Journal of Geography and Cartography 2026, 9(1), 026090004.
https://doi.org/10.24294/jgc026090004

Article

Assessment of land degradation and sustainable land management in Niger

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CITATION

Mahamane M, Matchi I I, Abdourahamane Z S, et al. Assessment of land degradation and sustainable land management in Niger. Journal of Geography and Cartography. 2026; 9(1): 026090004. https://doi.org/10.24294/jgc026090004

ARTICLE INFO

Received: 26 February 2026
Accepted: 20 April 2026
Available online: 21 May 2026

Abstract: Land degradation threatens food security and biodiversity conservation affecting ecosystem services and the well-being of the population. Therefore, this study aimed to assess the spatial and temporal dynamics of land degradation and restoration in Niger using the indicator 15.3.1 of the Sustainable Development Goal (SDG). The assessment was conducted using the Trends.Earth plugin for a baseline period (2001–2015) and a reporting period (2016–2022). The results indicate that improvement is predominantly within Niger's Great Green Wall (GGW). This reflects extensive land restoration initiatives aimed at combating desertification. Additionally, land productivity doubled between the baseline (14%) and the reporting period (28%). Although soil organic carbon declined slightly in bare lands (−2%), it increased in tree-covered areas, grasslands, croplands, and artificial surfaces by 2%, 4%, 18% and 50% respectively. The proportion of degraded land declined by half between the baseline (6.6%) and reporting period (3.3%). This highlights the effectiveness of the SDG 15.3.1 for evaluating land degradation. It also lays the basis for developing targeted conservation and sustainable land management strategies in Niger's GGW.

Keywords: Great Green Wall; Land degradation; land productivity; soil carbon content; Agenda 2030.

1. Introduction

Land degradation is among the most pressing environmental challenges, undermining ecosystem services, threatening food security and livelihoods, and complicating climate change mitigation and adaptation efforts. Studies indicate that land degradation reduces productivity, weakens ecosystem integrity, and heightens food and economic insecurity, particularly among vulnerable populations [1–3]. These impacts are especially pronounced in the African Sahel region, where desertification is driven by climate variability, fragile soils, and intensifying anthropogenic pressures arising from rapid population growth from 1.5% per year to 3% per year between 1950s to the 1990s, agricultural expansion, and overgrazing [2,4]. As economies in the region depend heavily on rain-fed agriculture, these interacting stressors exacerbate declines in ecosystem resilience, land productivity and food system sustainability [5,6]. In Niger, increase of agricultural land between 1950 to 1998 resulted in a 7 to 16% increase in eroded land at the detriment of the savannah [4].

In response, the United Nations Convention to Combat Desertification (UNCCD) has prioritized sustainable land management (SLM) and land degradation neutrality (LDN) under Sustainable Development Goal (SDG) target 15.3, operationalized through indicator framework 15.3.1 integrating land-use/land-cover (LU/LC) change, land productivity, and soil organic carbon (SOC). In spite of the wide application of these indicators, many assessments remain spatially fragmented or temporally inconsistent, failing to achieve the UNCCD-recommended four-year monitoring cycles required to detect meaningful trends and inform adaptive land-use planning. However, recent advances in Earth Observation (EO) have significantly enhanced the capacity for repeatable, spatially explicit monitoring of land degradation and recovery processes [7,8], including SOC dynamics, which are increasingly recognized as central to soil fertility, climate regulation, and the sustainability of land-use systems in dryland environments [9,10]. The median SOC content was 3.12 g kg^{-1} in the topsoil's (0–20 cm) [4]

Niger's Great Green Wall represents a flagship restoration initiative to curb desertification and enhance socio-ecological resilience across Sahelian landscapes. However, comprehensive and temporally consistent evaluations of its effectiveness remain limited [11–13]. Therefore, this study seeks to provides a spatio-temporal assessment of land degradation and SLM dynamics in Niger's Great Green Wall belt by integrating LU/LC change, land productivity, and SOC indicators using harmonized EO-based methods aligned with UNCCD guidelines to provides policy-relevant information and sustainable land-use decision-making.

2. Materials and methods

2.1. Study areas

The study area covers the Sahelian ecoclimate zone of Niger, Africa (**Figure 1**). It is a semi-arid area prone to desertification and land degradation. However, Koppen climate classification of Niger is characterized by the Warm desert climate (BWh) in the north dominating almost all the territory and Warm semi-arid climate (BSh) in the south [14]. The climate is categorized by dry season that extends from October to May and a short-wet season (June to September) [15] with annual rainfall range of 300 mm to 600 mm [7]. The vegetation in the area is mostly shrubs from the north between annual and perennial grasses to taler vegetation to the south [16].

Agricultural production is the dominant economic activity in the region [7]. Soils are predominantly sandy and are largely deficient in phosphorus and nitrogen [17]. In the southern part of the region, crop production is more diversified, and farming systems are dominated by cassava, sorghum, and maize cultivation, whereas in the northern part, millet and sorghum are dominant. Most of the producers are small-scale farmers, who are increasingly facing significant challenges due to climate change.

Additionally, wind and water erosion significantly contribute to soil degradation in the region [18,19]. Erosion causes substantial losses of soil nutrients, negatively affecting crop productivity and food security. In addition, high evaporation rates promote surface crust formation and laterite development. Recurrent droughts in the region represent one of the main climate variability and change [20]. Severe droughts during 1983–1984 led to a southward shift of desert conditions into the Sahel region [21]. Drought is also a major driver of land degradation, reducing crop yields and triggering population displacement. Furthermore, population growth is considered as a key driver of land degradation [22], as it has intensified agricultural expansion, charcoal production, and illegal mining activities. Trends and variability in rainfall directly and indirectly influence crop production, vegetation dynamics, and ecosystem functions and services [23].

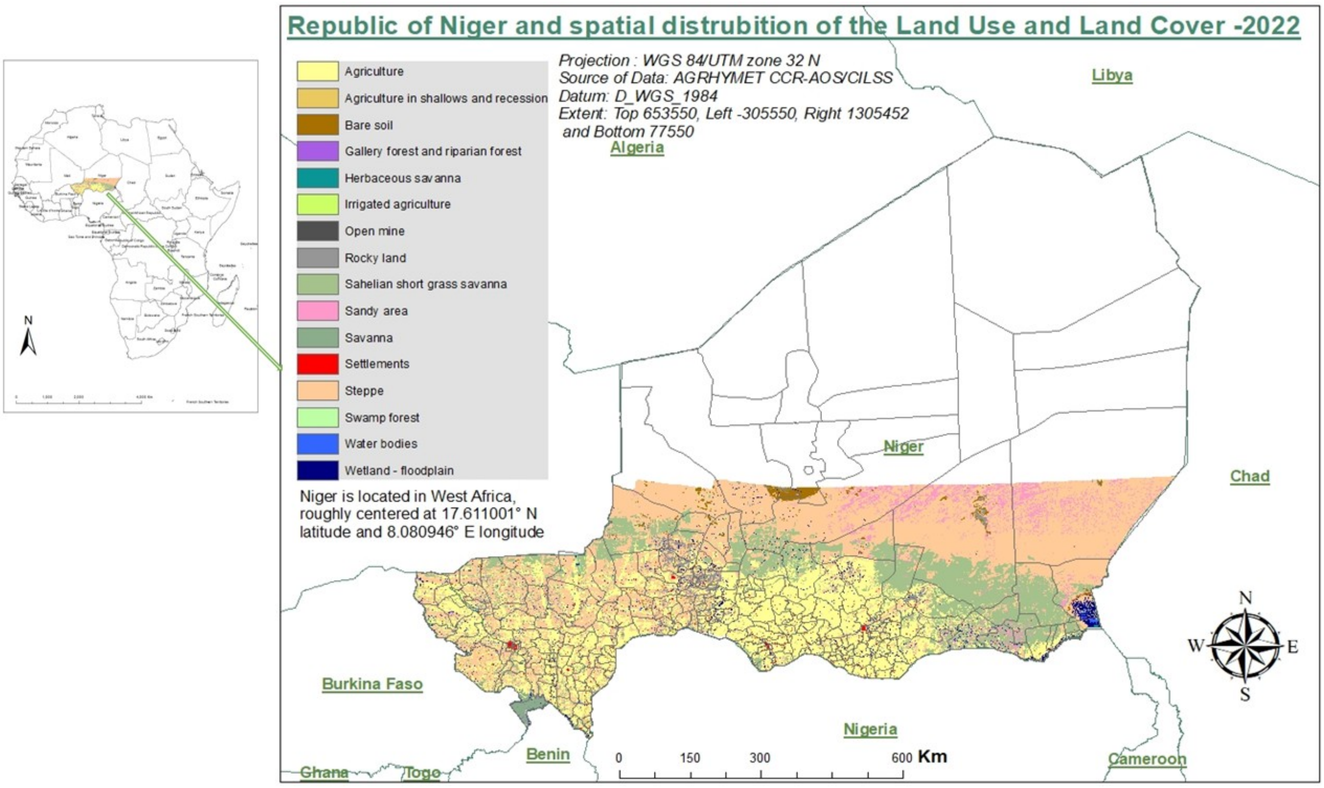


Figure 1. Study area and its distribution of the Land Use/Land Cover in 2022.

2.2. Trends earth data

The MOD13Q1 Normalized Difference Vegetation index (NDVI) from Moderate Resolution Imaging Spectroradiometer (MODIS) [24] was used as the vegetation index (**Table 1**). The ESA Climate Change Initiative (ESA-CCI) dataset for the period from 2001–2022 was also used (**Table 1**). This dataset is used to monitor land cover change by reclassifying its 22 LU/LC classes into the seven classes (artificial area, bare land, cropland, forest, grassland, water and wetland) that are necessary for the UNCCD reporting. The computing of the initial SOC content was performed using the ISRIC SoilGrids data (**Table 1**). This data predicts soil properties at six different depths. Landsat 9 images with a cloud cover of less than 5% and acquired in 2022 were collected from the archive of the US Geological Survey. For the classification purposes of this study, the bands 4, 5 to 7 were exclusively employed.

Table 1. Trends Earth data from [25].

Product	Remote sensing data	Period	Spatial resolution
NDVI	AVHRR/GIMMS	2001–2022	8 km
	MOD13Q1-coll6	2001–2022	250 m
Soil Humidity	MERRA 2	2001–2022	0.5° × 0.5°
	ERA 1	2001–2022	0.75° × 0.75°
Precipitation	GCP v2.31	2001–2022	2.5° × 2.5°
	GPCC v7	2001–2022	1° × 1°
	CHIRPS	2001–2022	5 km
	PERSIANN-CDR	2001–2022	25 km
Evapotranspiration	MOD16A2	2001–2022	1 km
ESA CCI Land Cover	CC by-SA 3.0	2001–2022	300 m
Soil Grids (ISRIC)	CC by-SA 4.0		250 m
G Agro-ecological Zones	Globsl	2000	8 km
Administrative Boundary	Global		10/50 m

2.3. Participatory approaches

Participarory approach are organized around a topic, which typically emphasizes a specific theme that can be explored in depth [26]. A participatory workshop was adopted to integrate expert and local knowledge into the LU/LC harmonization process, consistent with best practices for incorporating field-based expertise into geospatial analyses [26]. To ensure consistency across classification schemes, national stakeholder consultation workshops were conducted in Niamey to support the reclassification of the ESA-CCI land cover dataset (22 classes) and the Yangambi classification system (16 classes) into the seven IPCC land-use classes (**Table 2**) with stakeholders working in natural resource management institutions at national level (29 participants). These workshops facilitated structured feedback on LU/LC characteristics, land management practices, and agricultural productivity dynamics, enabling the incorporation of context-specific knowledge into the classification framework. Detail of the methods followed can be found in Appendix A.

In addition, expert consultations were undertaken to define land-cover transition matrices representing dominant LU/LC change processes and management trajectories. These transition matrices were used to parameterize the network inputs linking observed land-cover changes to underlying land-use practices and degradation or recovery pathways. The participatory inputs were designed to strengthened the reliability of LU/LC transitions and ensured that classification and change-detection procedures reflected locally relevant land management dynamics.

Table 2. Land Cover classification System (Reclassification of the ESA-CCI land cover classes and the Yangambi classification system into the seven IPCC land-use classes.

Land cover CCI legend (Level 1)	**Yangambi classification**	**Land cover legend by UNCCD**
-Tree cover, broadleaved, evergreen, closed to open (>15%) -Tree cover, broadleaved, deciduous, closed to open (>15%) (Tree cover, broadleaved, deciduous, closed (>40%) and Tree cover, broadleaved, deciduous, open (15–40%)) -Tree cover, needle leaved, evergreen, closed to open (>15%) (Tree cover, needle leaved, evergreen, closed (>40%) and tree cover, needle leaved, evergreen, closed to open (>15%)) - Tree cover, needle leaved, deciduous, closed to open (>15%) (Tree cover, needle leaved, deciduous, closed (>40%) and Tree cover, needle leaved, deciduous, open (15–40%)) -Tree cover, mixed leaf type (broadleaved and needle leaved) -Sparse tree (<15%) -Shrubland (Shrubland evergreen and Shrubland deciduous) -Sparse vegetation (tree, shrub, herbaceous cover<15%), Sparse tree (<15%), Sparse shrub (<15%) and Sparse herbaceous cover (<15%) -Mosaic T and shrub (>50%) / herbaceous cover (<50%)	Gallery forest and riparian forest Herbaceous savanna Savanna Swamp forest	Tree- covered
-Grassland - Mosaic herbaceous cover (>50%)/T and shrub (<50%)	-Grassland -Sahelian short -Grass savanna -Steppe	Grasslands
- Cropland, rainfed (Herbaceous cover and Tree or shrub cover) -Mosaic natural vegetation (Tree, shrub, herbaceous cover) (>50%)/cropland (<50%) - Mosaic cropland (>50%)/natural vegetation (Tree, shrub, herbaceous cover) (<50%) - Cropland irrigated or post-flooding	-Agriculture -Agriculture in shallows and recession -Irrigated agriculture	Cropland
-Shrub or herbaceous cover flooded, fresh/saline/brakish waters - Tree cover, flooded, saline water -Tree cover, flooded fresh or brakish water	-Wetland-floodplain	Wetland
-Water bodies	-Water bodies	Water bodies
-Urban areas	-Settlements	Artificial surfaces
-Bare areas (consolidated and unconsolidated)	-Bare soil -Open mice -Rocky land -Sandy area	Other lands
-No data -Permanent snow and ice -Lichens and mosses	-No data	No Data

2.4. Land degradation trend analysis

This study applies an integrated methodological framework to assess the implementation and impacts of the Niger GGW initiative. Changes in land degradation status (increased, stable, or decreased) were evaluated using the SDG indicator 15.3.1. The indicator integrates three sub-indicators, following [27]. The assessment of land degradation status was achieved by comparing a reporting period (2016–2022) against a reference baseline period (2001–2015) to determine recent changes in land condition in the study area. Each sub-indicator was derived using appropriate subsets of the baseline and reporting periods, depending on the specific requirements for trend estimation. The land productivity time-series analyses were conducted consistently across state, trajectory, and performance components using the same temporal window. The three sub-indicators were subsequently integrated using the "one out, all out" decision rule to generate a composite land degradation indicator, expressed as the proportion of degraded land relative to the total study area. Under this rule, a land unit is classified as degraded if at least one sub-indicator reveals degradation or remains stable following prior degradation in a previous assessment period [28].

2.5. Land use and land cover dynamics

Rapid Land Cover Mapper (RLCM) tool [29] was used to generate LU/LC maps and geo-statistics based on Landsat imagery of September 2022. The RLCM tool was developed by the U.S. Geological Survey's Earth Resources Observation and Science Centers. It is based on visual interpretation and requires special skills and detailed local knowledge about the area of interest Satellite images. The image interpretation process was facilitated with interpretation guidelines for Yangambi Nomenclature [30], which included written and illustrated definitions of all of the LU/LC classes. Reclassifying the 18 classes of the LU/LC of 2022 from Yangambi classification system into the seven land cover classes recommended by UNCCD and the validation was based on national stakeholders' consultation workshops.

ESA CCI land cover time series (2001–2022) at 300 m spatial resolution and annual temporal resolution were used [31]. MERIS FR/RR, SPOT-VGT and PROBA-V sensor were used. The typology was defined using LU/LC classification system of the FAO [32]. The Land cover time series maps are provided as global attributes in the NetCDD file and are included in the GeoTIFF raster [33]. The change module developed by the University of Louvain was applied for change detection and change delineation. Thes annual classification derived from LU/LC for 2022 and ESA CCI land cover were used to determined LU/LC change. For the validation process was based on the:

- LU/LC stakeholders' consultations workshop which helped to determine the accuracy of the map.
- As a preliminary validation process, ESA CCI Land cover time series was assessed using the GlobCover validation data [34] to determine the accuracy of the CCI- land cover map. LU/LC transition matrices were derived and overall accuracies were calculated based on the diagonal cells of the matrix and the other cells which mark agreement between the product and the validation dataset.

2.6. SDG indicator and trends earth tool

The Trends. Earth tool under the GNU General Public License version 2.0 is used for monitoring multiple SDGs indicators supporting by QGIS-based platform (QGIS 4.0). It harvests earth observation datasets from different sources. The user can integrate national data, and uses Google Earth Engine to compute the sub-indicators. However, the final indicator is computed locally [35]. The outputs are in tabular format (Excel files) with metrics and spatial distribution of different indicator. Each of the indicators were computed for the baseline period (2001–2015) and the reporting period (2016–2022). The MODIS dataset MOD13Q1 was computed for the trends in land productivity (trajectory, state, performance) for the vegetation monitoring. Climate calibration through RUE was applied to drive land productivity. Five classes namely, declining, early signs of decline, stable but stressed, stable, increasing were used for Land productivity. Whereas, three classes were considered for land degradation indicator, (Degraded, Stable, Improved). The carbon stocks (SOC) change was derived by considering the initial SOC from the SoilGrids dataset (Table 1) and a transition matrix from the workshop.

This transitions matrix was based on the local knowledge of the LU/LC changes. the national LU/LC for 2022 and the global land use land cover data were applied as input parameters for land degradation model.

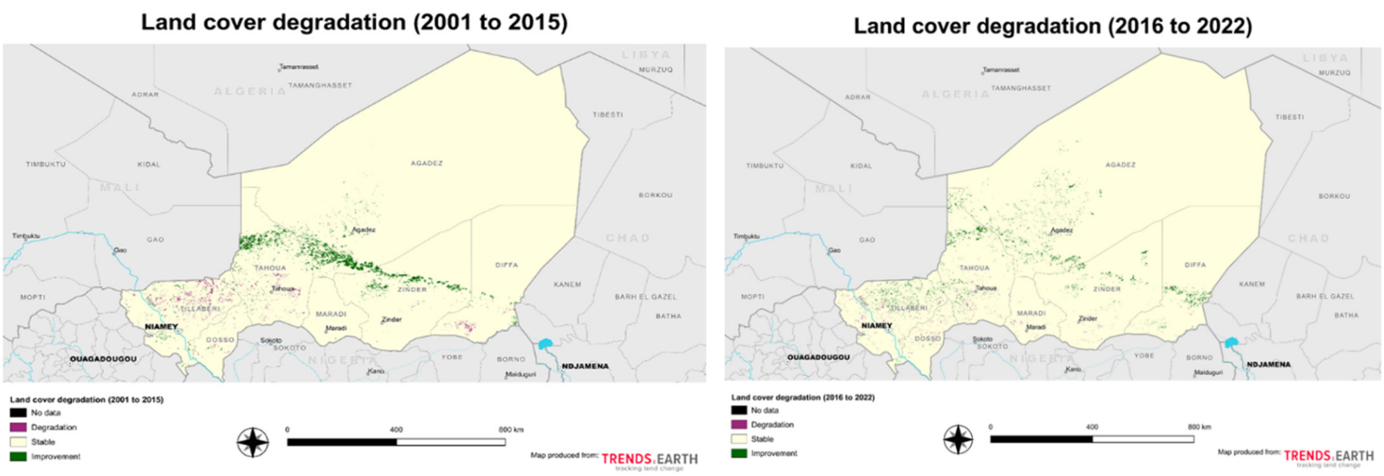
3. Results and discussion

3.1. Land degradation metrics

The section provides the results of the investigation carried out on assessment of land degradation in the study area, the Land degradation metrics for baseline and reporting periods in Niger as generated using Trends-Earth by combining LU/LC computing using Rapid Land Cover Mapping (RLCM) classification System for 2022 and ESA CCI Land cover time-series (2001–2022). The land degradation metrics is based on the transitions of the LU/LC from initial year to the final year. It is a result of transition from one land use and landcover to another. A transition matrix contains the transitions as degraded, stable and improved lands.

A comparative assessment of the land degradation was conducted using the baseline period from 2001 to 2015 and reporting period 2016 to 2022 (see **Figure 2**). For the baseline and reporting periods are presented in the **Figure 2**. The spatial distribution of improving land was showed in the Niger Great Green Wall due to a massive land restoration activity to combat desertification. This action involves planting trees and restoring degraded land by using different techniques such: Half-Moon (Demi lune), Zai, farmer managed Natural regeneration, scalable Model for the Sahel, to create a buffer against the Sahara Desert’s expansion

Land degradation metrics for baseline and reporting periods in Niger were generated using Trends-Earth by combining LU/LC computing using RLCM classification system for 2022 and ESA CCI Land cover time-series (2001–2022).



(a) (b)

Figure 2. Study area and its distribution of the Land degradation metrics for baseline from 2001 to 2015 (**a**) and reporting periods from 2016 to 2022 (**b**).

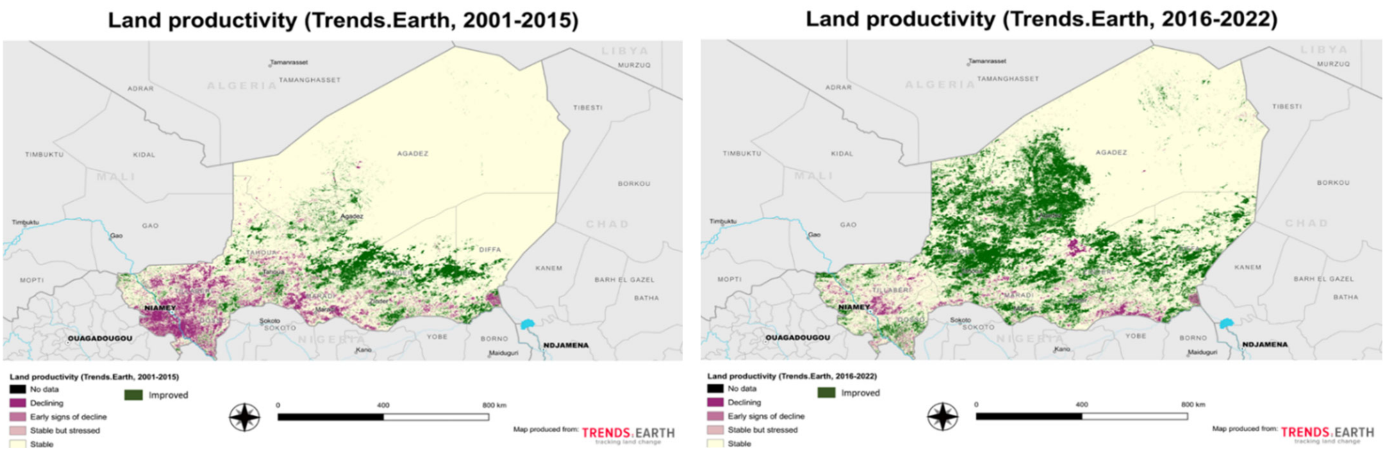
A slightly smaller area of degraded land was observed in the West (Tillabéri region) and East (Diffa region) of the study area during 2001–2015 (**Figure 2a**), with a shift toward improved land observed during 2016–2022 (**Figure 2b**). **Table 3** shows that although there a slight increase is observed in reporting period, land degradation remains largely stable. The stability increased slightly, from 1,160,089 km² during the baseline period to 1,168,064 km² during the reporting period.

Table 3. Land degradation metrics.

	Baseline		Progress	
	Area		Area	
	%	km²	%	km²
Improved	8.10%	101,919	7.64%	96,781
stable	91.58%	1,160,089	92.19%	1,168,064
degraded	0.32%	3992	0.17%	2155
Total	100%	1,267,000	100%	1,267,000

3.2. Land productivity Sub-indicator for baseline and reporting periods.

Land productivity, as shown in the national map (**Figure 3a,b**) and accompanying statistics (**Table 4**), reveals a diverse range of productivity levels across a total area of 1,267,000 km². Land productivity metrics indicate that; land productivity doubled between the baseline years (14%) to the reporting (28%). Most of the area, remain stable in terms of productivity, covering 80% during the baseline period and 69% during the reporting period.



(a) **(b)**

Figure 3. Study area and its distribution of the Land productivity for baseline from 2001 to 2015 (**a**) and reporting periods from 2016 to 2022(**b**).

Degradation affected 6% of the land during the baseline period and 3% during the reporting period. During the reporting period, an even greater proportion of the land exhibited improved productivity, particularly in the central region of the country and along the Great Green Wall of Niger (**Figure 3b**). Overall, the pattern of land productivity changes is consistent with the land degradation indicator.

Table 4. Land productivity metrics.

	Baseline		Progress	
	Area		Area	
	%	km^2	%	km^2
Improved	14%	172,305	28%	351,534
stable	80%	1,017,338	69%	879,214
degraded	6%	77,025	3%	36,253
Total	100%	1,267,000	100%	1,267,000

3.3. Soil Organic Carbon

SOC is the main component of soil organic matter and constitutes a crucial contributor to food production, mitigation and adaptation to climate change, and the achievement of the SDG [32]. The SOC has received great attention during the development of the greenhouse gas reporting program of the Intergovernmental Panel on Climate Change since the mid-nineties and it becoming sub-indicators for the SDG target 15.3.1 (Proportion of land that is degraded over total land area). In the study area, there is considerable variation in soil organic carbon (SOC) content in the surface layer (**Tables 5 and 6**).

Table 5. Soil Organic Carbon from initial year to final year (Baseline).

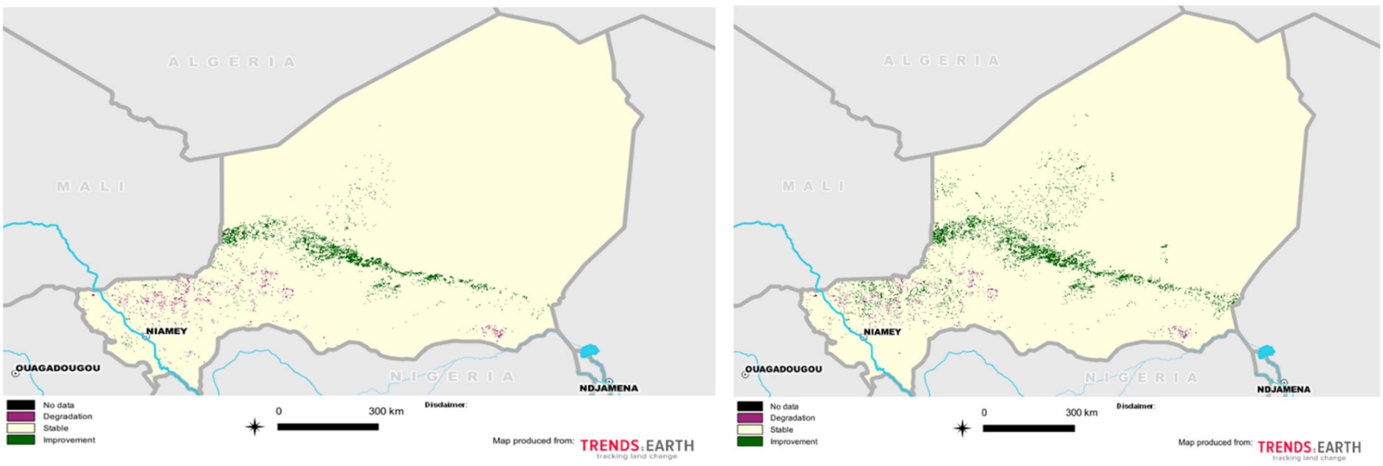
LU/LC	Initial SOC (t/ha)	Final SOC (t/ha)	Initial SOC(t)	Final SOC (t)	Change in SOC(t)	%Change in SOC
Tree-covered	21.08	21.30	14,658,862	14,889,517	230,654.74	2%
Grassland	10.05	10.02	270,734,533	281,053,717	10,319,183.78	4%
Cropland	15.55	15.54	152,714,869	152,547,880	-166,988.22	0%
Wetland	58.41	62.89	10,036,033	11,831,789	1,795,755.71	18%
Artificial	20.21	17.82	203,467	304,695	101,227.37	50%
Bare land	6.19	6.16	498,095,381	488,875,626	-9,219,754.47	-2%

A comparison of baseline SOC values indicates a slight decline in bare land (−2%) during the period. In contrast, SOC content increased in tree-covered areas, grasslands, and artificial lands by 2%, 4%, and 18%, respectively, while wetlands showed a 50% increase. Croplands remained stable (0%) (**Table 5**). **Table 6** presents the evolution of SOC from the initial year to the final year of the reporting period.

Table 6. Soil Organic Carbon from initial year to final year (reporting).

LU/LC	Initial SOC (t/ha)	Final SOC (t/ha)	Initial SOC(t)	Final SOC(t)	Change in SOC(t)	% Change in SOC
Tree-covered	21.33	21.54	14,983,736	15,651,774	668,038.18	4%
Grassland	10.02	10.07	283,049,689	293,078,731	10,029,042.43	4%
Cropland	15.53	15.44	152,451,844	153,676,874	1,225,030.89	1%
Wetland	62.89	62.96	11,831,789	11,840,900	9,111.53	0%
Artificial	17.59	14.74	332,235	399,794	67,559.78	20%
Bare land	6.16	6.13	487,184,801	478,631,147	-8,553,653.76	-2%

Figures 4a, b shows the spatial distribution of soil organic carbon for the baseline period (2001–2015) and the reporting period (2016–2022). Three soil organic carbon classes were considered: improvement, stable, and degradation. Degraded soil organic carbon was observed in the southeast and southwest regions, likely due to population pressure during both periods. The largest portion of soil organic carbon remained within the stable class from 2001 to 2022. In the study area, the improving class is associated with intensive activities carried out under the GGW program, particularly in the central region of the country. These improvements are attributed to effective natural resource management practices, properly timed land use, and the implementation of conservation measures. This observed improvement is a significant feature of the study area and is expected to enhance ecosystem services and the well-being of the local population.



(**a**) (**b**)

Figure 4. Study area and its distribution of the Soil organic for baseline from 2001 to 2015 (**a**) and reporting periods from 2016 to 2022(**b**).

Statistics at the country level were calculated for the study area. During both the baseline and reporting periods, more that 90% of the area exhibited stable soil organic carbon conditions (**Table 7**). Additionally, 8.07% of the area showed improved status during the baseline period, compared to 8.97% during the reporting period. Consequently, a low degradation rate was observed, accounting for 0.43% during the baseline period and 0.38% during the reporting period.

Table 7. Soil Organic Carbon for the baseline and reporting periods.

	Baseline		**Progress**	
	Area	**km²**	**Area**	**km²**
Improved	8.07%	102,330	8.97%	113,699
stable	91.50%	1,159,258	90.65%	1,148,467
degraded	0.43%	5412	0.38%	4837
Total	100%	1,267,000	100%	1,267,000

3.5. Analysis of the SDG 15.3.1

The section below presents the results obtained from the SDG 15.3.1 for the study area. **Figure 5** shows the results of summary tables for the SDG 15.3.1 indicator for both the baseline (**Figure 5a**) and reporting periods (**Figure 5b**). **Figure 6** corresponds to the produced Land degradation maps.

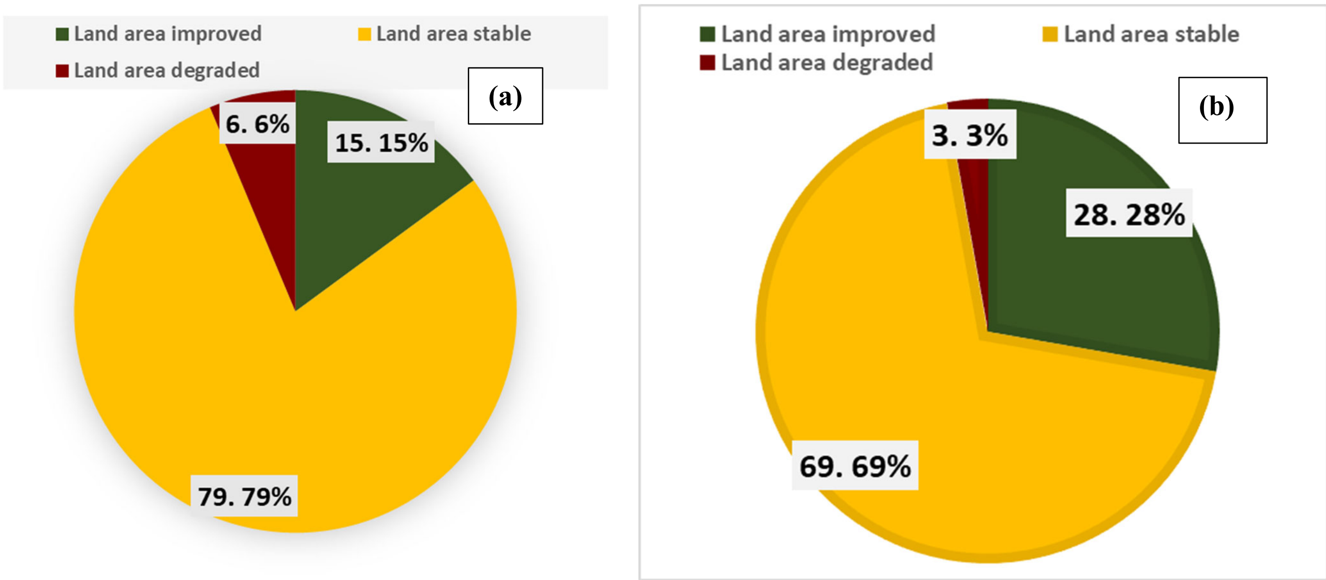
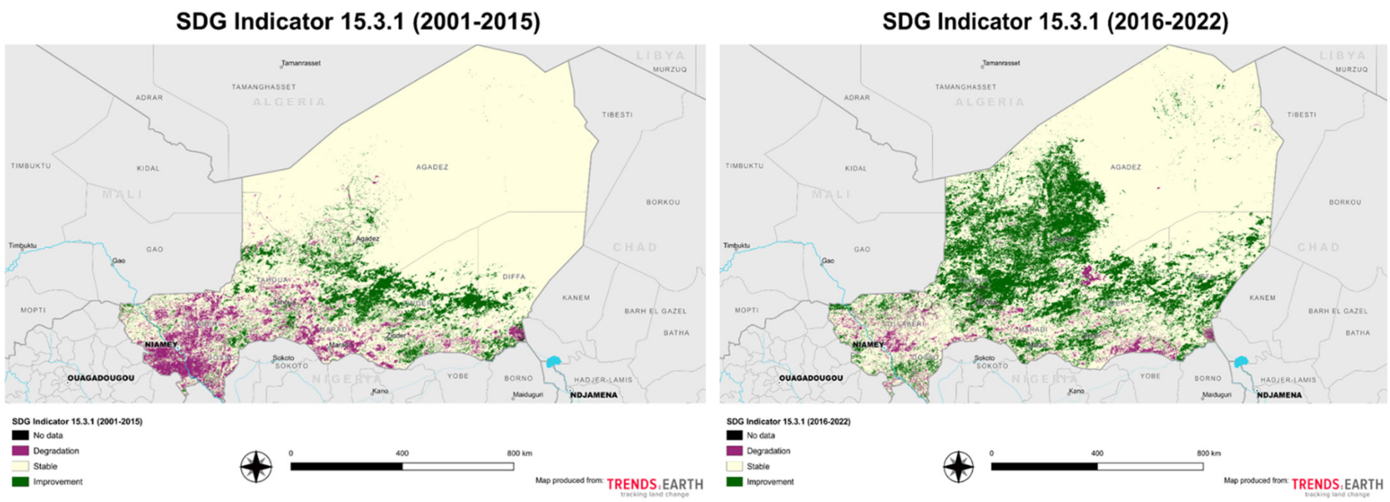


Figure 5. SDG 15.3.1 for the baseline from 2001 to 2015 (**a**) and reporting periods from 2016 to 2022 (**b**).

According to the land degradation metrics (**Figure 5**), in Niger, the percentage of degraded land decreased from 6.6% during the baseline period (**Figure 5a**) to 3.3% during the reporting period (**Figure 5b**), while the majority of the land remained stable, accounting for 79.79% during the baseline period and 69.69% during the reporting period.



(a) **(b)**

Figure 6. Study area and its distribution of the SDG 15.3.1 for the baseline from 2001 to 2015 (**a**) and reporting periods from 2016 to 2022 (**b**).

Figure 6 shows the spatial distribution of land degradation in Niger during the baseline period (**Figure 6a**) and the reporting period (**Figure 6b**). The maps highlight that the majority of land in Niger remained stable during both periods. Areas with improved land conditions were limited during the baseline period (**Figure 6a**) and were mainly concentrated in the GGW region of the country. Degraded lands were sparse and primarily located in the southern part of the country, likely due to increasing population pressure. **Figure 7** shows the spatial distribution of the SDG 15.3.1. during the both periods of investigation.

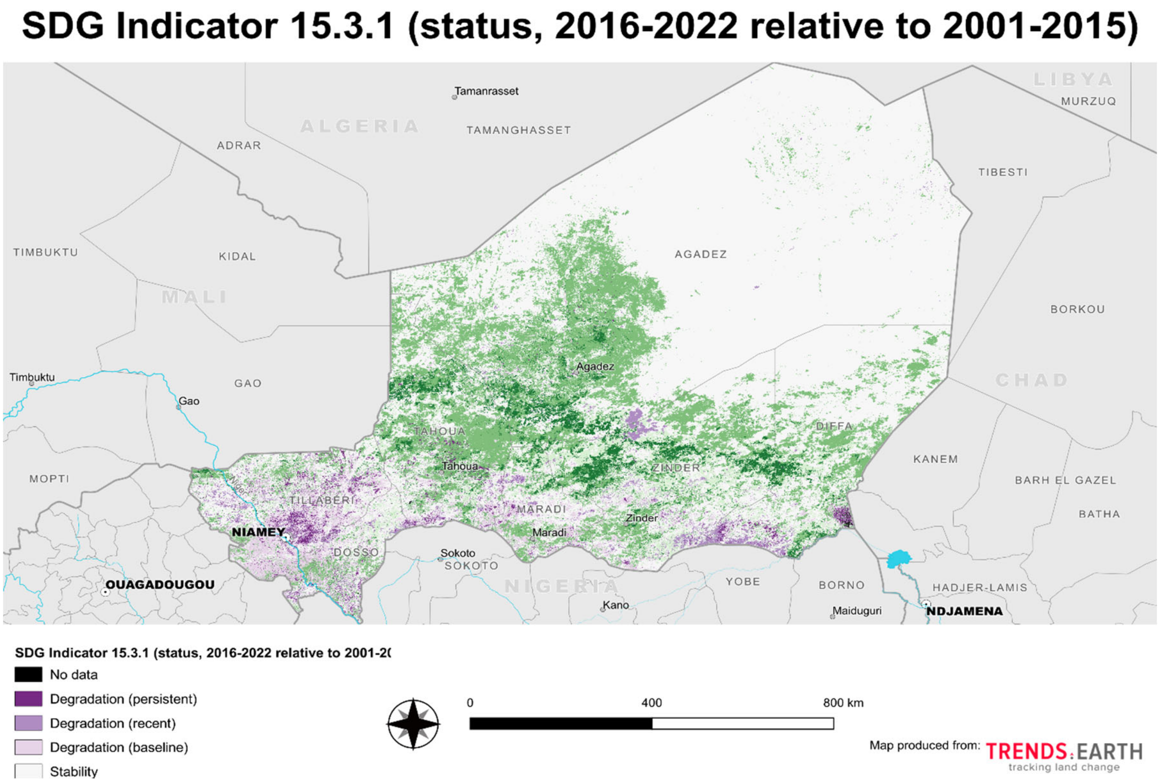


Figure 7. Study area and its distribution of the SDG indicator 15.3.1 (status, 2016–2022 relative to 2001–2015).

4. Conclusion

A comprehensive assessment of land degradation and restoration trajectories was made across the Niger landscape by systematically examining both temporal and spatial dynamics. The analysis was based on three sub-indicators and disaggregated degradation patterns across distinct physiographic regions characterized by variable soil humidity, precipitation, NDVI, evapotranspiration, soil properties, agro-ecological conditions, and land use and land cover. The UNCCD Good Practice Guidelines were followed, with the baseline period defined as 2001–2015 and the reporting period as 2016–2022. The spatial distribution of improving land was particularly evident in the Great Green Wall (GGW) of Niger, reflecting extensive land restoration efforts aimed at combating desertification. These efforts include tree planting and various land restoration techniques such as Half-Moons (Demi-Lune), Zai pits, farmer-managed natural regeneration, and scalable Sahel models, which collectively help create a buffer against the expansion of the Sahara Desert. This improvement is a key feature of the study area and is expected to enhance ecosystem services and the well-being of local populations.

Overall, the largest proportion of land remained stable, while land degradation was influenced by dynamics in land productivity, largely driven by population growth. This study represents an important step toward linking land degradation assessment specifically to GGW activities, where landscape conditions and improvements are determined by different management actions. The results highlight the need to regularly monitor restoration efforts to evaluate their contribution to achieving land neutrality targets. Trends.Earth proved to be a valuable tool for monitoring land degradation, offering flexibility for customization with specific datasets and targeted areas of interest.

Author contributions: Conceptualization, MM and BM; methodology, MM; software, MM and JCO validation, MM, IIM, and GE; formal analysis, MM; investigation, MM; resources, IG; data curation, MM; writing—original draft preparation, MM; writing—review and editing, GE, AZ and IIM; visualization, MM; supervision, IG and BM; project administration, IG; funding acquisition, BM, IG and IG. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded from ENABEL.

Availability of data: The datasets were downloaded and accessed through the Trends.Earth plugin and LU/LC 2022 used and/or analyzed during the current study will be available from the corresponding author on reasonable request.

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Appendix A

A guideline for the participatory approach for a national stakeholder on the use of the Trends Earth tool for monitoring degraded land in Niger

Grant agreement within the framework of the Sahel Climate Thematic Portfolio regional component (PTCS) of **Enabel: NER2100411**

Niamey—27 September 2024

I. Introduction

Niamey, from March 31 to April 4, 2025, a workshop for National actors on the use of the Trends.Earth tool for monitoring degraded land in Niger took place in the Centre Regional Agrhymet CCR-AOS. The activity is part of the implementation of the agreement signed between Enabel and the Centre Regional Agrhymet CCR-AOS in June 2024 relating to the capacity building of national actors working in sustainable land management and Land Degradation Neutrality (LDN) to better monitor Desertification/Land Degradation and Drought (LDDS).

It follows a series of training courses including the production of land cover maps with the Rapid Land Cover Mapper (RCLM) tool and the assessment of soil and vegetation carbon.

Representatives from the state's technical services and research institutions were present (see attendance list). The agenda items included:

- Sustainable Development Goal (SDG) 15.3.1 relating to land degradation;
- A detailed presentation of the Trends.Earth tool, its functionalities, and its importance in monitoring changes in land conditions;
- the Land Use /Land Cover harmonization process
- Land Use /Land cover transition matrices
- Practical exercises on data collection, spatial analysis, and the generation of maps and indicators using the platform;
- A discussion session on best practices and challenges encountered in monitoring land degradation.

II. Progress of the workshop

Opening Ceremony

The workshop opened with welcoming remarks from the activity coordinator, representatives from Enabel, CNEDD, and the Director General of Centre Regional Agrhymet CCR-AOS. The Enabel representative thanked the participants for attending and reminded them of the workshop's purpose, noting that it followed a series of capacity-building sessions. He concluded by urging the participants to attend regularly. The CNEDD representative also thanked the participants and Enabel for funding the activity. She reiterated the series of capacity-building sessions and the expected outcomes. The Director General of Centre Regional Agrhymet CCR-AOS then spoke, thanking everyone and assuring the participants that everything would be done to ensure they understood the training content. Afterwards, presentation of participants and a group photo were done.

Next, the agenda was presented, discussed, adjusted, and adopted. To facilitate and report on the workshop activities, a bureau was established, composed By:

- President: Mme BouBacar Zalia Yacouba from CNEDD;
- First rapporteur : GARBA BOULAMINE Mounkail from l'ICRISAT
- Second rapporteur: SANDA ALTINE Mahamane Lawali Expert GIS and remote sensing from IGNN.

Installation of QGIS and Trends.Earth software and overview of Trends.

The trainers provided participants with QGIS V 3.34.6 software on a USB drive, one of the stable versions for using Trends Earth, followed by its installation. After installing QGIS, the software interface was explored, followed by the installation of Trends Earth via the extensions window.

A presentation followed to explain the benefits of its use. The presentation revealed that Trends.Earth was developed as part of the project "Enabling the use of global data sources to assess and monitor Land Degradation at different scales", funded by the Global Environment Facility.

It is free and open-source, licensed under the GNU General Public License, version 2.0 or later. It allows users to evaluate time series of key indicators of land change to produce maps and other graphs that can be used for monitoring and reporting, and to track the impact of Sustainable Land Management (SLM). It installs as a QGIS plugin and uses the Google Earth Engine platform to calculate indicators in the cloud (remote computing).

This presentation highlights the types of data used by the platform. These include the Natural Development Index (NDVI), precipitation, soil moisture, evapotranspiration, land cover/land use, and many others. For each data point, the sensor or dataset, spatial resolution, coverage, and license are specified.

A review of the SDGs helped clarify target 15.3 of SDG 15, which aims to combat desertification by 2030, restore degraded land and soils, including land affected by desertification, drought, and flooding, and strive for a land-degradation-free future. To assess degraded areas, SDG indicator 15.3.1 uses data from three sub-indicators: land productivity, land cover, and carbon stocks (aboveground and belowground), currently represented by organic carbon stock (OCS).

ESA-CCI land cover dataset (22 classes) and the Yangambi classification system (16 classes) IPCC land-use classes

The first presentation about Land use and Land cover in West Africa:

Dr. Mansour Mahamane, explained the Land Use and Land Cover activities for west Africa and presented:

- The Land Use and Land cover (LULC) data and maps will require periodic updates to support: monitoring the effects of human activities and climate change, providing support to the region, and to countries in the preparation of action plans under the international conventions (UNCCD, UNC BD, UNFCCC, …) and of accurate and timely data for the required periodic reporting;
- Providing information to promote best agricultural practices and land use planning (providing information for sustainable management of natural resources and to serve multiple purposes and a variety of different applications (water erosion model wind erosion model, biodiversity model, landscape structure model, Land degradation model and drivers, desertification model, suitable area of pastoralism, hopshop etc)

For the challenges in the region, the presentation and discussion were done on:

- The cost and amount of time to produce the maps due of the method used
- Lengthy history of LULC analysis
- Need of Automation of the method of LULC in order to make availability the product biannual.

Achievement of LULC product were also presented with the result of the three regionals conference was organized by west Africa in Senegal and Ghana in order to answer different question such as

- Who is the end- users of the LULC product?
- What are the policies or decisions affected by the product?
- How does the resolution, accuracy and periodicity of the LULC product correspond to requirements of the end-users?
- How can this effort be sustained over time?

The content of the atlas was shared to the participant

Second presentation

This presentation highlights the land use and land cover land system used in Niger

- Yangambi
- FAO Land Cover classification System

- Intergovernmental Panel on climate
- Anderson
- CORINE Land Cover
- ESA-CCI Land cover
- IPCC Land-use classes

Practical work

The practical work focused on:

- using the Trends.Earth tool integrated into QGIS for the analysis of land degradation in Niger.
- Harmonization of Yangambi and ESA-CCI Land cover elements in IPCC Land-use classes
- Development of Matrice of changes

The first day was dedicated to installing QGIS, and the Trends.Earth, creating Trends.Earth accounts, configuring the tool, and running the first queries, particularly on productivity. Also, Once the data was acquired, it was visualized, analyzed, and then used to create a productivity map of the Niger region. During this workshop, participants learned how to add a shapefile layer, make it transparent, extract an area of interest, apply a style, and then create a complete layout including scale, title, logo, and grid, before exporting the final map as an image. Basemaps such as OpenStreetMap, ESRI, and Google Satellite were added for improved readability of the land cover.

The second day began with a review of the previous day's report, followed by discussions that led to suggestions for improvement, such as a reminder of the parameters considered (productivity, soil carbon, land use). Activities then focused on verifying responses to queries submitted the previous day, interpreting the data, and addressing some connection issues, for which solutions were found. It was agreed to extend the analysis period to 2020-2022, in addition to the previously reported period of 2001-2019. Harmonization of Yangambi and ESA-CCI Land cover elements in IPCC Land-use classes were discussed.

The third day began with the amendment of the previous report, followed by verification of Harmonization of Yangambi and ESA-CCI Land cover elements in IPCC Land-use classes were discussed at the national level. This session led to discussions on concepts such as grassland, wetland, and body of water, and concluded with practical exercises to reinforce learning.

The analysis of the results sparked discussion, particularly regarding an apparent improvement of the harmonization that might not reflect the reality on the ground, highlighting the importance of reviews some classes.

Questions were raised concerning the possibilities for comparison between two maps at same period. For that the land cover of Niger from "Centre de Suivi Écologique" of 2022 and land cover product from the Trends.Earth for the 2022 base of the harmonization of the workshop were compared. The result shows the similarity of the two maps.

Subsequently, the harmonization result was adopted.

The fourth day began with the review and improvement of the report from the third day. Following this, the Ecological Monitoring Center presented the results of a study on the use of remote sensing and GIS to assess land degradation and restoration opportunities in Niger. This study aimed to estimate the state of land degradation in 2020 using spatial and field data, identify areas suitable for restoration, create a bioclimatic map, and calculate the percentages of degraded areas per bioclimatic zone. Several questions were raised regarding the purpose of the study, its integration into national reports, and the inclusion of areas larger than 50 hectares. The results of this presentation were used to inform the Matrice of change following with the discussion.

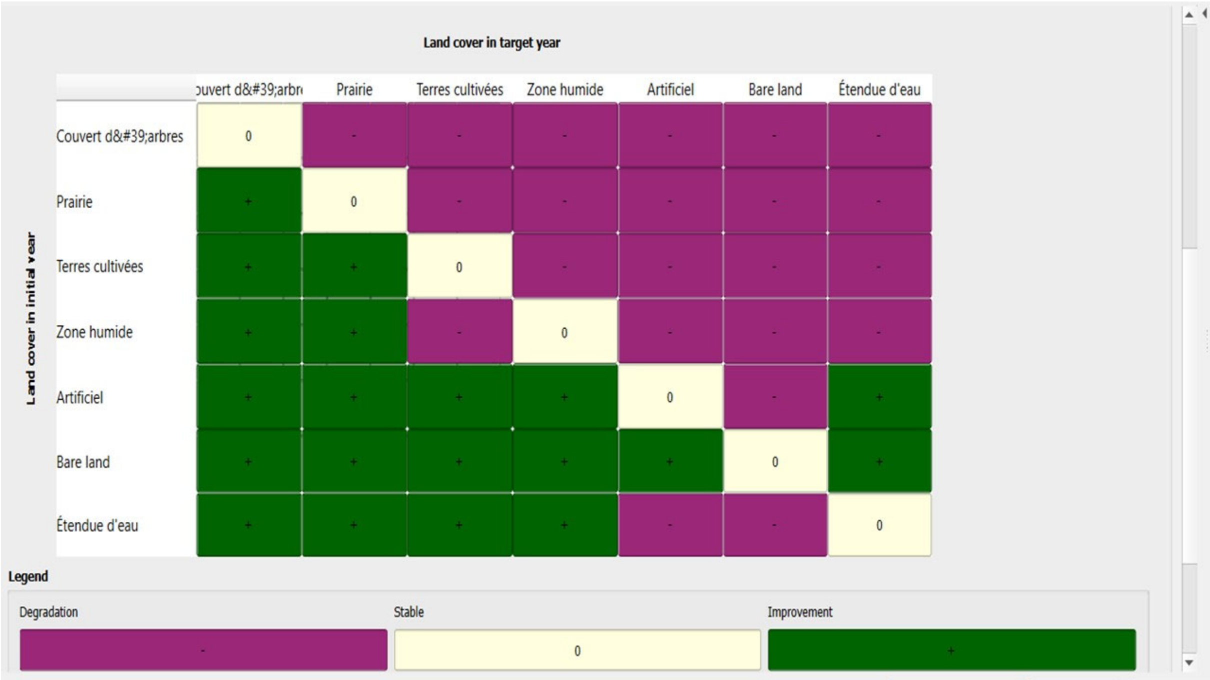


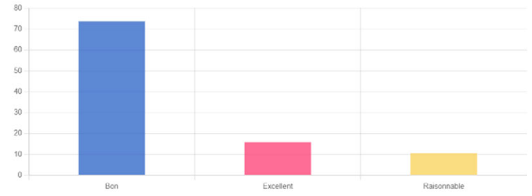
Figure A1. Interface of the transition matrix that developed using participatory approach.

This transitions matrix was based on the local knowledge of the Land use land cover changes. the national land use and land cover for 2022 and the global land use land cover data were applied as input parameters for land degradation model

It should be noted that several questions were asked by the participants about the transition's matrix, and they were satisfied with the appropriate answers provided. The participants also contributed their own insights, which subsequently allowed the participants to expand his knowledge base. With the diverse experiences of both the trainer and the participants, the day was highly interactive.

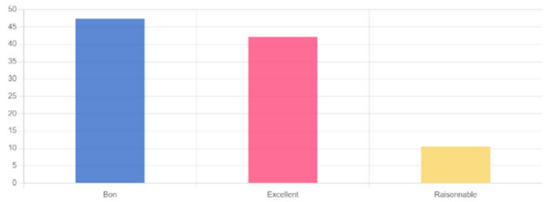
Evaluation of the participants of the workshop

The participants expressed a positive opinion of the workshop, which perfectly met their expectations. **Figure A2** below are some points of feedback regarding their learning level, the usefulness of the acquired knowledge in relation to their work and the NDT process, their ability to use Trends.earth after the workshop, and their capacity to generate any indicator from Trends.earth.

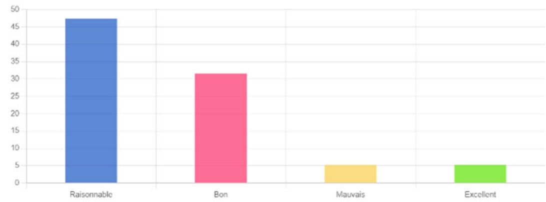


Assessment of your learning

Usefulness in relation to your work and the NDT process



Using Trends.Earth as a solution to SDG 15.3.1



Creating any sub-indicator within an intervention zone

Figure A2. Evaluation of the participants.

III. Conclusion

This workshop was a crucial step in structuring a national system for monitoring land degradation. By improving the national stakeholders with practical skills on the Trends.Earth tool, it directly contributes to the implementation of Niger's commitments to combat desertification. It is now essential to ensure the continuity of this momentum, particularly through:

- the deployment of the tool at the regional and departmental levels;
- the establishment of a mechanism for capitalizing on results and monitoring and evaluation land degradation;
- the strengthening of partnerships between national institutions and technical and financial partners

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