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Geomatics Approach for Land Degradation Risk Assessment in Lattakia Governorate, Syria

Mohammad AlAbed

m.abed@yahoo.com

Department of Geoenvironmental Analysis, Fluminense Federal University (UFF), Niterói, Brasil
https://orcid.org/0009-0007-3949-959X

Rosa Karmoka

General Organization of Remote Sensing, Department of Research Center, Syria
https://orcid.org/0000-0003-4024-3755

Silva Loulou

Geography Faculty, Damascus University, Syria https://orcid.org/0009-0006-3265-1811

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Abstract

Lattakia governorate faces significant land degradation, deforestation, and improper utilization despite its high agricultural potential. This study applies the United Nations Environment Program PAP/RAC methodology using an integrated geomatics approach, including Land Use/Land Cover (LULC) change detection and NDVI trend analysis. Utilizing multi-source remote sensing data (Landsat 5/7/8), the study mapped stable/unstable areas and quantified temporal dynamics over 37 years (1985–2022). Results reveal that 69.5% of the region remains stable, while 23.5% is actively degraded by sheet and rill erosion, primarily in urban-fringe zones and steep coastal slopes. A multi-criteria prioritization identified 186.49 km² for immediate curative intervention and 33.44 km² for preventive protection. LULC analysis showed significant transformation, including a 71.21% loss of Closed Needleleaf Forest and a 136.52% expansion of Urban Areas, indicating severe ecosystem fragmentation. NDVI analysis showed a general positive trend (42% growth) between 1985 and 2022, though a sharp decrease from 2000–2012 confirms that localized degradation is often masked by broader regional recovery. These findings support the implementation of Syrian environmental laws and municipal master plans for effective resource allocation and ecological restoration.

1. Introduction

Lattakia Governorate is situated in northwestern Syria along the eastern edge of the Mediterranean Sea, and is shown as a red polygon in Fig. 1. According to the Central Bureau of Statistics (CBS) in 2018 the population estimated at about 1,481,000 [1].

The region's topography varies from beaches and flat plains to hills and mountain range, this range rise gradually from south to north with average elevation of between 1200-1300m. In many places, the slopes are gentle and gradual, and in some locations, they can exceed 65 degrees. The coastal plains lie at an altitude of 0-300 meters at the western foothills of the coastal mountains. The surface of these plains generally slopes gently towards the sea and westward. The coastal region is located within the subtropical belt and is characterized by its moderate Mediterranean climate with relatively high rainfall rates exceeding 825 mm annually. The natural and forest vegetation cover in the region is characterized by its great diversity and belongs to the category of Mediterranean forests which characterized by its instability and sensitivity. Among the most important forest species found in the region are conifers, most notably the Aleppo pine, in addition to some cedars and firs. Oaks of various types, both evergreen and deciduous, are also widespread [2]. Mediterranean soils predominate in the coastal region, with the presence of Vertisol and Alluvial soils. In general, the main soil types Chernozems, Cambisols, Lithosols, and Fluvisols [3]. The main environmental concerns of the study area mostly arise from the high concentration of people (high natural growth and migration) and related activities (intensive agriculture, heavy industry, transportation). Degradation processes are furthermore accelerated by the natural assets of the landscape as to relief, geomorphology, geology and soil characteristics, as well as by the climatic type of the concerned zone in terms of rain intensity, drought and climate change [4–6]. Thus, Land degradation mapping is a very an essential tool for the knowledge of the distribution and geographic

extent of the phenomena, as well as for its qualitative characterization. The erosion map provides information about nature, intensity and distribution of the relevant phenomena. On this basis it is possible to identify the most severely affected areas and the dominant type of erosion processes. Consequently, the current study aims to address this critical need by applying an integrated geomatics approach, mainly by adapting and applying the United Nations Environment Program, Priority Actions Program Regional Activity Centre (UNEP, PAP/RAC. 1997) methodology [7]. The methodology is reliable and used in different Mediterranean environments addressing water-scarcity-related degradation [4, 8–12]. The core objectives of this study are to thoroughly evaluate land degradation processes by classifying their specific type, mapping their spatial extent, determining their severity grade, and analyzing their expansion trend. Furthermore, the research aims to prioritize intervention areas by identifying the main degradation hotspots within the study area, thereby providing a clear, actionable basis for implementing successful and targeted land degradation control measures.

2. Analysis of the Problem of land degradation

Land degradation is a global environmental challenge, particularly in the Mediterranean basin, where fragile ecosystems are increasingly vulnerable to soil erosion, biodiversity loss, and desertification. In the Mediterranean context, the intensification of human activities—coupled with the effects of climate change—has accelerated the degradation of soil resources, which are essential for food security and ecological stability [7]. In the Lattakia Governorate of Syria, the problem is multifaceted. The region's complex geomorphology, characterized by steep coastal slopes and high-relief mountains, naturally predisposes the soil to water erosion. However, these natural factors are significantly exacerbated by high human pressure. Specifically, the region faces rapid urbanization, agricultural intensification, and deforestation [6].

The "state" of research in this region shows a reliance on traditional erosion modeling. Previous studies in nearby basins, such as the Al-Hweiz and Kurdaha dam basins, have successfully utilized the Revised Universal Soil Loss Equation (RUSLE) and the CORINE model to predict soil loss [16, 17]. While these models provide valuable estimates of soil loss quantity, there is a technical gap in identifying localized "hotspots" that require immediate curative vs. preventive intervention. The core problem addressed in this study is the lack of a spatially explicit, multi-criteria prioritization framework that integrates long-term vegetation dynamics (NDVI) with land use/land cover transformations. By applying the UNEP/MAP PAP/RAC methodology [7], this research seeks to move beyond general erosion estimation to provide a precise mapping of stable and unstable areas, allowing for a targeted resource allocation in line with Syrian environmental protection and land security laws.

3. Material and Methods

3.1 Mapping land degradation

Mapping Land degradation in Lattakia was assessed according to the common consolidate methodology of Mapping of Rainfall-Induced Erosion processes in the Mediterranean Coastal Area, [13]. The method is based on elaboration of the Geographic Information System, GIS, in accordance with the criteria and standards for elaboration of Landsat image and maps with scale 1:50000 using ArcGIS, QGIS.

Mapping stable and unstable areas for Lattakia Governorate was done by cross-referencing data from landcover / landuse maps, physiographic unit maps, and data from field survey for about 156 sites. Where for each site, type of stable land, factors affecting its stability, and degree of risk were identified. Similarly, the type of unstable land, its extent, and the expansion trend were identified. This approach allowed us to classify land into the two main categories—stable and unstable areas—as defined by the PAP/RAC methodology [13].

The stable land units were evaluated based on their functional category, the level of erosion risk, and the causative factors driving that risk. This process identifies the dominant stable land types like Unmanaged areas (for forestry or agriculture), Managed areas (for forestry or agriculture), stable-natural/artificial re-vegetation, and physical infrastructure (terraces, check dams, contour bunds, etc.). Then, each type was ranked for instability risk on a 0–3 scale, where 0 indicates no risk and 3 signifies critically unstable conditions. This ranking incorporated the leading degradation drivers: topographic steepness, geological structure, vegetation cover, and anthropogenic use. For unstable units, the classification identified the degradation type, its extent, and its expansion trend. This process identifies the dominant erosion types like Sheet erosion, Rill erosion, Gully erosion, and mass earth movement. Then, the extent of the affected area was classified as localized (< 30%), dominant (30%–60%), or widespread (> 60%). The expansion trend of erosion was similarly scored from 0 to 3: 0 for stabilizing conditions, 1 for locally expanding, 2 for regionally expanding, and 3 for an advancing trend toward irreversibility.

3.2 Prioritization of degraded hotspots

Successful land degradation control requires the efficient use of resources and the establishment of clear intervention priorities. To facilitate this, a prioritization procedure was developed based on a scoring system designed to identify areas requiring urgent action. This system employed 14 selected variables, chosen for their relevance to both the land degradation processes and the local socio-economic context. Following the UNEP, PAP/RAC methodology [4], each variable was assigned a score from 1 (lowest impact/ risk) to 3 (highest impact/risk), reflecting its contribution to either land stability or instability. Weights for these variables were determined through a structured expert consultation process. The specific scoring assigned to each variable is as follows:

A. Physical instability risk (for stable areas)

B. Extent of the affected area (for unstable areas)

C. Expansion trend of the degradation process (for unstable areas)

D. Multiplication factors for unfavorable combinations of causative agents

E. Influence on adjacent areas

F. Overexploitation as an aggravating socio-economic factor

G. Rural exodus as an aggravating socio-economic factor

H. Land tenure as an aggravating socio-economic factor

I. Other aggravating socio-economic factors

J. Value of current land use according to the local population

K. Value of current land use according to national policies

L. Potential for forestry

M. Potential for agricultural use

N. Other land use potentials

After scoring all criteria for each identified area, final prioritization scores were calculated as follows:
- Stable Areas Priority = [(A × D + E) × F × G × H × I] + [(J + K) × L × M × N] (1)

- Unstable Areas Priority = [(B × C × D + E) × F × G × H × I] + [(J + K) × L × M × N] (2)
Final scores were grouped into three priority categories: High (≥ 60), Medium (21–59), and Low (≤ 20).

3.3 Analysis of land use and cover change (1985–2022)

Multi-source satellite imagery used to assess Land Use and Land Cover (LULC) in Lattakia, employing Landsat 5 TM (1985) and Landsat 8 OLI (2022), both 30m resolution, to enable temporal comparison for the years 1985, 2000, 2012 and 2022 using supervised classification. Images were selected from summer months to minimize cloud cover and maintain comparable environmental conditions across the study years. A Maximum Likelihood Classifier was applied to categorize land cover into 9 classes representative of the region. Classification accuracy was assessed using ground truth data collected through field surveys and high-resolution Google Earth imagery. These reference data were used to construct an error matrix and calculate standard accuracy metrics, namely Overall Accuracy and the Kappa Coefficient. Several preprocessing steps were implemented to ensure data consistency, including geometric correction, projection harmonization and surface reflectance calibration using built-in tools in ArcGIS and Google Earth Engine. Spatial filtering was also applied to reduce noise and improve class homogeneity.

3.4 Calculate Normalized Difference Vegetation Index (NDVI)

Landsat images for years 1985, 2000, 2012, and 2022 were obtained from the USGS, specifically the Landsat Collection 2 Level-2 dataset, covering Path 176 and Rows 35 & 36. The following sensors and bands were used for NDVI computation:

- 1985 and 2000: Landsat 4/5 Thematic Mapper (TM), using Band 3 (Red) and Band 4 (Near-Infrared; NIR).
- 2012 and 2022: Landsat 8/9 Operational Land Imager (OLI), using Band 4 (Red) and Band 5 (NIR).

Preprocessing involved mosaicking images to ensure full spatial coverage of the study area. The “Mosaic To New Raster” tool was applied separately to the Red and NIR bands, producing single-band mosaics with the following parameters: spatial reference system (WGS_1984_UTM_Zone_37N), and pixel type (16-bit unsigned). The mosaicked bands were subsequently clipped to the study area using the “Extract by Mask” tool, generating spatially consistent Red and NIR rasters restricted to the area of interest. NDVI was then calculated using the “Raster Calculator” tool according to the standard NDVI formula [14]. This process produced NDVI layers for each reference year, enabling temporal analysis of vegetation cover dynamics across the study period. The use of Landsat Collection 2 Level-2 surface reflectance products ensures radiometric consistency and atmospheric correction across sensors, thereby supporting robust long-term NDVI analysis [15].

4. Results and Discussion

4.1 Nature and extent of land degradation

The resulted land degradation map (Fig. 2) clearly shows that the stable and unstable categories are inversely related to terrain steepness: stability is found in the dense forest of the steepest mountains and the agriculture of the flat plains, while degradation risk is highest on the slopes connecting these two zones.

The analysis reveals that stable areas are strongly influenced by topography. Stable forest areas and areas with forest potential are the dominant stable categories in the high-relief mountainous zones of the northern and eastern portions of the study site. Conversely, stable agricultural use is spatially restricted to the western parts of the study area, particularly in the low-lying plains directly adjacent to the coastline. This distribution reflects the fertile and accessible areas traditionally reserved for stable farming. Meanwhile, stable areas with agricultural potential forms a transitional belt between the coastal plains (stable agriculture) and the steep mountains (forests). It is found in hilly areas and low-to-moderate mountain slopes, suggesting land that is suitable for farming but may be currently under other cover or prone to agricultural development (e.g., terracing, orchards). As for the unstable types where the dominant type is the sheet erosion it distributed in scattered small patches, appearing near the transition

zones between forest/mountain areas and agricultural/hilly areas, suggesting where land-use pressure or terrain instability is highest. Rill and gully erosion are predominantly observed in the foothill regions of the Kurdaha and Jabla districts.

Based on the provided data in Table 1, the study area in Lattakia is predominantly characterized by Stable Areas, which account for 69.5% of the total mapped area (1705.04 Km^2). The Managed Areas with Agriculture Use (Code 04) is the single largest stable category, covering 620.93 Km^2, which accounts for 25.31% of the total area. This indicates a high proportion of established agricultural land. Managed Areas with Forest Use (Code 03) is the second-largest stable category, covering 416.07 Km^2 or 16.96%. The potential areas collectively cover 403.67 Km^2 (16.46%) Unmanaged Areas with Forest Potential (Code 01) and 264.37 Km^2 Unmanaged Areas with Agriculture Potential (Code 02) accounts for 264.37 Km^2 (10.78%).

Table 1
Areas of Degradation and Stability Patterns in Lattakia

(Source: own elaboration)

Area Type	Code	Land Category Type	Area (ha)	Area (Km^2)	Area (%)
Stable Areas	01	Unmanaged Areas with Forest Potential	40367.17	403.67	16.46
	02	Unmanaged Areas with Agriculture Potential	26436.99	264.37	10.78
	03	Managed Areas with Forest Use	41607.16	416.07	16.96
	04	Managed Areas with Agriculture Use	62093.15	620.93	25.31
	Total		**170504.47**	**1705.04**	**69.5**
Unstable Areas	L	Sheet Erosion	53300.99	533.01	21.73
	D	Rill Erosion	3855.29	38.55	1.57
	C	Gully Erosion	470.60	4.71	0.19
	M	Mass Earth Movement	112.37	1.12	0.05
	Total		**57739.25**	**577.39**	**23.5**
		Not Relevant (Urban, Water)	17055.13	170.55	6.95
Total			**245298.85**	**2452.99**	**99.95**

For the unstable Areas (Degradation Patterns) constitute 23.5% (577.39 Km^2), are overwhelmingly dominated by Sheet Erosion, with other forms of erosion representing only a minor fraction of the total unstable area. Sheet Erosion (Code L) is the most extensive degradation pattern, covering 533.01 Km^2,

which is 21.73% of the total study area and constitutes 92.3% of all unstable areas. The more severe, localized forms of erosion (Rill, Gully) and mass movement collectively make up only 1.77% (43.48 Km^2) of the total area. Rill Erosion (Code D) covers 38.55 Km^2 (1.57%), Gully Erosion (Code C) covers 4.71 Km^2 (0.19%) and Mass Earth Movement (Code M) is the least extensive, covering only 1.12 Km^2 (0.05%). The remaining 6.95% (170.55 Km^2) classified as Not Relevant (Urban, Water).

The successful application of the integrated geomatics approach in this study is strongly supported by similar, localized erosion assessments conducted in the Lattakia region. Our findings, which characterize sheet and rill erosion as the dominant forms of degradation, align with the established scientific understanding derived from predictive modeling in key water catchment areas. For instance, the use of the Revised Universal Soil Loss Equation (RUSLE) integrated with GIS has been instrumental in predicting the quantity of soil lost due to water erosion in specific micro-basins, such as the Al-Hweiz dam basin [16]. The consistent reliance on these factors and the validation of their spatial mapping in prior local studies provides a robust methodological foundation for the region. The utilization of NDVI in those RUSLE models for calculating the C-factor further validates our use of NDVI trend analysis within the PAP/RAC framework to characterize the spatial dynamics of the protective vegetation cover across the Lattakia Governorate. This convergence of methodologies confirms that our approach is well-suited to the geographical and environmental characteristics of the Syrian coastal mountains.

4.2 Conservation prioritization mapping

Based on Fig. 3, the study area has been categorized into Stable (Preventive Action) and Unstable (Curative Action) zones, each further refined by low, medium, and high conservation priority. This classification demonstrates that while the region is predominantly stable, a significant portion requires immediate conservation intervention. The Stable Areas account for 69.53% as in Table 2 are characterized by existing land use or potential that is not currently undergoing significant degradation. Conservation efforts here focus on prevention and sustainable management to maintain long-term stability.

- Stable Medium Priority (1147.67 Km^2 or 46.79% is the single largest category and represents nearly half of the study area. These zones likely correspond to the established Managed Areas with Forest Use and Managed Areas with Agriculture Use (Codes 03 and 04 from Table 1). The medium priority designation indicates the need for routine sustainable land management practices to prevent future degradation. On the map, this is the light green area, dominating the stable forest zones and the main agricultural plain, mainly spread in the western and northern parts
- Stable Low Priority (524.56 Km^2 or 21.38% represents areas where current conditions are highly stable, requiring minimal, routine monitoring and maintenance. This is likely found within the most robust forest and agricultural zones in the central eastern parts of Hafa and Kurda district.
- Stable High Priority (33.44 Km^2 or 1.36%): This category, while small, is critical. It refers to stable land uses that are geographically adjacent to or highly susceptible to degradation risks (e.g., highly

fertile lands or critical watershed areas), and mainly spread in the upper northern parts of Lattakia Center district. These require high-level preventive planning and protective measures.

Table 2
Spatial extent of conservation priority zones in Lattakia

(Source: own elaboration)

Areas	Conservation Priority	Area (km^2)	Area (hec)	Area (%)
Stable Areas	Stable Low Priority	524.56	52456.33	21.38
	Stable Medium Priority	1147.67	114767.39	46.79
	Stable High Priority	33.44	3343.85	1.36
	Total Stable Areas	**1705.67**	**170567.57**	**69.53**
Stable Areas	Unstable Low Priority	145.62	14562.04	5.94
	Unstable Medium Priority	243.11	24310.66	9.91
	Unstable High Priority	186.49	18648.52	7.60
	Total Unstable Areas	**575.22**	**57521.22**	**23.45**
	Not Relevant (Urban, Water)	172.54	17253.62	7.03
	Total Areas	**2453.42**	**245342.40**	**100.02**

The Unstable Areas (totaling 575.22 Km^2, or 23.45% are undergoing active degradation, primarily Sheet Erosion (Table 2), and require curative measures to restore productivity and stability.

- Unstable High Priority (186.49 Km^2 or 7.60%): These areas demand the most urgent intervention. Based on the degradation map (Fig. 2) and the conservation map (Fig. 3), this high-priority zone (colored red on the map) corresponds directly to the regions experiencing the most intensive Sheet Erosion (Code L), and often includes areas where Rill and Gully Erosion (Codes D and C) are concentrated, particularly within the mountainous and foothill regions of Kurdaha and Jabla districts. Curative actions here must focus on immediate soil conservation structures and land treatment.
- Unstable Medium Priority (243.11 Km^2 or 9.91%): this is the largest unstable category, covering significant areas undergoing degradation where restoration measures are necessary but perhaps less immediately critical than the High Priority zones, mainly spread in the western parts of Lattakia center district. This category represents a broad swath of the degradation-affected area.
- Unstable Low Priority (145.62 Km^2 or 5.94%): these areas are unstable but possess inherent resilience or are undergoing milder forms of degradation. Maily occur in central parts of Hafa, Kurda,

and Jabla districts. Restoration efforts here can focus on less intensive, long-term programs.

The Unstable High Priority zones identified in our study, which require immediate curative action, are spatially consistent with the highest-risk areas identified in predictive models for Lattakia's sub-basins. For instance, the Kurdaha region (which encompasses the Bahmra dam basin) is consistently mapped as highly susceptible to significant water erosion. This convergence of findings—where our regional LULC and degradation mapping confirms the localized predictive modeling—underscores the reliability of our integrated approach in accurately pinpointing the most critical conservation hotspots. The concentration of sheet and rill erosion in these areas is a direct consequence of the interacting factors (S, C, R, and K) confirmed by the CORINE model, suggesting that mitigation measures must prioritize slope stabilization and vegetation enhancement to address the dominant drivers of degradation [17].

4.3 Land use and land cover change mapping

The resulting maps constitute a consistent temporal dataset that documents land use changes in the study area over nearly four decades. These outputs considers as a basis for analyzing long-term spatial dynamics and for supporting land-use planning, natural resource management and sustainable development strategies. The findings further contribute to understanding the impacts of population growth, urban expansion and agricultural change on land cover patterns. The Land Use/Land Cover (LULC) analysis for the Lattakia Governorate between 1985 and 2022 reveals significant and directional changes (Table 3), primarily characterized by a net loss in forest cover types and a substantial increase in Mixed Crop & Natural Vegetation, Bare Land, and Urban Areas.

Table 3
Landuse/Landcover Change Analysis in Lattakia (1985–2022)

(Source: own elaboration)

Year	LULC	Area (ha)	Area (Km^2)	Area (%)
1985	Agricultural Area	119867.29	1198.67	48.87
	Bare Land	15134.90	151.35	6.17
	Mixed Crop & Natural Vegetation	34667.01	346.67	14.13
	Shrubland	388.06	3.88	0.16
	Tree Cover – Closed Broadleaf Deciduous Forest	4851.22	48.51	1.98
	Tree Cover – Closed Needleleaf Forest	30331.05	303.31	12.36
	Tree Cover – Open Mixed Leaf Forest	36372.32	363.72	14.83
	Urban Areas	1974.41	19.74	0.80
	Waterbodies	1712.59	17.13	0.70
2000	Agricultural Area	114017.15	1140.17	46.48
	Bare Land	15806.66	158.07	6.44
	Mixed Crop & Natural Vegetation	57130.78	571.31	23.29
	Shrubland	473.00	4.73	0.19
	Tree Cover – Closed Broadleaf Deciduous Forest	5632.67	56.33	2.30
	Tree Cover - Closed Needleleaf Forest	21660.05	216.60	8.83
	Tree Cover - Open Mixed Leaf Forest	26554.99	265.55	10.83
	Urban Areas	2309.30	23.09	0.94
	Waterbodies	1714.26	17.14	0.70
2012	Agricultural Area	114137.86	1141.38	46.53
	Bare Land	14555.69	145.56	5.93
	Mixed Crop & Natural Vegetation	58880.14	588.80	24.00
	Shrubland	505.66	5.06	0.21
	Tree Cover - Closed Broadleaf Deciduous Forest	4035.06	40.35	1.64

Year	LULC	Area (ha)	Area (Km^2)	Area (%)
	Tree Cover - Closed Needleleaf Forest	16468.71	164.69	6.71
	Tree Cover - Open Mixed Leaf Forest	31254.75	312.55	12.74
	Urban Areas	3748.76	37.49	1.53
	Waterbodies	1712.21	17.12	0.70
2022	Agricultural Area	122128.76	1221.29	49.79
	Bare Land	13492.78	134.93	5.50
	Mixed Crop & Natural Vegetation	48211.55	482.12	19.65
	Shrubland	530.79	5.31	0.22
	Tree Cover - Closed Broadleaf Deciduous Forest	2482.95	24.83	1.01
	Tree Cover - Closed Needleleaf Forest	8735.60	87.36	3.56
	Tree Cover - Open Mixed Leaf Forest	43230.75	432.31	17.62
	Urban Areas	4668.68	46.69	1.90
	Waterbodies	1817.00	18.17	0.74
	Total Area	245298.85	2452.99	100.00

The key trends and most prominent changes in Table 3 are highlighted below:

- Forest cover loss (decrease in area)

The analysis shows a clear and consistent reduction across almost all categorized forest types, indicating a widespread transformation of natural forest ecosystems (Fig. 4). Closed Broadleaf Deciduous Forest: This category experienced the most severe proportionate decline, decreasing by over 80% from 48.51Km^2 in 1985 to 24.83 Km^2 in 2022. Closed Needleleaf Forest: This type saw a significant loss, falling from 303.31 Km^2 in 1985 to 87.36 Km^2 in 2022, representing a loss of nearly 71% of its original extent. Open Mixed Leaf Forest: this category ended the period with a net gain but its contribution was significantly lower in the middle years before sharply increasing in 2022 (432.31 Km^2 or 17.62%). However, when considering the *loss* in the more 'closed' forest types, the overall forest health is diminished. These findings align with the Global Forest Watch (GFW) which indicated that From 2001 to 2024, Lattakia lost 17 kha of tree cover, equivalent to a 31% of the 2000 tree cover area, 2.0% of tree cover loss occurred in areas where the dominant drivers of loss resulted in deforestation, 76% of tree cover loss occurred within natural forest [18].

- Mixed crop & natural vegetation expansion (major increase)

This category showed the most substantial expansion, suggesting the fragmentation of natural areas and the integration of diverse, often transitional, land cover types. This class increased by over 40% from 346.67 Km^2 (14.13%) in 1985 to 482.11 Km^2 (19.65%) in 2022. This gain primarily appears to absorb the land lost from the Closed Forest categories and potentially represents agricultural expansion into marginal lands and degradation of forest areas into scrub/shrubland.

- Bare land and urban expansion

These changes reflect increasing pressure on the landscape from human activities, degradation as well as forest fire. Forest fire is one main causative agent for bare land, from 2001 to 2024, Lattakia lost 10 kha of tree cover from fires and 6.2 kha from all other drivers of loss. The year with the most tree cover loss due to fires during this period was 2012 with 3.0 kha lost to fires [18]. Bare Land steady increase from 6.17% in 1985 to 6.44% in 2000, and ultimately settling at 5.50% in 2022. While the final change is a slight reduction from the peak in 2000, the high figures throughout the period, coupled with the massive Sheet Erosion area (533.01 Km^2 from Table 1, suggest a persistent problem with land surface exposure. While Urban Areas showed a increase rising from 19.74 Km^2 (0.80%) in 1985 to 46.69 Km^2 (1.90%) in 2022, an increase of nearly 137%. This highlights the impact of urban sprawl on the surrounding natural and agricultural landscapes.

- agricultural area the total area dedicated to agriculture remained relatively stable across the 37-year period, fluctuating within a narrow range (from 1198.67 Km^2 in 1985 to 1221.29 Km^2 in 2022). This suggests that while land use *types* shifted (e.g., loss of forests), the overall economic reliance on agricultural land was maintained, often at the expense of natural ecosystems.

The net percentage change for each Land Use/Land Cover (LULC) category in the Lattakia Governorate between 1985 and 2022 highlights significant shifts, particularly in forest cover loss and urban/transitional area expansion. The calculations for the net percentage change (Table 4) done by applying this formula:

$(Area_{_2022} - Area_{_1985} / Area_{_1985}) * 100$

Table 4
Landuse/Landcover Net Change Analysis in Lattakia between 1985 and 2022

(Source: own elaboration)

Landuse/Landcover LULC	Area (Km^2) 1985	Area (Km^2) 2022	Net Change (Km^2)	Net Percentage Change (%)
Urban Areas	19.74	46.69	+ 26.95	+ 136.52
Mixed Crop & Natural Vegetation	346.67	482.11	+ 135.44	+ 39.07
Shrubland	3.88	5.31	+ 1.43	+ 36.86
Tree Cover - Open Mixed Leaf Forest	363.72	432.31	+ 68.59	+ 18.86
Waterbodies	17.12	18.17	+ 1.05	+ 6.13
Agricultural Area	1198.67	1221.29	+ 22.62	+ 1.89
Bare Land	151.34	134.93	-16.41	-10.84
Tree Cover - Closed Broadleaf Deciduous Forest	48.51	24.83	-23.68	-48.82
Tree Cover - Closed Needleleaf Forest	303.31	87.36	-215.95	-71.21

The most dramatic (Gains) over the 37-year period are mainly in Urban Areas with an increase of + 136.52%, highlights intense demographic and developmental pressure on the region. Mixed Crop & Natural Vegetation saw a substantial gain of + 39.07% is likely a direct result of the degradation of former closed forests or the intensification of agriculture in marginal, hilly areas, often indicative of land fragmentation and reduced ecological integrity. Open Mixed Leaf Forest increased by + 18.86%, suggesting that some closed forest areas transitioned into more open, less dense mixed systems. Conversely, the most dramatic (Losses) in Closed Needleleaf Forest suffered a devastating loss of -71.21% and Closed Broadleaf Deciduous Forest decreased by nearly half at -48.82%. while Agricultural Area remained relatively stable, with a slight + 1.89% increase, confirming that agricultural land use was largely maintained, but often at the expense of surrounding natural forest areas.

The rapid and uncontrolled urban sprawl into productive land is a recognized, long-standing issue in the Lattakia region. Sami Cheikh Dib, 2020 [19] showed that reasons may due to several factors, including fast demographic growth, state policies that permit the establishment of new residential neighborhoods in or adjacent to fertile agricultural lands, and the weakness of deterrent urban planning laws that fail to protect agricultural property, as well as the economic incentive provided to landowners in the city suburbs for converting agricultural plots to non-agricultural uses further fuels this process. Consequently, the observed degradation in the urban-fringe zones (where active sheet and rill erosion are concentrated) is not a natural process but a direct outcome of this unsustainable urban growth pattern.

Consequently, the loss of protective vegetation cover and the alteration of surface hydrology in these expanding areas severely compromises soil stability, particularly on the vulnerable slopes surrounding the city. Mitigation strategies must therefore prioritize directing future urban development away from high-value agricultural and ecologically sensitive forest lands to align with the core planning principles set forth in relevant national decrees.

While our temporal analysis documented significant urban sprawl as a primary driver of land degradation in Lattakia, the integrity of the remaining forest wealth is simultaneously compromised by severe disturbance events, notably forest fires. The forests of the Al-Bayer and Al-Basit region, in the northwestern part of the governorate, are among Syria's most important forest areas, yet they have been subjected to both unauthorized cutting and repeated fire encroachments. The devastating fires that occurred in October 2020 are particularly highlighted in local research, as they turned vast expanses of the coastal mountains into ash. The damage was not limited to the forest canopy; it had a profound negative impact on the properties of the underlying soils. Soil degradation resulting from fires, which often leads to the depletion of soil quality, threatens the basis for forest renewal, biodiversity conservation, and the sustainability of agricultural production in the region. The use of remote sensing and GIS techniques to assess fire severity (e.g., using Landsat 8 imagery from before and after the 2020 fires) demonstrated that burned areas constituting a high level of danger amounted to 14 Km^2 in the Al-Bayer and Al-Basit region alone [20]. This high fire severity index validates our prioritization of protective measures, such as creating firebreak lines, particularly in the high-risk zones noted in our management strategy. The conversion of fire-damaged areas into agricultural lands, as documented in regional studies, represents a permanent loss of forest cover and an acceleration of soil exposure, directly contributing to the sheet and rill erosion observed in our degradation maps.

4.4 Detailed analysis of NDVI trends

The 40-year assessment of vegetation dynamics in Lattakia (1985–2022), using Landsat-derived NDVI data (Table 6), reveals a significant overall positive trend in both maximum and mean vegetation health across the study area. This finding initially suggests an overall improvement in land cover stability, but a detailed inter-period analysis is required to understand the spatial heterogeneity and the underlying causes of this recovery.

Table 6
Comprehensive NDVI Trend Analysis for Lattakia Area (1985–2022)

(Source: own elaboration)

Year	Max NDVI	Mean NDVI	Change Rate (Mean NDVI)	Interpretation
1985	0.773	0.367	Baseline	
2000	0.833	0.429	+ 16.9% (1985–2000)	Period of strong vegetation recovery/growth
2012	0.833	0.419	-2.3% (2000–2012)	Period of slight stagnation or minor loss
2022	0.856	0.521	+ 24.3% (2012–2022)	Period of very strong increase

NDVI analysis reveals a significant overall positive temporal trend in mean vegetation health across the Lattakia area over the 40-year, suggesting a dominant trend of land cover recovery or intensification. Over the entire period (1985–2022), the mean NDVI increased substantially from 0.367 to 0.521, representing a net growth of approximately 42%. A breakdown of the multi-period data reveals distinct phases of change:

- 1985 to 2000: This period exhibits the most substantial initial gain in mean vegetation index (from 0.367 to 0.429, a 17% increase), likely reflecting the success of early large-scale afforestation efforts and recovery of some agricultural lands following previous pressures. The maximum NDVI value also increased from 0.773 to 0.833, indicating that the healthiest vegetation areas achieved higher overall biomass.
- 2000 to 2012: This subsequent decade shows a slight stagnation or minor decline in the mean NDVI (from 0.429 to 0.419, a 2.3% decrease). This drop suggests localized vegetation loss or a temporary increase in agricultural land pressure, potentially related to drought cycles or minor urban expansion.
- 2012 to 2022: The final period demonstrates a rapid return to growth, showing the sharpest increase in mean vegetation health (to 0.521), a 24% jump in this decade. This strong trend is particularly notable as it overlaps with periods of high regional instability, suggesting that aggressive afforestation projects and intensive agricultural practices have dominated the overall statistical trend of the governorate.

Crucially, while the regional mean NDVI trend is overwhelmingly positive, this statistical average mask the spatial heterogeneity of severe land degradation. The observed widespread increase in vegetation cover primarily reflects healthy forest areas and intensive agriculture. However, the localized, high-risk areas identified by the LULC change detection (specifically the 23.5% of the region categorized as actively degraded by sheet and rill erosion) are critical hotspots characterized by critically low vegetation cover and high bare soil exposure. Therefore, the NDVI analysis confirms a broad regional recovery trend

but underscores the necessity of a spatially explicit methodology—like the PAP/RAC model—to detect and isolate localized degradation hot spots that are not captured by simple regional averaging.

To illustrate the major temporal shifts in vegetation dynamics, four representative years (1985, 2000, 2012, and 2022) were selected and classified (Fig. 5).

The integrated approach used in this study (combining the PAP/RAC methodology, LULC change, and NDVI analysis) is well-supported by, and provides a broader context for, targeted erosion studies in Lattakia. The assessment of degradation risk in the Kurdaha Basin, confirms the necessity and validity of modeling water erosion in this area. Localized studies on the Kurdaha Basin, utilizing the CORINE model, showed that between 2014 and 2020, 64.01% of the study area was classified as having a high risk of water erosion. This high proportion of risk in a sub-region (Kurdaha) directly aligns with our finding that 23.5% of the entire governorate is actively degraded and that the Unstable Areas are disproportionately concentrated in the Kurdaha and Jabla districts [21]. The CORINE model's application in Kurdaha, which is based on calculating four core factors—soil erodibility, erosivity, slope, and land cover—further validates our integrated methodology. Specifically, the regional studies rely on quantifying soil erodibility through indicators like soil texture, depth, and stoniness percentage, and calculating rainfall erosivity using monthly precipitation and average temperature data. The consistent emphasis across multiple regional studies on these identical causative factors confirms the environmental dynamics that lead to the sheet and rill erosion observed in our LULC analysis. This robust local consistency provides high confidence in our prioritization mapping, particularly for the high-risk coastal and mountainous slopes surrounding Kurdaha.

5. Proposed Management Recommendations for Land Degradation Control

Based on the spatial distribution and conservation prioritization of land degradation hotspots identified in the study, we propose actionable management measures tailored to the environmental and socio-economic context of the mountainous and coastal Lattakia Governorate. These recommendations address both existing unstable areas (requiring curative action) and at-risk stable zones (requiring preventative action).

5.1 Unstable areas: curative and protective actions (575.22 km^2)

These Unstable Zones, which include the High Priority (186.49 Km^2), Medium Priority (243.11 Km^2), and Low Priority (145.62 Km^2 zones, are defined by active sheet and rill erosion, slope fragility, and illegal urban encroachment. Interventions must focus on immediate stabilization and ecosystem recovery:

- Engineering and Runoff Control: Structural soil conservation measures are urgently required on erosion-prone hillslopes. This includes the installation of surface drainage outlets, check dams,

contour farming, and terracing. Priority must be given to the coastal foothills highly susceptible to rainfall-induced runoff, specifically the active erosion sectors in the eastern and southern parts of the Kurdaha and Jabla districts.

- Agro-Ecological Restoration: Reforestation and ecological recovery should utilize locally adapted and fruitful-forest species such as *Pinus pinea* (Stone Pine), *Castania vesca* (Chestnut), *Ceratonia siliqua* (Carob), and *Crataegus* spp. (Hawthorn). Integrating species suitable for apiculture (bee breeding) will provide dual ecological and socio-economic benefits to the rural economy.
- Socio-Economic Support and Extension: Providing training and extension facilities to the rural population is crucial for promoting improved agriculture through participatory approaches. This ensures farmers are updated with the latest soil conservation techniques and helps identify viable, non-timber alternatives for materials previously sourced from forests.
- Financial Incentives: Financial aids should be provided to local farmers to enable the sound reclamation of degraded lands and investment in conservation-focused practices.
- Regulatory Enforcement: Strict regulatory enforcement is essential. This entails imposing an absolute ban on unauthorized forest cutting and rigorously applying slope-use and land-use restrictions according to the Syrian Forest Protection Law No. 7 (1994). Furthermore, strict adherence to Municipalities Decree Law No. 96 (1974) is required to enforce spatial segregation of urban development from forestlands.

5.2 At-Risk stable areas: preventive and protective zones (1705.67 km^2)

These areas, although currently stable, are under environmental stress (e.g., vegetation stress, peri-urban pressure). The high-priority preventive zone (33.44 Km^2) requires particular attention, with measures focused on long-term ecological resilience:

- Sustainable Forest Management: Key measures for forest stability include: implementing bans and restrictions on logging and forest fires; creating strategic fire break lines (primarily in Kasab and the eastern study area); preventing grazing in sensitive forestlands; and strictly prohibiting the transfer of forestland into arable or urban uses. Capacity building for forest guards and the continued application of afforestation and reafforestation programs based on Decree Law No. 86 (1953) are foundational.
- Sustainable Agricultural Practices: Conservation agriculture must be promoted, emphasizing practices like contour terracing, incorporating fallow periods and crop rotation, and using green manure. Land-use planning must also involve increasing cattle breeding rates in less productive lands (e.g., southern of Kurdaha) and strictly preventing the expansion of olive groves onto sensitive mountain peaks due to their potential for accelerating soil instability.
- Public Awareness and Education: Continuous educational programs targeting local communities are vital to build awareness regarding the importance of forestland conservation and sustainable land management techniques.

6. Conclusion

This study utilized an integrated remote sensing methodology, combining the PAP/RAC methodology, Land Use/Land Cover (LULC) change detection, and (NDVI) analysis, to assess and prioritize land degradation risk in the Lattakia Governorate. The analysis revealed that while the majority of the region remains stable (69.5%), a critical 23.5% is actively degraded, primarily by water erosion in the form of surface erosion (sheet erosion). The severity of this degradation is heterogeneous: the risk is highest in sloping areas, where it is governed by rainfall intensity, slope gradient, and vegetation cover, and is concentrated in the steep coastal slopes and urban-fringe zones. In contrast, degradation risk in flatter areas is principally linked to poor agricultural practices and urban expansion. The conservation priority mapping precisely located the most vulnerable areas, identifying 186.49 Km^2 requiring high-immediate curative intervention (Unstable High Priority) and 33.44 Km^2 requiring high-priority preventive protection (Stable High Priority). This urgency is substantiated by the temporal analysis (1985–2022), which documented a clear and problematic urban expansion (net change of + 26.95 Km^2) and significant contraction of vital ecosystems, notably the Closed Needleleaf Forest (-215.95 km^2) and Closed Broadleaf Deciduous Forest (-23.68 km^2). Effective implementation of conservation measures requires leveraging the existing national legal framework, including the following key instruments (Table 7):

Table 7
Summary of Primary Syrian Legislation Pertaining to Municipal Land Use Planning and Forest Protection

Law Name and Date of Issue	Areas of Concern Relevant to Land Management
Municipalities Law No. 9 (1974)	Governs the division and organization of comprehensive land use planning (e.g., administrative, industrial, green, and residential zones).
Municipalities Decree Law No. 96 (1974)	Establishes the core principles for land use planning in cities, towns, and villages, explicitly mandating that development be far from established forestlands.
Forest Protection Law No. 7 (1994)	Provides the regulatory basis for forest protection, conservation, and sustainable investment.
Decree Law No. 86 (1953)	Organizes and formalizes national afforestation and reafforestation activities.

The spatial outputs (maps of degradation and priority zones) provide local authorities and planners with a powerful and precisely located tool for integrating findings into municipal planning. Future work must prioritize field validation of erosion zones through detailed hydrological monitoring and sedimentation measurements. Integrating a participatory approach with local stakeholders is crucial to ensure that these scientific outputs are translated into sustainable, socially acceptable, and context-specific conservation measures.

Declarations

Author Contributions

- Mohammad Al Abed: Conceptualization, methodology, supervision, writing original draft. results, discussion, management, recommendations, and conclusion.
- Rosa Karmoka: landuse and land cover changes, data analysis, geoprocessing analysis, maps layout, revision of the manuscript
- Silva LouLou: NDVI analysis, Literature review, revision of the manuscript, and maps layout.

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Figures

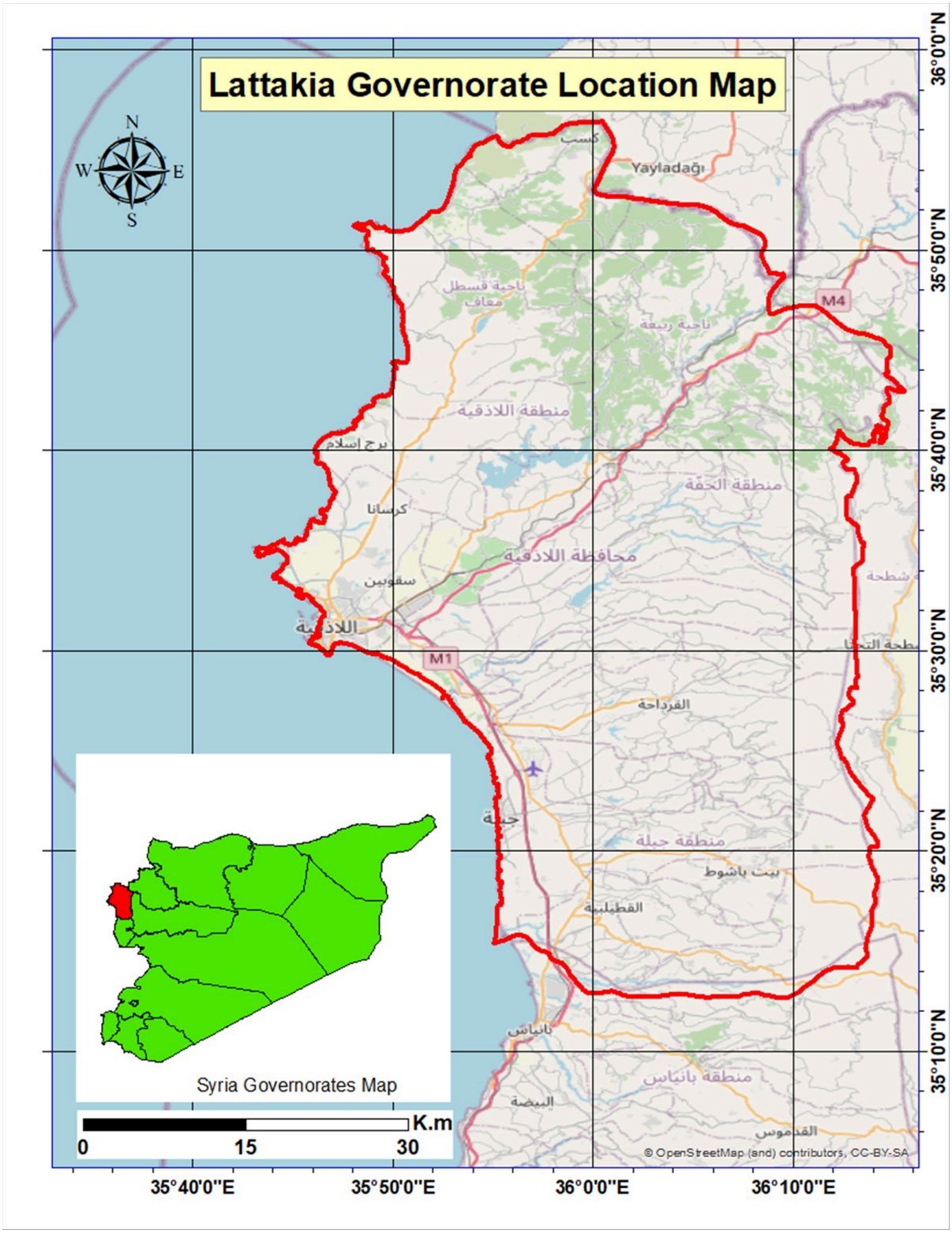

Figure 1

Study area location: Lattakia Province, Syria. (Source: own elaboration)

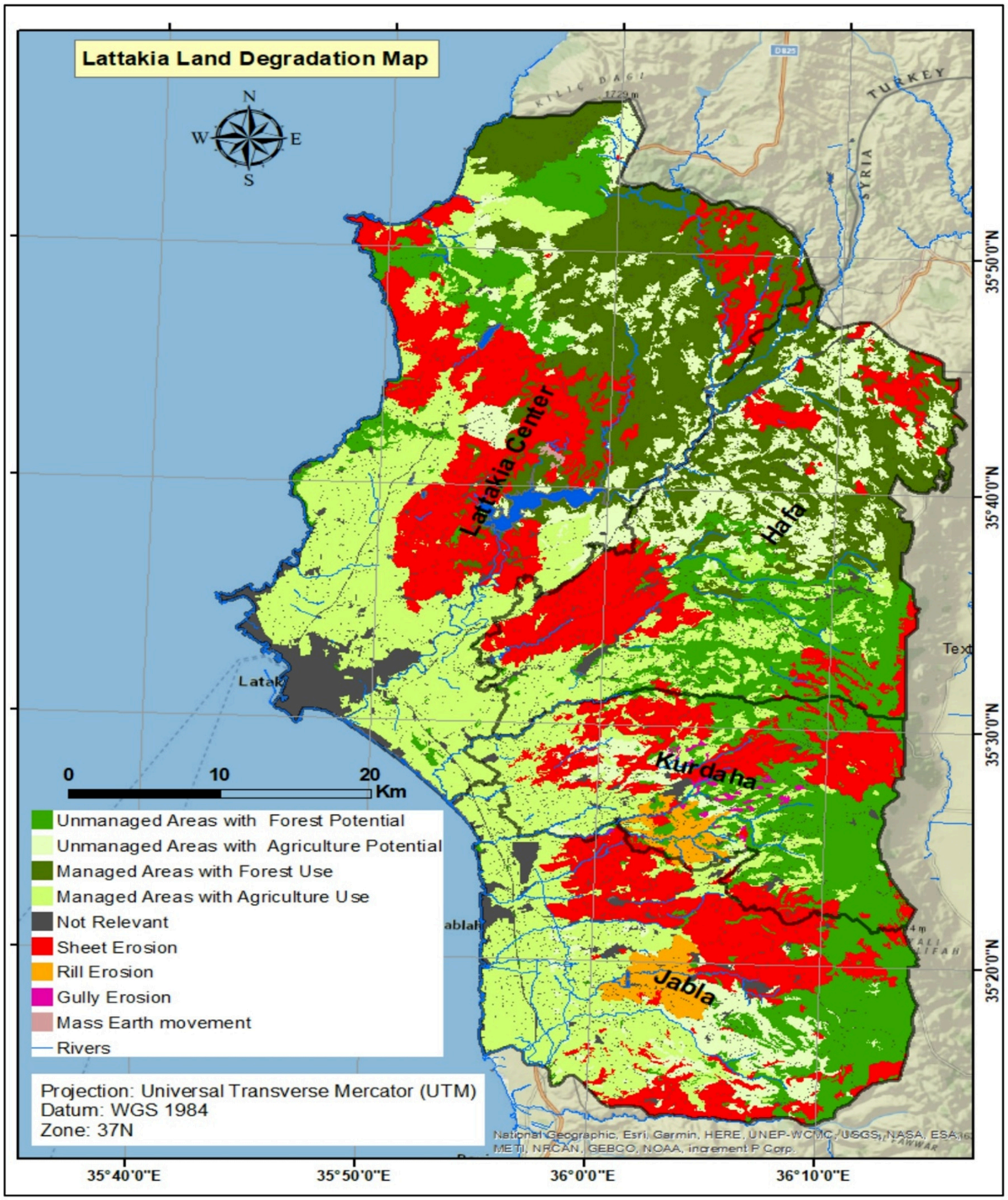

Figure 2

Land degradation map showing stable areas and unstable erosion hotspots (Source: own elaboration)

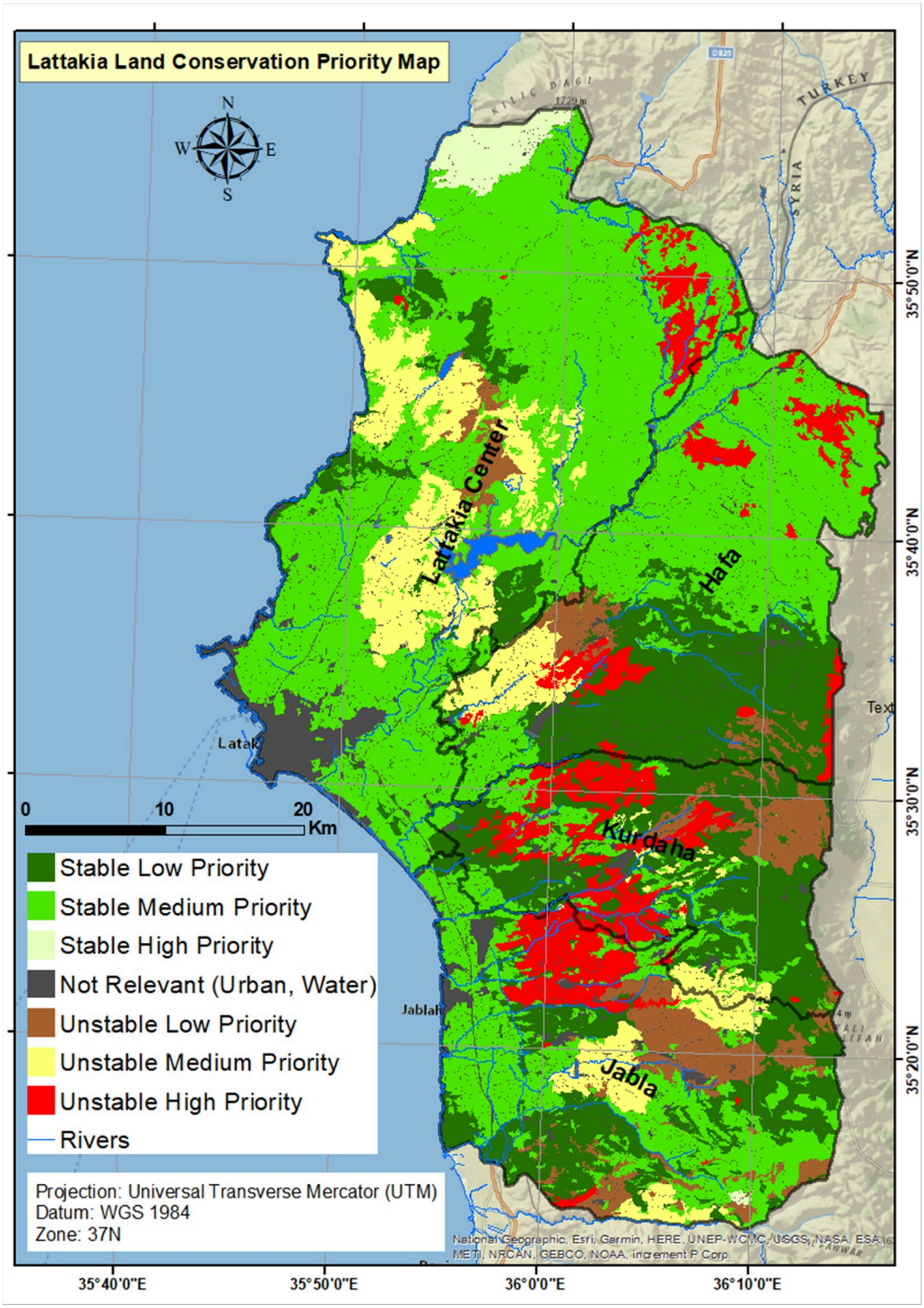

Figure 3

Land conservation priority zones for curative and preventive action (Source: own elaboration)

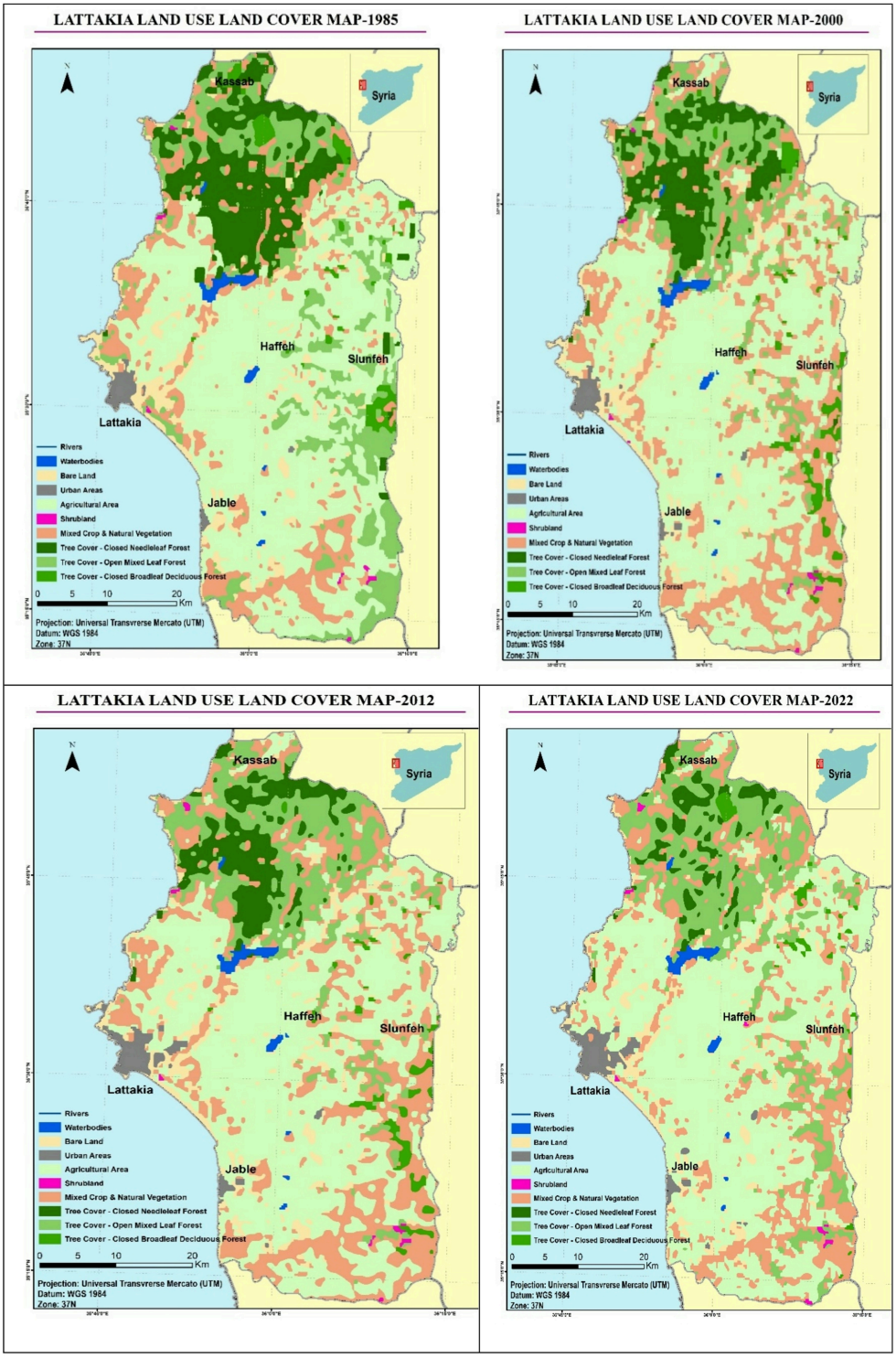

Figure 4

Lattakia Landuse/Landcover Changes between 1985 and 2022 (Source: own elaboration)

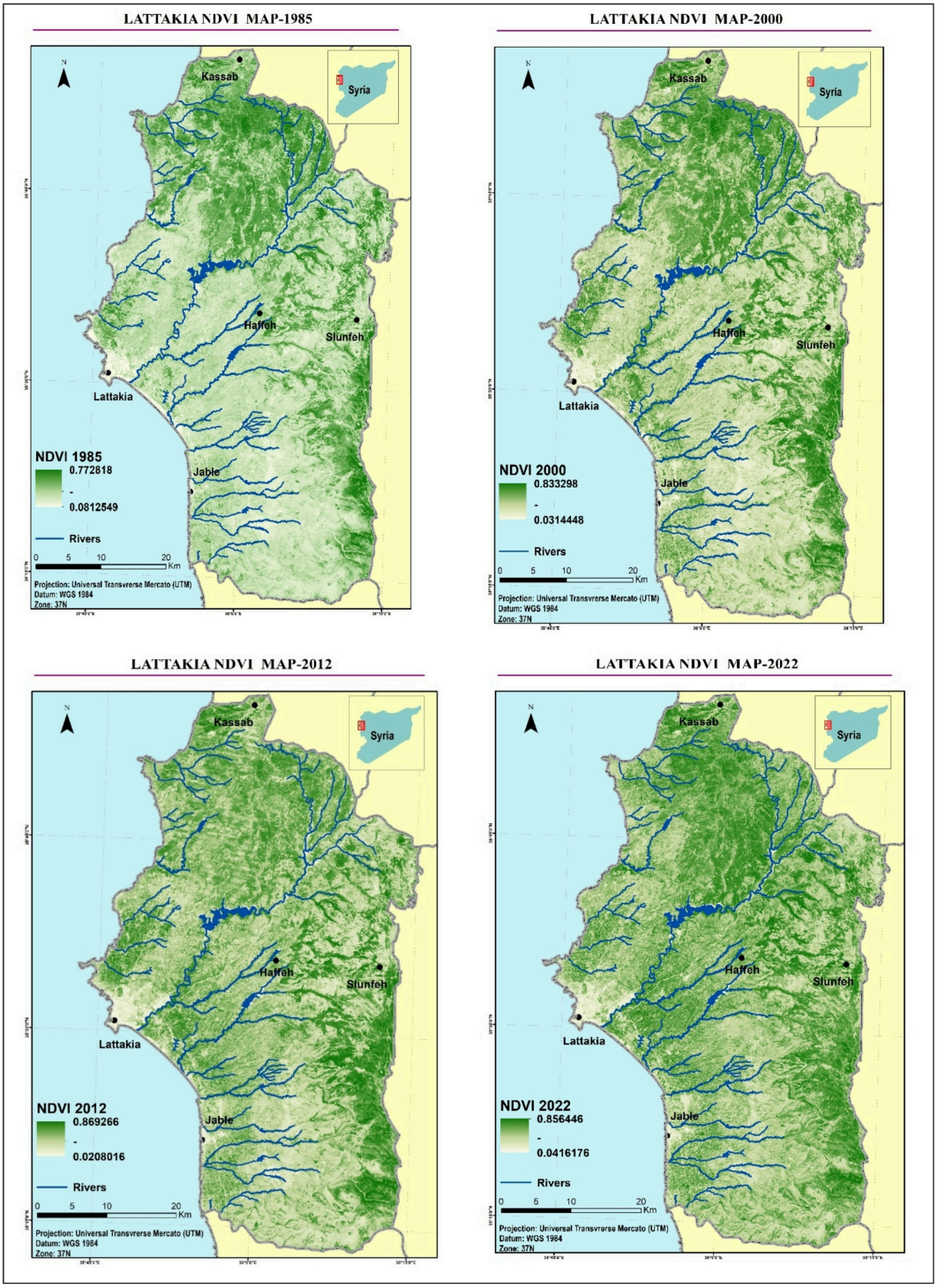

Figure 5

Temporal Evolution of NDVI (1985 - 2022) (Source: own elaboration)