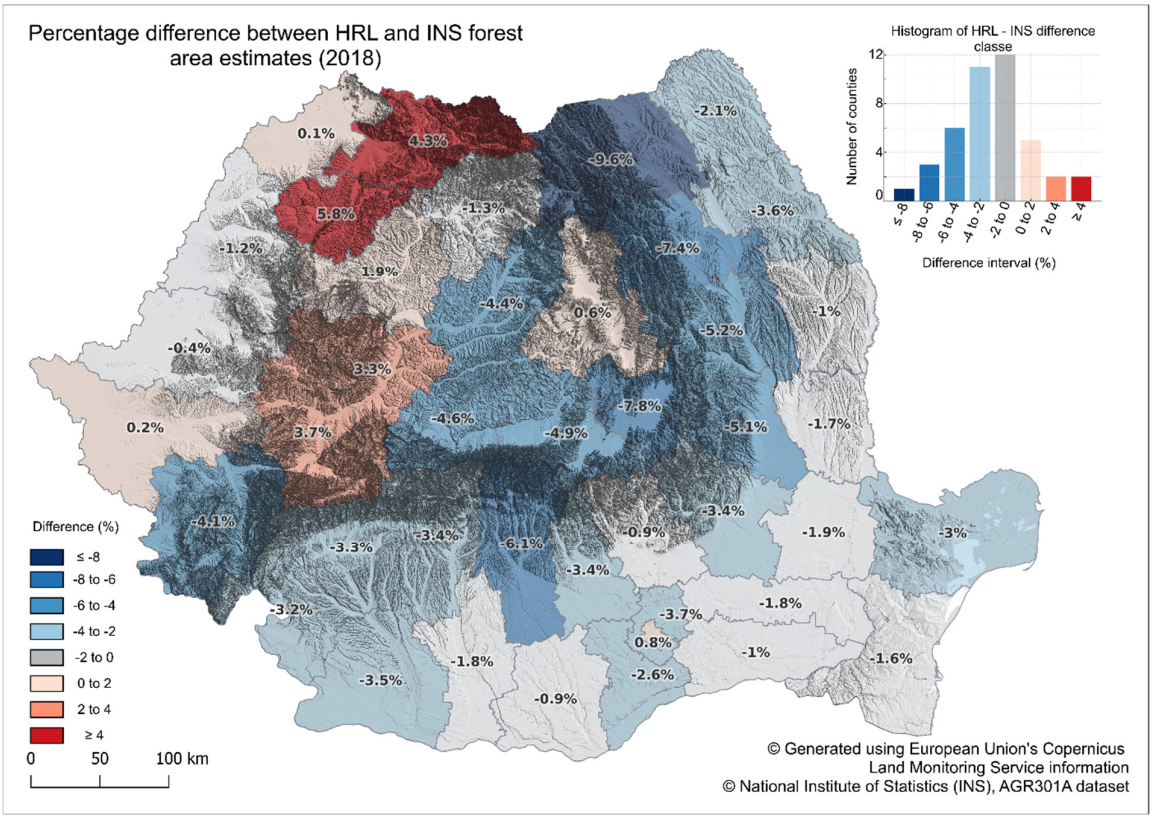

Figure 5. Difference map between High Resolution Layer (HRL) and National Institute of Statistics (INS) data

Local distribution

Based on the data provided by the Copernicus service, HRL, the percentage of forest cover could also be analysed at a finer scale, at the level of local administrative territorial units. As with counties, the lowest percentages for LAU are found in extra Carpathian areas and Transylvania. In the case of LAUs, 1968 of them - representing 62% of the total - are below the multi-year average forest cover percentage according to INS data, which is 25.13%. Compared to the global average reported by FAO, 31.15%, 2148 - equivalent to 67.4% - are below this threshold.

Notably, Seaca de Câmp (Dolj), Siliștea, and Castelu (Constanța) are the only ones in Romania where the forest cover percentage is 0. Similarly, for these three LAU, GFW reports identical information for the year 2020 – 0% forest cover. These values confirm the information provided by the HRL dataset, which is valid for the year 2018. Although the complete absence of forests is somewhat surprising, it can be explained by the exclusive agricultural use of the land, identified through satellite imagery, as well as by the minimum mapping unit of 0.5 hectares required by the HRL dataset. Additionally, 350 LAU, mostly located in the Romanian Plain and the Western Plain, have a forest cover percentage of less than 1% (Figure 6).

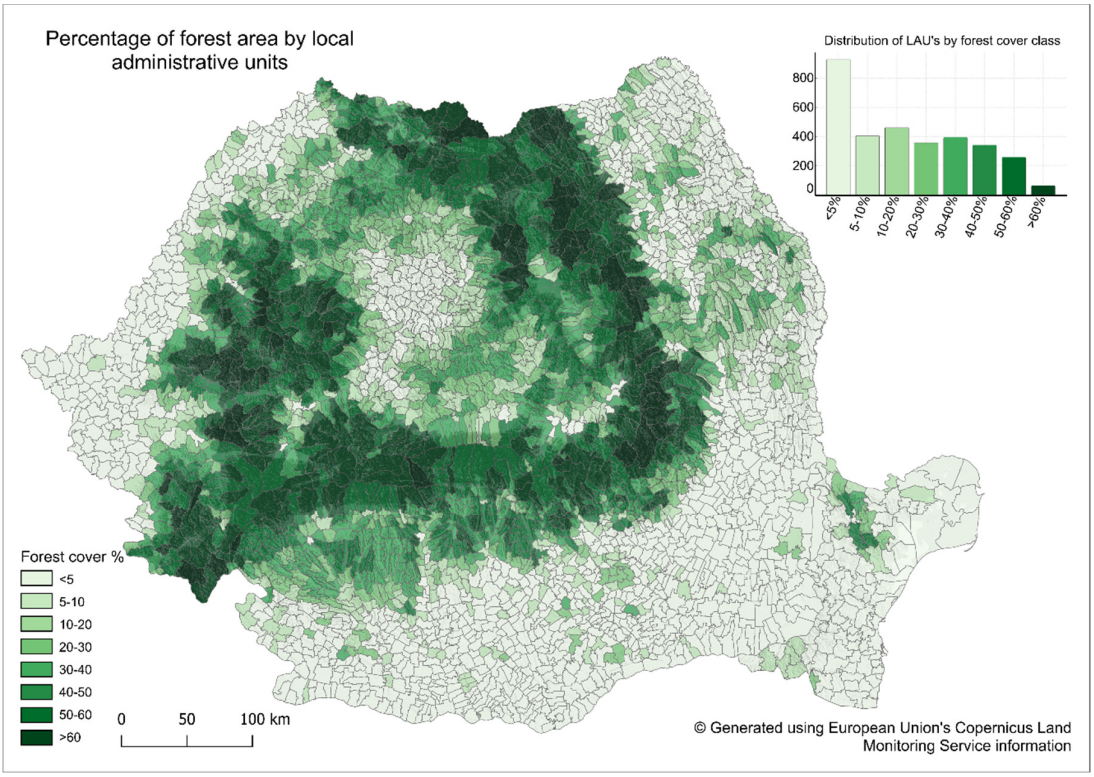

Figure 6. Forest area by local administrative units (LAU)

Discussion

Although numerous studies focus on Romania's forests, many of them rely on very recent data (Blaga *et al.,* 2023; Georgescu and Nica, 2024) and methodologies (Dumitrașcu *et al*., 2020; Prăvălie *et al*., 2023) but do not address the issue of forest dynamics at the county or LAU level. It is also worth mentioning that, although there is limited information regarding the data collection methodology conducted by the National Institute of Statistics (INS), these data are official, endorsed by the Romanian state, and should be considered a starting point for future analyses.

The integration of statistical analyses, spatial assessments, and data comparisons provides insights into the dynamics of forest cover in Romania over the period from 1990 to 2023. This extensive analysis revealed several potential areas for in-depth research. One of the key findings underscores the critical importance of data consistency and integrity. Despite the overall stability at the national level, pronounced anomalies at the county level indicate the presence of inconsistencies and potential inaccuracies in data collection methods or land classification processes. The discrepancies identified between the INS, HRL, and FAO datasets highlight the importance of analysing data from multiple sources. For the current study, data provided by INS and FAO were used for the years 2000, 2018, and 2020, while HRL data were available only for 2018, with the analysis covering the entire territory of Romania. Among the three sources, a consistent difference of approximately 4-6% is observed between FAO and INS data, while HRL reports the lowest percentages, with only 23% forest cover in 2018. For the year 2020, with a percentage of 30.12% provided by FAO, Romania remains below the global forest cover average of 31.15% (Figure 7).

We find the difference between FAO and INS data surprising, especially since INS provides Romania's official statistical data for the year 2000. It is very likely that for data reported to FAO before 2015 (e.g., for the year 2000), earlier versions of the NFI were used, alongside the official statistical data (FAO, 2020).

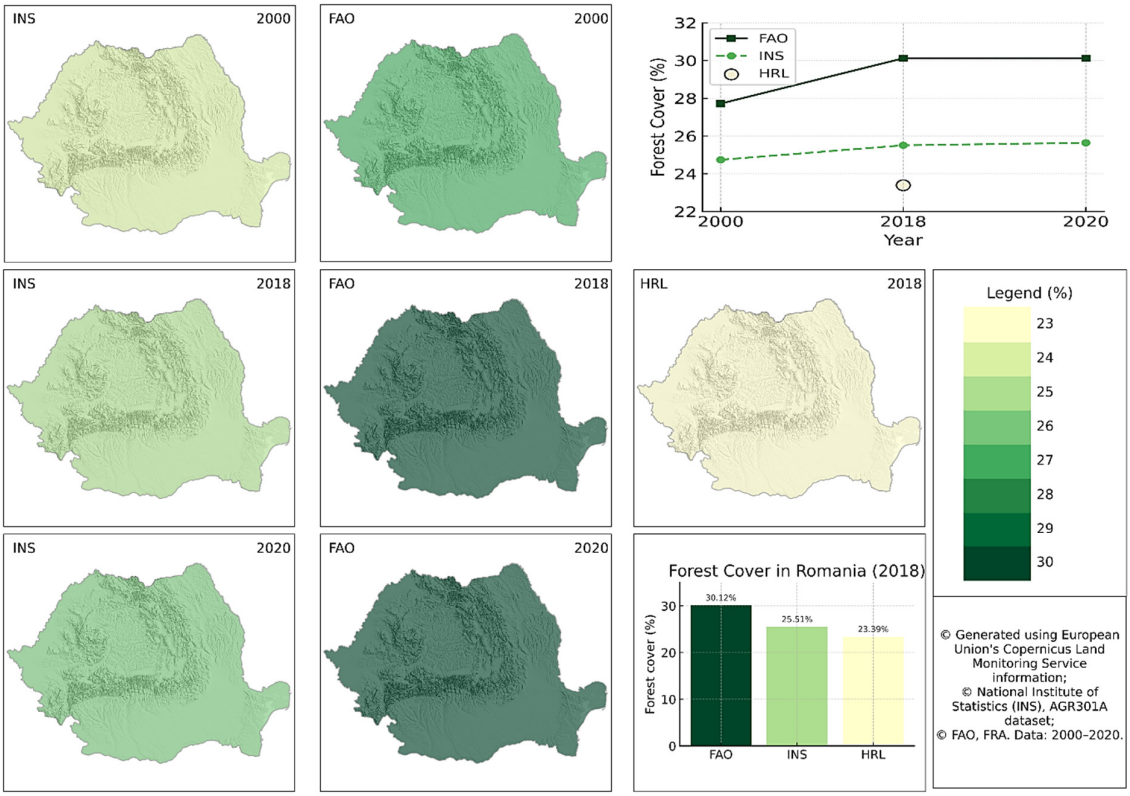

Figure 7. Food and Agriculture Organization (FAO), National Institute of Statistics (INS), High Resolution Layer (HRL) comparation

The insights generated by this study directly support the operationalization and monitoring of Sustainable Development Goal 15.1.1 by emphasizing the importance of geospatial approaches in assessing environmental sustainability. For future studies, we consider the exploration of additional geospatial datasets to be of interest. The ESA Climate Change Initiative - Land Cover provides global-level information with annual thematic layers between 1992 and 2020. Corine Land Cover can also supply significant data on the evolution of forest areas across Europe, even though the data are available at a frequency of every 6 years, from

1990 to 2018. Additionally, for a highly accurate understanding of potential anomalies observed at the county level, the Global Forest Watch project could provide key insights into areas where losses in forest cover have been recorded.

Current, modern, and standardized methodologies can make use of Earth observation data, such as Sentinel-2 imagery (Keskes *et al.*, 2025), to enable continuous monitoring of Romanian forests. When combined with accurate ground-based measurements, these methods can significantly improve data quality and enhance their applicability in forest fund management and scientific research.

Conclusions

This study provides a comprehensive assessment of forest cover dynamics in Romania from 1990 to 2023, utilizing statistical analyses, geospatial data, and advanced visualization techniques. The findings significantly contribute to understanding sustainable forest management, environmental governance, and Sustainable Development Goal (SDG) 15.1.1. The identified anomalies and inconsistencies underscore the critical importance of data quality and reporting protocols. According to statistical data, the percentage of land area showed a slight increase from 1990 to 2023, reaching a maximum of 25.68% in 2023. The discrepancies observed between statistical datasets (INS) and geospatial datasets (HRL) highlight the need to integrate multiple data sources, including high-resolution Earth Observation data. Advanced spatio-temporal visualization tools have been essential in clearly presenting the complex forest dynamics. While this analysis is comprehensive, it is important to acknowledge limitations related to data resolution and availability, as well as the study's predominantly quantitative focus.

Authors' Contributions

The authors confirm their contribution to the paper as follows: Conceptualization: MB, and AM; Data curation: MB; Software and Visualization: MB; Investigation and Methodology: MB, AM, Writing – original draft: MB; Writing – reviewing and editing: MB, AM. All authors read and approved the final manuscript.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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Annex A

Table A1. Annual forest cover by county and unit of measurement (1990–2023), expressed in thousand hectares* (kha), square kilometres (km²), and percentage of total land area (%)

Year	UM	County		
		Bistrița-Năsăud	Dâmbovița	Iași
1990	kha	187.90	116.30	95.00
1991	kha	188.30	116.20	95.10
1992	kha	188.40	116.40	94.80
1993	kha	188.30	116.50	95.00
1994	kha	187.20	115.70	95.10
1995	kha	186.80	115.80	95.00
1996	kha	185.40	116.10	95.00
1997	kha	186.90	115.80	94.70
1998	kha	186.00	115.40	94.10
1999	kha	185.60	115.80	94.10
2000	kha	186.00	115.60	94.40
2001	kha	186.30	115.60	94.30
2002	kha	197.30	115.60	94.20
2003	kha	187.00	115.60	94.30
2004	kha	186.60	115.50	94.70
2005	kha	188.60	115.20	94.90
2006	kha	187.50	115.70	95.00
2007	kha	187.70	115.10	94.90
2008	kha	186.10	115.70	95.60
2009	kha	188.30	115.00	95.20
2010	kha	188.70	116.30	95.20
2011	kha	188.70	116.70	95.20
2012	kha	188.80	116.30	95.10
2013	kha	188.60	116.30	95.00
2014	kha	188.70	116.00	94.60
2015	kha	187.80	116.60	94.80
2016	kha	187.60	116.60	94.90
2017	kha	187.80	116.60	95.10
2018	kha	188.10	116.60	95.10
2019	kha	188.10	116.30	95.00
2020	kha	188.00	116.30	95.20
2021	kha	188.00	116.20	95.20
2022	kha	187.90	116.30	95.00
2023	kha	187.90	116.30	95.00
1990	km²	1879	1163	950
1991	km²	1883	1162	951
1992	km²	1884	1164	948
1993	km²	1883	1165	950
1994	km²	1872	1157	951
1995	km²	1868	1158	950
1996	km²	1854	1161	950
1997	km²	1869	1158	947
1998	km²	1860	1154	941
1999	km²	1856	1158	941
2000	km²	1860	1156	944

2001	km²	1863	1156	943
2002	km²	1973	1156	942
2003	km²	1870	1156	943
2004	km²	1866	1155	947
2005	km²	1886	1152	949
2006	km²	1875	1157	950
2007	km²	1877	1151	949
2008	km²	1861	1157	956
2009	km²	1883	1150	952
2010	km²	1887	1163	952
2011	km²	1887	1,167	952
2012	km²	1888	1163	951
2013	km²	1886	1163	950
2014	km²	1887	1160	946
2015	km²	1878	1166	948
2016	km²	1876	1166	949
2017	km²	1878	1166	951
2018	km²	1881	1166	951
2019	km²	1881	1163	950
2020	km²	1880	1163	952
2021	km²	1880	1162	952
2022	km²	1879	1163	950
2023	km²	1879	1163	950
1990	%	35.06	28.74	17.35
1991	%	35.13	28.72	17.36
1992	%	35.15	28.76	17.31
1993	%	35.13	28.79	17.35
1994	%	34.93	28.59	17.36
1995	%	34.85	28.62	17.35
1996	%	34.59	28.69	17.35
1997	%	34.87	28.62	17.29
1998	%	34.70	28.52	17.18
1999	%	34.63	28.62	17.18
2000	%	34.70	28.57	17.24
2001	%	34.76	28.57	17.22
2002	%	36.81	28.57	17.20
2003	%	34.89	28.57	17.22
2004	%	34.81	28.54	17.29
2005	%	35.19	28.47	17.33
2006	%	34.98	28.59	17.35
2007	%	35.02	28.44	17.33
2008	%	34.72	28.59	17.46
2009	%	35.13	28.42	17.38
2010	%	35.21	28.74	17.38
2011	%	35.21	28.84	17.38
2012	%	35.23	28.74	17.36
2013	%	35.19	28.74	17.35
2014	%	35.21	28.67	17.27
2015	%	35.04	28.81	17.31
2016	%	35.00	28.81	17.33
2017	%	35.04	28.81	17.36

2018	%	35.09	28.81	17.36
2019	%	35.09	28.74	17.35
2020	%	35.08	28.74	17.38
2021	%	35.08	28.72	17.38
2022	%	35.06	28.74	17.35
2023	%	35.06	28.74	17.35

* Forest cover area: kha (kilohectares; 1 kha = 10^3 hectares) or 10^3 ha (thousands of hectares).