

Towards assessment of the performances of multifunctional agroecology landscapes

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1. Introduction

In West Africa, landscapes are confronted with the dual challenges of deforestation and declining soil fertility, both of which threaten food security and the health of ecosystems. Enhancing the resilience of these social-ecological systems requires the development of multifunctional landscapes capable of delivering ecosystem services to local populations while preserving biodiversity. Such multifunctionality can be fostered through agroecological landscapes, defined as landscapes that enable the optimization of agroecological principles within a given context (Coquereau, 2026). These principles include improving resource efficiency (e.g. recycling and input use efficiency), strengthening resilience (e.g. soil health, biodiversity, synergies, economic diversification and animal health), and securing social equity and responsibility (e.g. connectivity, fairness, social values and diets, participation, co-creation of knowledge and natural resources governance) (HLPE, 2019; Wezel et al., 2020). However, it has not yet been explicitly demonstrated that these agroecology landscapes can also contribute to improving food security. This demonstration requires to assess landscape performances in terms of agroecology and food security.

While most of the agroecology principles can be applied across multiple scales, research has mainly focused on the plot or farm level. Few studies have translated and assessed these principles at the landscape scale. The same observation can be made for food security, which is more often addressed at the household level, with only a few studies taking into account the impact of landscapes on food security (Leroux et al., 2020). Recently, scholars have proposed a methodology to derive indicators of agroecological principles from land-use maps, enabling the assessment of the degree of agroecology within a given landscape (Coquereau, 2026). They also proposed indicators to assess three pillars of food security at landscape scale, e.g. availability (sufficient food supply), access (economic and physical capacity to obtain food) and utilization (proper biological use through adequate diet, clean water, and health care) (FAO, 2008). However, this exploratory approach has so far been tested only in a case study in Zimbabwe and still needs to be contextualized and validated in other landscape settings.

The objective of this report is to explore the potential of this new methodology to assess the degree of agroecology and food security in contrasting landscapes of West Africa.

This work represents a first step toward identifying landscape compositions that can enhance multifunctionality while ensuring sufficient nutrient provision for crop production. Our case study focuses on the area of Niakhar in Senegal.

We begin by presenting the land use and land cover map produced for the study area. We then describe the segmentation of the territory into several landscape units and the measurement of different indicators related to agroecology and food security for each of them. The third part presents the results regarding the degree of agroecology of each landscape and examines its relationship with food security.

This report presents non-calibrated simulations of agroecology and food security, with the aim of exploring the potential of the methodology in the context of the Niakhar area. The calibration and validation of the models will be carried out in subsequent work.

2. Land use land cover map of Niakhar

2.1. Data and method

The land use/land cover map is based on the Dynamic World dataset (Google, 2022), available on the Google Earth Engine¹ platform. This is a Near Real-Time (NRT) image collection that produces land cover classifications at a global scale, with a spatial resolution of 10 meters, derived from Sentinel-2 L1C satellite imagery.

The processing was carried out entirely on Google Earth Engine. For each pixel, the Dynamic World model estimates a probability of belonging to nine thematic classes and retains the class with the highest probability. Scenes with a cloud cover exceeding 35% were automatically excluded. A temporal composition using modal reduction was then applied to all available images for the year 2025, selecting, pixel by pixel, the most frequently observed class in order to produce a stable and representative land cover map of the Niakhar area.

The nine original classes were regrouped into six thematic classes suited to the local context: Water, Vegetation, Built-up, Cropland, Bare soil, and Wetlands.

Finally, the automated classification was refined through manual corrections by photo-interpretation, in order to improve thematic accuracy and reduce confusion between visually similar classes, particularly between cropland and bare soil, which is a common challenge in Sahelo-Sudanese environments such as Niakhar.

2.2. Land use and cover map obtained

The map obtained showed a dominance of croplands, with scattered tree vegetation within the plots, reflecting the parkland systems of Senegal (figure 1). No large patches of vegetation are visible on the map. In the northwest, the town of Niakhar occupies a prominent position, while the eastern part of the area is mostly covered by wetlands and bare soil.

¹ <https://earthengine.google.com/>

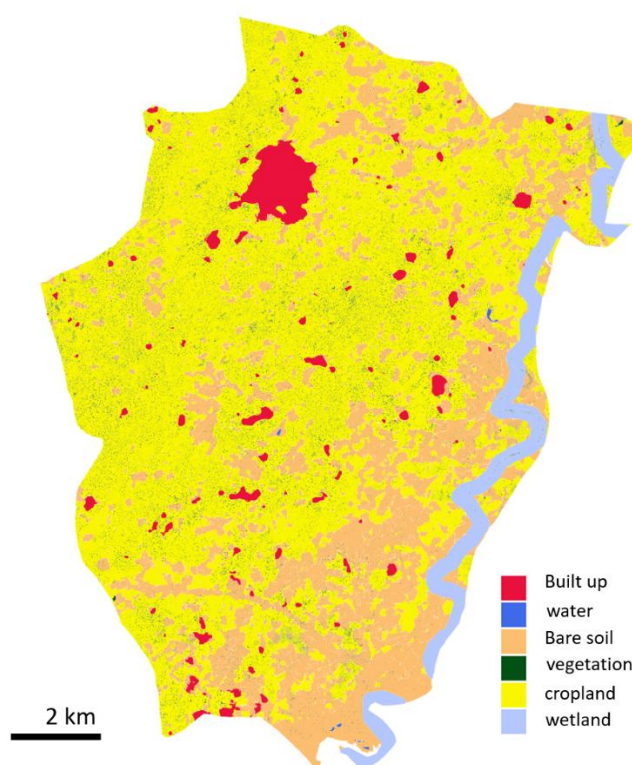


Figure 1. Land use and cover map of Niakhar

2.3. Assessment of the validity of the classification

Table 1. Accuracy assessment of the map

class	Real pixels	precision	Recall	F1-score
Water	15 094	100,00%	100,00%	1.00
Wetland	66 496	64,60%	54,50%	0.59
vegetation	166 650	96,00%	89,30%	0.93
cropland	2 222 832	55,80%	80,90%	0.66
Built up	628 819	82,90%	66,20%	0.74
Bare soil	492	—	—	—

The results show a good ability to discriminate shrub vegetation (Precision = 0.65), while wetlands display balanced performance (F1 = 0.34). In contrast, cropland and built-up classes are strongly under-detected, likely due to their seasonal dynamics and a pronounced class imbalance.

This map represents a first classification intended to support the indicator simulations; further work is currently underway to improve its accuracy and overall performance.

3. Sampling landscapes within the study area

3.1. Method for sampling landscapes

To assess landscape performances across the entire study area, we implemented a systematic spatial sampling approach. We generated a regular grid of sampling points at 500-meter intervals across the land use/land cover map extent. This sampling design produced 721 points, each representing the centre of a circular analysis unit. Only points falling within areas of valid data (non-NA values in the LULC raster) were retained to ensure analytical robustness.

We defined the spatial extent of the "lived landscape" around each sampling point as a circular buffer with an area of 5 km², corresponding to a radius of 1,261 meters (figure 2). This buffer size was selected based on the assumption that it represents a relevant scale for capturing the landscape actually experienced and utilized by local communities and agricultural activities in the Niakhar context. For each buffer, we extracted the underlying LULC data and calculated both the absolute area (in hectares) and the relative proportion of each land use class.

For spatial visualization of landscape indicators, we converted the point-based sampling framework into a regular grid of square cells. Each 500 m × 500 m cell was centred on its corresponding sampling point, creating a continuous tessellation across the study area. This grid structure enabled spatially explicit mapping of landscape indicators values at 500-meter resolution. The resulting maps provide a comprehensive spatial assessment of landscape performance metrics throughout the Niakhar commune, with values discretized using Jenks natural breaks classification to optimize the representation of spatial patterns.

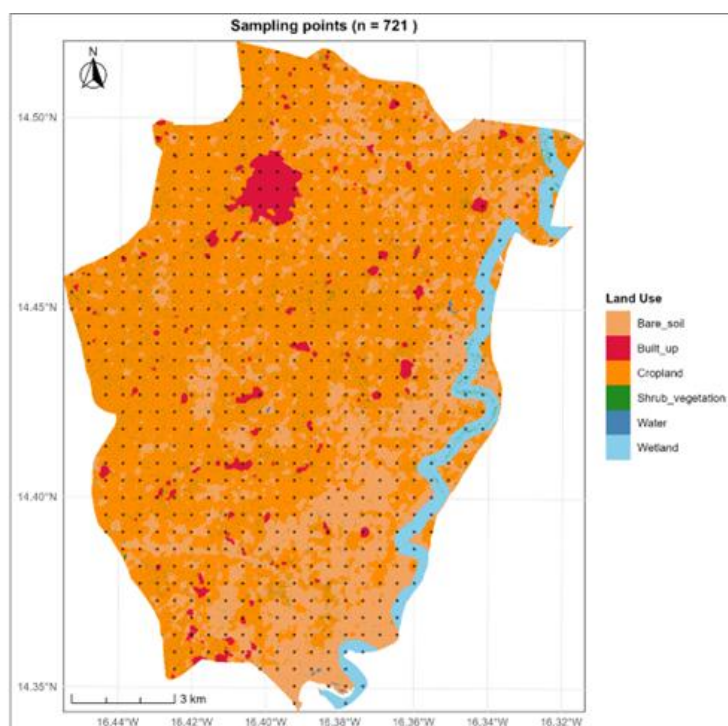


Figure 2. Sampling landscape points

3.2. Composition of the different landscapes

The landscape composition analysis reveals agricultural dominance, with cropland covering 62.5% on average (median 68.0%, max 93.3%). Bare soil (associated to fallow and grasslands) represents the second most abundant class (mean 27.3%). Natural vegetation remains limited, with shrub vegetation averaging only 2.5%. Wetlands and built-up areas show high spatial heterogeneity (medians of 0% and 1.8% respectively), but reach up to 58.9% and 54.4% in specific locations, indicating patchy distributions (figure 3).

To focus on agricultural systems and avoid indicator artifacts, we excluded landscapes with cropland area <20 ha within the 5 km² buffer (<4% coverage), removing 10 non-representative units (1.4%). The retained sample (n=711) captured the full gradient of functional farming landscapes.

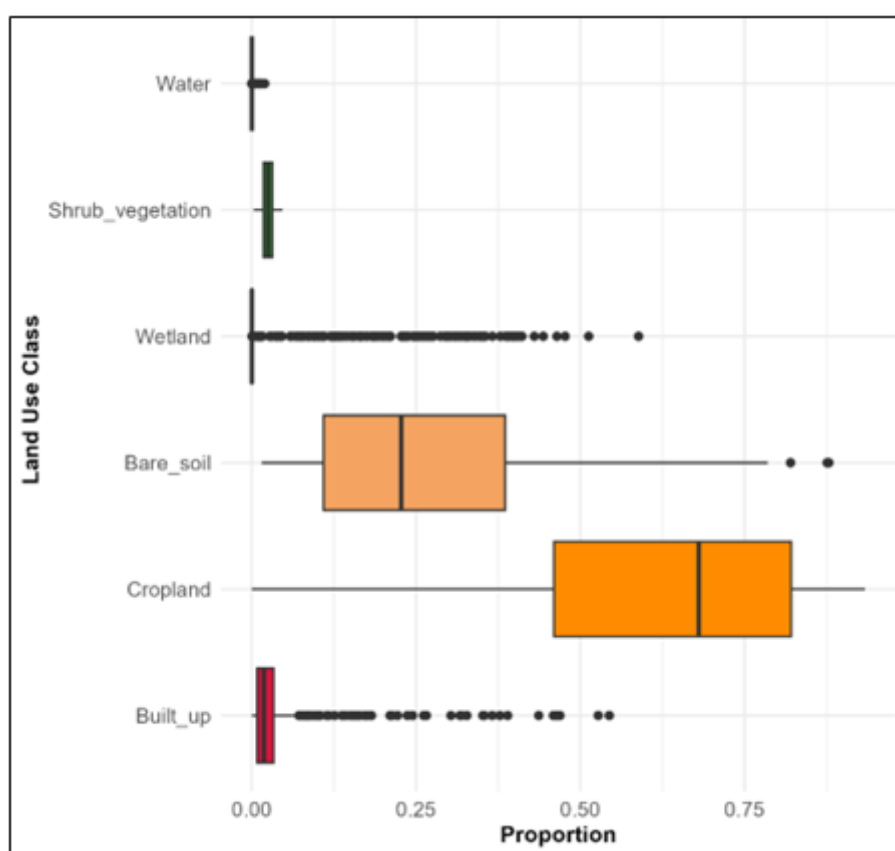


Figure 3: Distribution of land use class proportions across sampled landscape buffers (5 km², n = 721)

4. Assessing the agroecological principles and food security pillars at landscape scale

4.1. Method for calculating individual indicators

4.1.1 Overview of the method

The indicator framework follows the methodology presented in Coquereau (2026), originally designed for smallholder systems on communal lands in Zimbabwe. These indicators derive from land use composition data, where we obtained the area of each land use class, combined with several proxy values from the literature. For this application to the Senegal case, we maintained the same core parameters as the initial Zimbabwe study, modifying only a few key context-specific variables that were readily available for Senegal. These included population density of 190 people/km² (WorldPop 2020), mean annual precipitation of 548 mm/year (WorldClim) for the study area. For cropland composition, we estimated the proportions of the two dominant crop types: cereals (represented by maize) accounting for 74% of cropland, and legumes (represented by groundnuts) accounting for 26%.

The approach generates two complementary sets of indicators (figure 4). The first set addresses the principles of agroecology through 8 spatially explicit indicators derived from land use patterns. The second set evaluates three pillars of Food and Nutrition Security as established by FAO (availability, access and utilization).

All performance indicators build on landscape composition within each sampled unit. We calculated theoretical performance under three simplified assumptions. First, we modelled each landscape unit as a closed, self-reliant system where production depends exclusively on internally generated resources. Second, we considered all landscape resources as communally available and equally distributed among inhabitants, thus abstracting from socio-economic constraints such as land tenure arrangements. Third, the model does not account for limitations in capital or labour availability. While these assumptions simplify the complex reality of agricultural systems in Niakhar, they provide a standardized framework for comparing landscape performance across the study area and identifying spatial patterns in potential agroecological and food security outcomes.

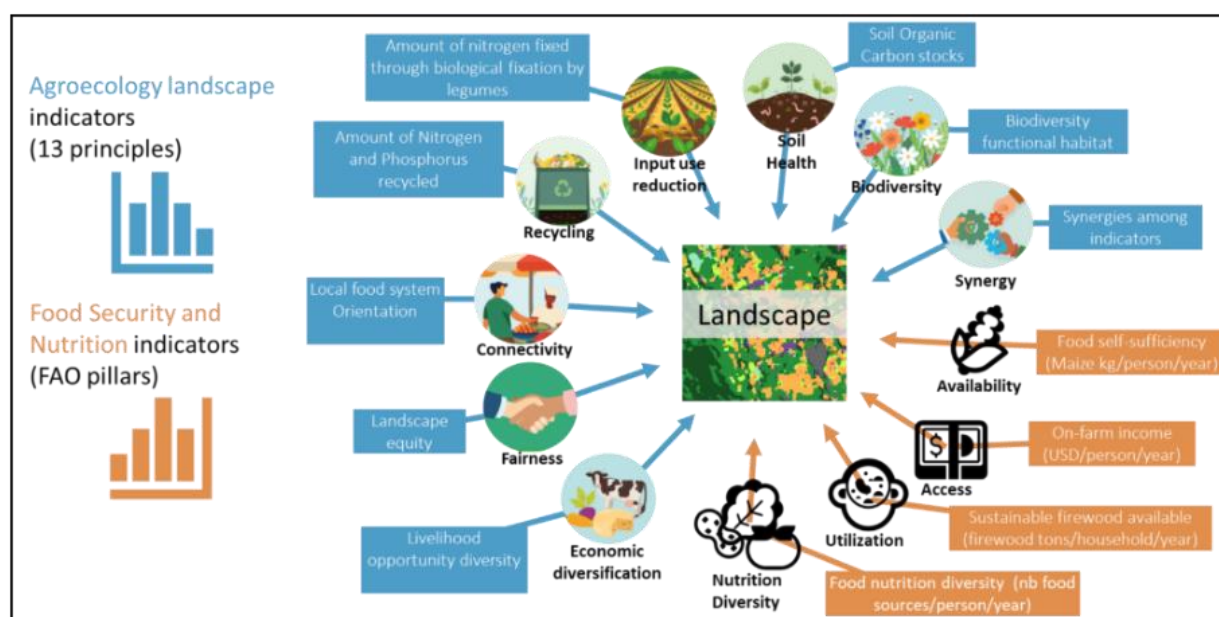


Figure 4: Individual indicators for assessing multifunctional landscapes. Pictogram illustration adapted from FAO (2024). Each indicator represents a specific landscape function or service contributing to the multifunctionality assessment framework. Figure credit: Coquereau (2026). Detailed calculation methods are provided in Coquereau et al., 2026, Chapter 1 and 2.

4.1.2 Data

The next table present the different data used to simulate the different indicators (table 2).

Table 2. List of input data

Data	Description	Spatial resolution	Acquisition period	Source
LULC data	Six-class LULC map	Raster 10 m	2026	This study
Above-ground Biomass	Raster woody above-ground biomass (AGB)	Raster 50 m	2016	(Bouvet et al., 2018)
Landscape preferences	Stakeholder preference profiles (n=105)	Individual	2024	Coquereau (2026)
Land use practices	Land use practices and resource management strategies (2 sessions, 44 participants)	Village	2024	Coquereau (2026)

4.1.3 Agroecology landscape indicators

Based on the thirteen HLPE (2019) agroecological principles, we operationalized eight landscape indicators spanning ecological, social, and economic dimensions:

1. Recycling: Nitrogen and Phosphorous cycling through crop-livestock integration.

This indicator measures the total nitrogen (N) and phosphorus (P) recycled internally within each landscape, expressed per hectare of maize cultivation. It accounts for three distinct nutrient pathways:

Woodland litter nutrients: Nutrient inputs were estimated from the area and productivity of woody vegetation classes (dense woodlands, open woodlands, and tree hedges) within the landscape, using specific litter production rates reported for dry savannah woodland (Frost, 1996) and nutrient concentrations from Southern African regional studies (Musvoto et al., 2000). This potential supply is constrained by a fixed household collection capacity (Musvoto et al., 2000).

Livestock manure nutrients: Manure inputs were determined by the sustainable cattle population that landscapes can support year-round. We calculated this population using an iterative equilibrium model that balances seasonal forage availability. Wet season grazing capacity was calculated from the total area of rangelands (i.e., bare soils, wetland), each with distinct grass productivity coefficients (Frost, 1996). Dry season feed availability depends on both the reduced productivity of these rangelands and the crop residues generated from maize areas (Rufino et al., 2011; Rusinamhodzi et al., 2015). The model's core feedback loop relies on maize yields, calculated using empirical response curves (Zingore et al., 2007), which in turn determine residue availability (Rusinamhodzi et al., 2015). Manure nutrient concentrations were derived from the literature (Falconnier et al., 2023).

Biological nitrogen fixation: Nitrogen contributions from legume crops were calculated as described in indicator 2 below.

The final indicator represents the total nutrient availability from these three sources, divided by the total maize cultivation area in each landscape.

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2. Input use reduction: Biological Nitrogen Fixation via legume-based nitrogen supply.

This indicator specifically quantifies the nitrogen input from legume-based biological fixation, expressed per hectare of maize cultivation. Total N uptake was calculated using tissue N concentrations of 2.0% for residues (stem, leaves and roots) and 3.8% for grain, derived from field measurements conducted within the study area (RAIZ project mid-term report). We assumed full incorporation of crop residues into the soil, with N export limited to harvested grain. Following Falconnier et al. (2023), we included belowground biomass (shoot:root ratio = 0.3), set the proportion of nitrogen derived from the atmosphere (%Ndfa) at 62%, and subtracted grain N export to obtain net soil N input from fixation per hectare of legume cultivation. This plot-level value was then normalized to the maize cultivation area based on the current share of legumes (26%) and maize (74%) in the agricultural landscape.

3. Fairness: Equitable satisfaction of stakeholder preferences weighted by resource dependence.

The Equity indicator quantifies how a landscape composition equitably satisfies the land use preferences of different stakeholder groups; a method adapted from Neyret et al. (2023). Stakeholder preferences were quantified through surveys (n=105) where participants from nine distinct groups distributed a fixed total of 20 points among the different land uses based on their perceived importance. These groups were categorized by their dependency on

landscape resources. Direct users (weight=3) included farmers (n=72), hunters/fishermen (n=2), and local services/trades (n=13). Local technical advisers (weight=2) included environmental, crop, forestry, horticulture, and livestock advisers (n=6). Distant advisers (weight=1) represent researchers (n=12).

The calculation involves two main steps. First, a satisfaction score is calculated for each stakeholder group by weighting the land use proportions in the landscape according to that group's stated preferences. This represents how well the landscape composition aligns with what each group values. Second, these group-level satisfaction scores are aggregated into an overall landscape equity score using an inverted, weighted Gini coefficient. The weighted Gini coefficient measures the inequality in satisfaction scores across the stakeholder groups, explicitly accounting for the pre-defined group weights. The final equity score ranges from 0 to 1, where a value of 1 indicates perfect equity (all stakeholder groups achieve satisfaction levels proportional to their weight), while a value closer to 0 signifies high inequity in the fulfillment of preferences.

4. Connectivity: Local food system orientation through short supply chains and local consumption.

This indicator assesses the degree to which a landscape prioritizes production destined for short supply chains and local consumption. The calculation process follows several steps. First, we identified the potential agricultural productions associated with each of the nine land use classes, based on consultations with local stakeholders. Each food production was assigned a score from 1 (export-oriented) to 6 (subsistence-oriented) based on authors' classification. For example, cash crops (e.g., tobacco) scored 1, crops sold in local markets scored intermediate values (3–4), and subsistence staple crops for household consumption scored 6.

Second, a local food system orientation score was derived for each land-use class through three distinct methods: For multi-activity land-use classes like dense woodland or grassland, the score is the arithmetic mean of the scores of their constituent food productions (for example, for dense woodland, livestock grazing is scored as 5, reflecting its primary role in local subsistence systems, while NTFP collection (4) and firewood (3) receive intermediate scores as they serve both household needs and local markets). For the cropland class, the score is an internal area-weighted average based on the proportional cultivation of maize (6) and legumes (3).

Finally, the landscape-level local food system orientation score is calculated as the area-weighted average of all these land-use scores. Landscapes dominated by land-uses oriented towards local food production and consumption receive higher scores, while those dominated by export-oriented production receive lower scores. Higher values signify a landscape more strongly oriented towards subsistence and local food systems, while lower values indicate a greater integration with external, export-oriented markets.

5. Soil Health: Soil Organic Carbon Stock.

This indicator assesses the landscape's capacity for carbon sequestration by quantifying the total Soil Organic Carbon (SOC) stocks across the entire 5 km² area. The total SOC stock (in tonnes of C) is calculated as the area-weighted sum of stocks from all LULC classes. The reference SOC stock values for each LULC class are derived directly from measurements of topsoil (0-20 cm depth) SOC in the study area. The final absolute value (total tonnes of C) represents the landscape's carbon storage capacity and is subsequently normalized to derive the soil health score.

6. Biodiversity: Functional habitat provision through semi-natural habitat proportion and integrity.

This indicator assesses the landscape's capacity to support biodiversity and related ecosystem services by quantifying the quality-weighted area of semi-natural habitats. This indicator is inspired from the InVEST Habitat Quality model (Natural Capital Project et al., 2025), simplified to use only landscape composition and not configuration. This accounts for the differential habitat value of various land cover types for supporting organisms that provide agricultural benefits, such as pest predators.

The calculation involves assigning habitat quality weights to each land cover class, ranging from 0 to 1 based on land-use intensity and structural complexity. We assigned the highest weight ($w=1.0$) to dense woodland, representing the most intact habitat. Intermediate weights ($w=0.5$) were assigned to open woodland, grasslands, and tree hedges, while intensively managed or non-vegetated areas (e.g., cropland, urban) received a weight of zero. The total weighted habitat area is calculated by multiplying the area of each land cover class by its habitat quality weight and summing across all classes.

7. Economic Diversification: Diversity of livelihood opportunities.

The economic diversity indicator assesses the capacity of land uses present in a landscape to support a diversity of potential income-generating activities. It utilizes the same comprehensive list of economic activities established for the Local food system orientation indicator. The calculation process involves three steps. First, the total area for each specific activity (e.g., firewood collection) was determined by summing the areas of all land use classes that provide it (Shrub vegetation). For agriculture, the cropland area was further partitioned into predefined shares for cereal production (74%), legume production (26%), and cash crops.

Second, for each activity, we calculated its proportional area relative to the cumulative area of all potential activities within the landscape. This accounting method explicitly recognizes the multifunctional nature of the landscape, where a single land use class can contribute to multiple economic outputs.

Finally, the score is calculated using the Shannon Diversity Index, providing a single metric that incorporates both the number of different activities (richness) and the relative balance of the areas dedicated to them (evenness). Higher values indicate greater economic diversification potential within the landscape.

8. Synergies: Aggregating performance across the seven other agroecology indicators.

The synergy indicator aggregates the other individual indicators, adapting a method used for ecosystem service bundles (Chen et al., 2021; Leroux et al., 2022). The calculation follows a ranking and classification procedure. For each indicator, the raw values from all landscape units were ranked and classified into quartiles. Each landscape unit was then assigned an ordinal score from 1 (representing the lowest-performing 25% of units) to 4 (the highest-performing 25%). Prior to this classification, all indicators were standardized to ensure that a score of 4 consistently represented the highest agroecological outcome. The final Synergy indicator for each landscape is the sum of its seven ordinal scores.

4.1.4 Food and Nutrition Security landscape indicators

Based on the Four Pillars of Food Security (FAO, 2008), we operationalized four indicators spanning availability, access, and utilization dimensions. The stability pillar, assessing temporal reliability of food sources, was not included in this landscape assessment. The FSN indicators translate food security pillars into quantifiable landscape features through four core indicators:

1. Food self-sufficiency (Availability): Landscape capacity to meet staple food requirements through maize production per capita.

This indicator assesses the landscape's capacity to meet staple food requirements through internal maize production. Maize production potential was estimated using nutrient availability calculated through the agroecology recycling indicator, accounting for nitrogen and phosphorus from woodland litter, biological nitrogen fixation through legume rotation, and livestock manure based on carrying capacity. Total maize production was then expressed as kilograms per capita per year, using demographic data obtained from focus group surveys.

2. On-farm income (Access): Monetary capacity to purchase food, calculated as net agricultural revenues from maize and groundnut per farming capita.

On-farm income quantifies the monetary capacity to access food through agricultural revenues. We calculated net benefits for four key farm productions: maize, groundnut, tobacco, and horticulture. Maize net benefit was derived from production quantities converted to USD using mean market prices after seed costs. Groundnut production was estimated from biological nitrogen fixation calculations, accounting for shelling ratios and market prices minus seed costs. Total agricultural income was expressed as net revenue per farming capita.

3. Cooking energy (Utilization): Household firewood availability based on woody vegetation regeneration capacity.

This indicator quantifies firewood availability per household based on the landscape's woody vegetation regeneration capacity. We calculated sustainable annual firewood yield from woody vegetation using median Above-Ground Biomass values by land cover class and dry savannah woodland regeneration parameters. Net household firewood availability was expressed as the total sustainable woody biomass production divided by the number of households. This metric indicates whether the landscape can sustainably meet household energy demands, with higher values representing greater energy security.

4. Nutritional diversity (Utilization): Landscape capacity to provide diverse food groups across FAO dietary diversity categories.

This indicator assesses the landscape's capacity to provide essential food groups aligned with the FAO minimum dietary diversity framework (FAO, 2021). Each production system was evaluated for its contribution to specific food groups: maize cultivation for grains; legume cultivation for pulses; cattle production for milk and meat; and woodland for bushmeat and wild fruits. Each food group was scored as available if at least one production system could meaningfully contribute to that group, or unavailable otherwise. The composite nutritional diversity score represents the total number of food groups for which the landscape provides adequate production capacity, ranging from zero (no food groups available) to ten (all food groups available).

4.2. Simulation of individual indicators

4.2.1. Distribution of the individual indicators results

The ridge plots (figure 5) display the variability in agroecology and food security indicator performance across the sampled landscape units. The shape and spread of distributions reveal contrasting patterns of landscape performance. Several agroecology indicators exhibit right-skewed distributions with most landscapes achieving low performance (Recycling N and P, Biodiversity functional habitat), while others show broader, more uniform distributions across the performance gradient (Input use reduction, Local food system orientation, Economic diversification). Food security indicators demonstrate similarly diverse patterns, with Food self-sufficiency and On-farm income displaying relatively flat distributions across their range, while Cooking energy shows concentration at lower values and Nutrition diversity presents a more bell-shaped distribution centred around mid-range scores.

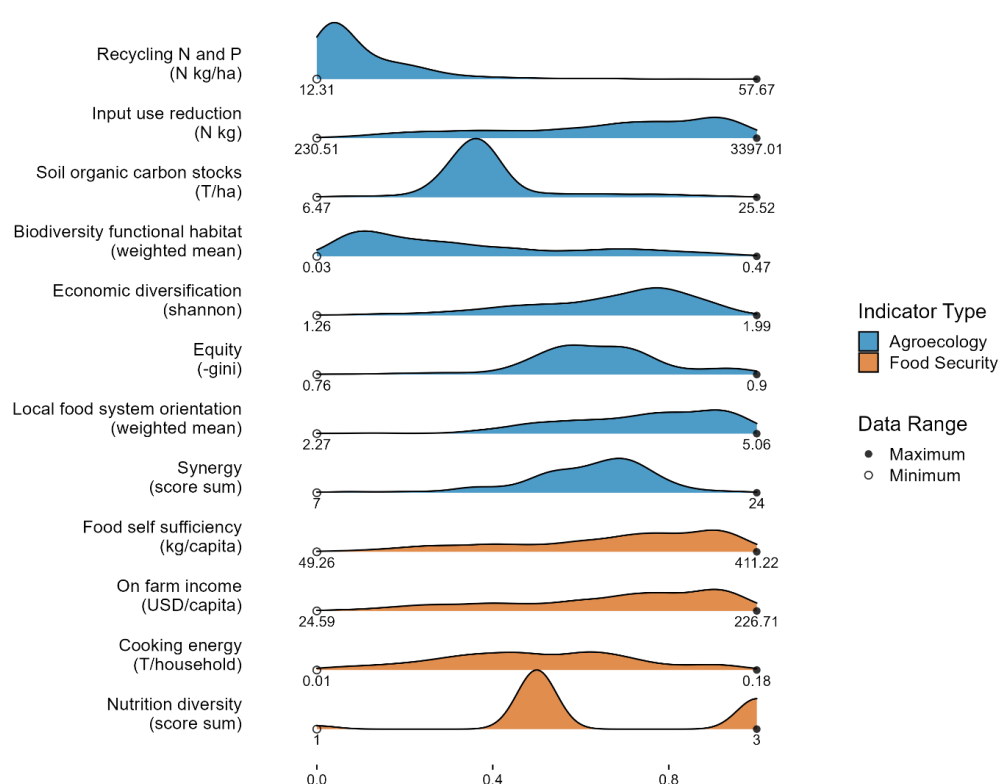


Figure 5. Distribution of the individual indicators results

4.2.2. Mapping of the individual indicators

Recycling and Input Use reduction indicators maps are presented in figure 6. Nitrogen recycling from manure and woodland litter ranged from 12 to 58 kg N/ha (mean: 17.0 ± 5.4 kg N/ha), while phosphorus recycling spanned 0.2 to 6.3 kg P/ha (mean: 0.77 ± 0.71 kg P/ha). Both nutrients exhibited nearly identical spatial distributions, reflecting their co-occurrence in organic amendments. The recycling indicator captured a nutrient concentration effect: extensive pastoral and woodland areas in low-cropland landscapes funneled organic inputs onto limited maize surfaces, yielding high per-hectare availability in the southeast, whereas cropland expansion toward the northwest diluted these resource pools. Conversely, biological nitrogen fixation from groundnut cultivation displayed the opposite spatial pattern, with higher

contributions in cropland-rich northwestern zones where legume cultivation area was greatest. This inverse relationship between recycling (favoring extensive pastoral mosaics in the southeast) and input reduction through BNF (favoring intensive cropland zones in the northwest) highlights contrasting pathways for nutrient provisioning across the agricultural landscape gradient.

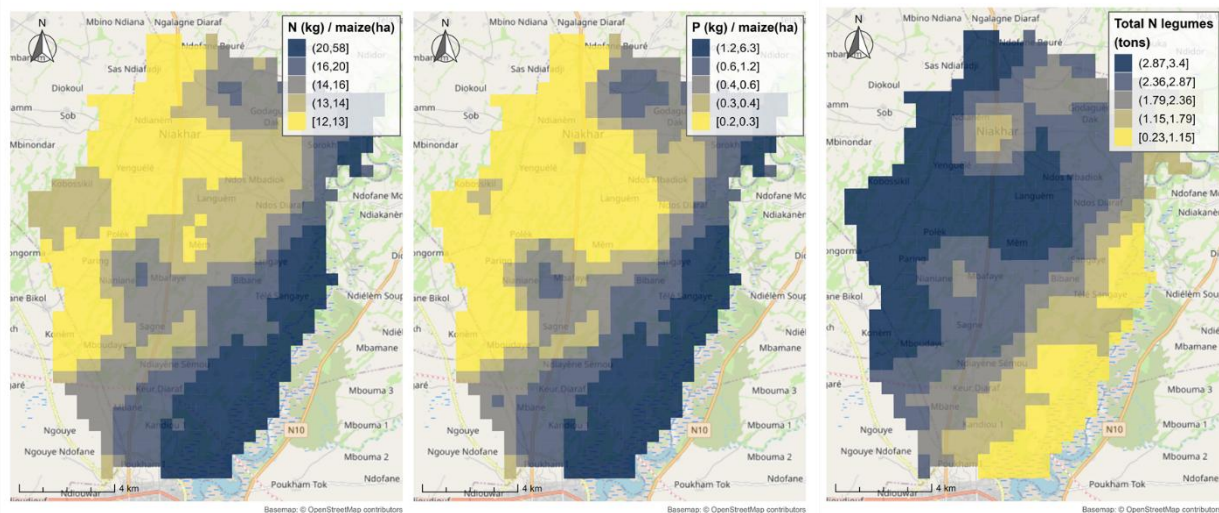


Figure 6. Agroecology indicators maps, Recycling N and P, Input use reduction.

Soil Health, Biodiversity, Connectivity indicators maps are presented in figure 7. Soil organic carbon stocks ranged from 6.5 to 25.5 t C/ha (mean: 14.0 ± 2.6 t C/ha), with highest values (>17 t C/ha) concentrated along the wetland corridor extending from the eastern to southeastern boundary. The biodiversity habitat indicator (0.03–0.47, mean: 0.18 ± 0.11) followed a similar spatial pattern, with higher scores in southeastern wetland-adjacent areas where natural vegetation persists, declining progressively toward the northwest along the cropland expansion gradient. Conversely, local food system orientation scores (2.3–5.1, mean: 4.3 ± 0.5) displayed the opposite distribution, reaching maximum values (>4.6) in northwestern cropland zones dominated by diversified food production systems, while declining in extensive pastoral landscapes and wetland peripheries.

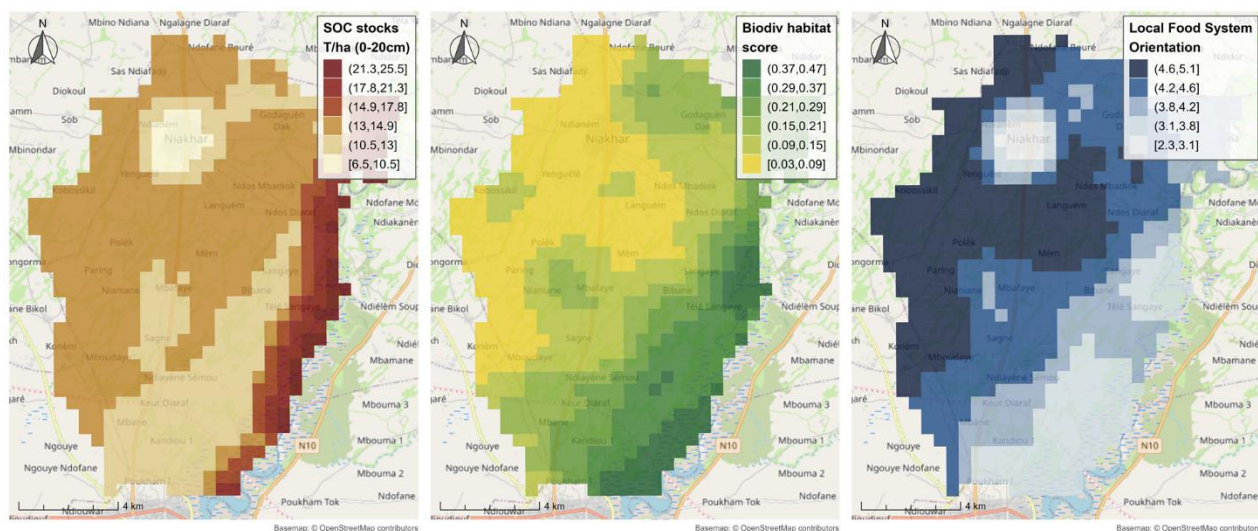


Figure 7. Agroecology indicators maps, Soil Health, Biodiversity, Connectivity

Economic diversification, Fairness and Synergy indicators maps are presented in figure 8. Economic diversification, measured via Shannon's diversity index ($1.3\text{--}2.0$, mean: 1.74 ± 0.14), displayed strong spatial variation with highest values (>1.7) concentrated in the northwestern cropland-dominated zones featuring diversified agricultural mosaics, while lowest scores (<1.5) occurred in southeastern peripheral areas where landscapes are more specialized toward extensive rangeland or wetland systems.

Landscape equity scores ($0.76\text{--}0.90$, mean: 0.85 ± 0.02) remained consistently high across the study area, indicating that current land-use configurations provide relatively balanced preference satisfaction among stakeholder groups. These preference weights were derived from surveys conducted in Zimbabwe, where stakeholders (livestock advisers, horticulture specialists, researchers, and farmers) expressed subtle sectoral preferences—for instance, livestock advisers weighted grasslands more heavily—but overall maintained balanced distributions across land uses. While direct transferability to the Senegalese context requires caution, we assume similar preference-function linkages exist where stakeholder groups prioritize landscapes supporting their dominant activities. Slightly lower equity scores ($0.76\text{--}0.83$) appeared in highly specialized landscapes (e.g., wetland-dominated southeastern peripheries).

The Synergy Indicator, quantifying multifunctional performance across all seven agroecological principles (theoretical range: $7\text{--}28$), yielded observed scores of $7\text{--}24$ (mean: 17.5 ± 2.5 , median: 18). Hotspots of high synergy (scores >19) emerged in southeastern pastoral-woodland mosaics where nutrient recycling, biodiversity habitat, and soil health converge, while coldspots (scores <14) dominated northwestern intensive cropland zones where trade-offs between productivity-oriented functions and environmental regulating services were most pronounced.

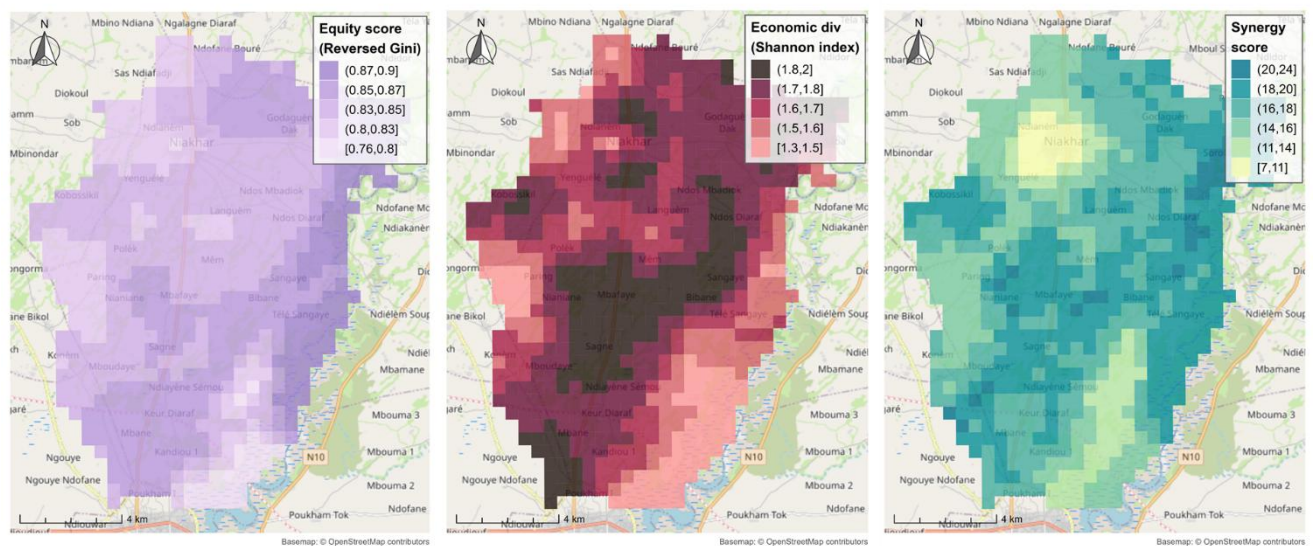


Figure 8. Agroecology indicators maps, Fairness, Economic diversification, Synergy

The Food and Nutrition Security Indicators for Availability and Access pillars are presented in figure 9. Food self-sufficiency ($49\text{--}411$ kg maize/farming capita/year, mean: 293 ± 85 kg) and on-farm income ($25\text{--}227$ USD/farming capita/year, mean: 160 ± 48 USD) displayed nearly identical spatial patterns, with highest values concentrated in northwestern and north-central cropland zones where nutrient availability supports intensive maize production. Since groundnut contributes minimally to total agricultural income compared to maize revenues, the income indicator essentially mirrors the maize production gradient across the landscape.

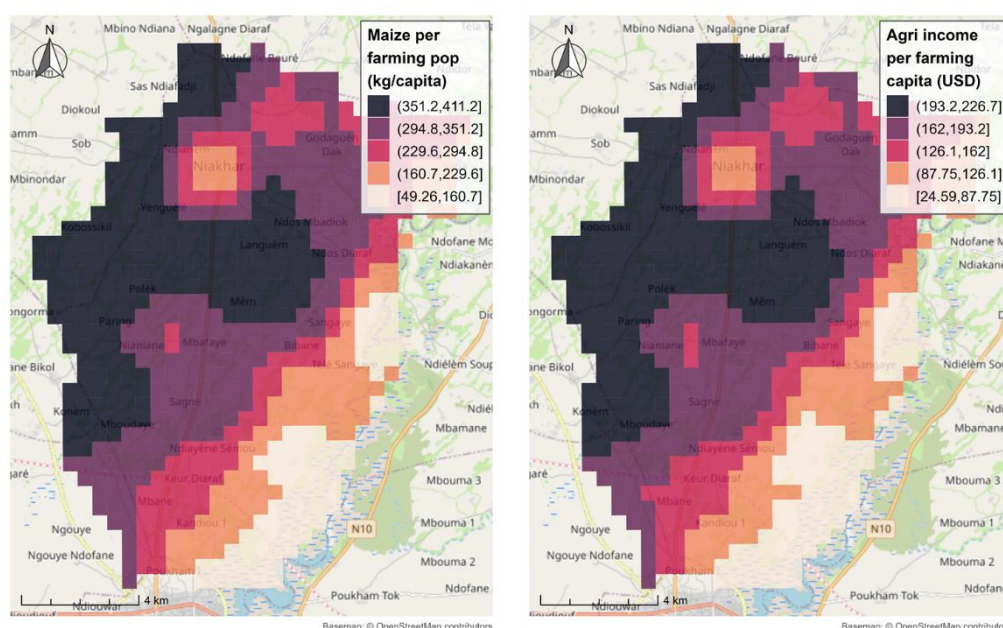


Figure 9. FSN indicators maps, Access, Availability

Food and Nutrition Security indicators maps related to Utilization and Nutrition diversity are presented in figure 10.

Cooking energy availability remained low across the study area ($0.01\text{--}0.18$ t wood/household/year, mean: 0.09 ± 0.04 t), reflecting severe wood scarcity in this agricultural landscape. Maximum sustainable yields (177 kg/household/year) derive solely from scattered trees within agricultural plots, representing less than 10% of the ~ 2 tons/household/year demand documented in Zimbabwe reference areas through focus group discussions.

Nutritional diversity scores ranged from 1 to 3 viable food group sources (mean: 2.3 ± 0.5), far below the FAO minimum dietary diversity threshold of 5 food groups. This assessment captured only maize (grains), groundnut (pulses), cattle (dairy/meat), and woodland resources (bushmeat/wild fruits), likely underestimating actual dietary diversity due to data limitations. The LULC classification did not distinguish horticultural areas that typically provide fruits and vegetables, and localized production systems (e.g., small livestock, homestead gardens) were not captured at the landscape scale, suggesting these results reflect incomplete rather than actual food diversity capacity of the landscape.

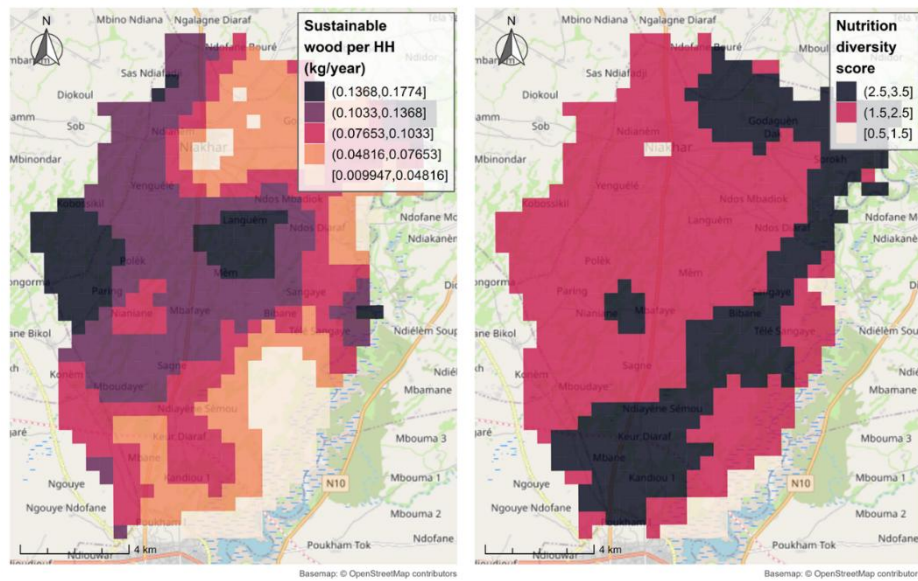


Figure 10. FSN indicators maps, Utilization, Nutrition.

5. Exploring the link between agroecology and food security at landscape scale

5.1 Method to Aggregate indicators

Two composite indicators were constructed to provide an overall view of landscape performance: one aggregating the eight agroecology indicators and one aggregating the four FSN indicators. Both use geometric mean aggregation of normalized individual indicator values, preventing compensation between dimensions and ensuring balanced achievement across all components.

5.2 Results

The composite indicators map for agroecology and FSN are presented in figure 11. The agroecology composite score (0.04–0.66, mean: 0.42 ± 0.09) revealed pronounced spatial heterogeneity across the landscape. Lowest-performing areas (scores <0.32 , orange zones) concentrated in northwestern and western cropland-dominated zones around Niakhar town and along the central agricultural corridor, where intensive cultivation generates trade-offs between productivity-oriented functions and environmental regulating services. Conversely, highest scores (>0.47 , blue zones) emerged in southeastern and northeastern peripheral landscapes featuring agro-pastoral mosaics that support synergies across nutrient cycling, biodiversity habitat, and soil health dimensions.

The food and nutrition security composite score (0.02–0.85, mean: 0.60 ± 0.17) displayed a nearly inverse spatial pattern. Highest-performing landscapes (scores >0.60) concentrated in northwestern and north-central cropland zones where maize production capacity and agricultural income generation support food availability and access. Lowest scores (<0.34) occurred in southeastern extensive pastoral systems and northeastern wetland peripheries where limited crop production constrains food self-sufficiency despite higher nutritional diversity from livestock-based systems.

This divergence between the mapped composite scores highlights the tension between agricultural intensification for food production and multifunctional landscape management for agroecological sustainability. High-performing agroecology landscapes exhibit lower FSN scores due to reduced crop production potential, while high-performing FSN landscapes face environmental trade-offs from intensive agricultural land use.

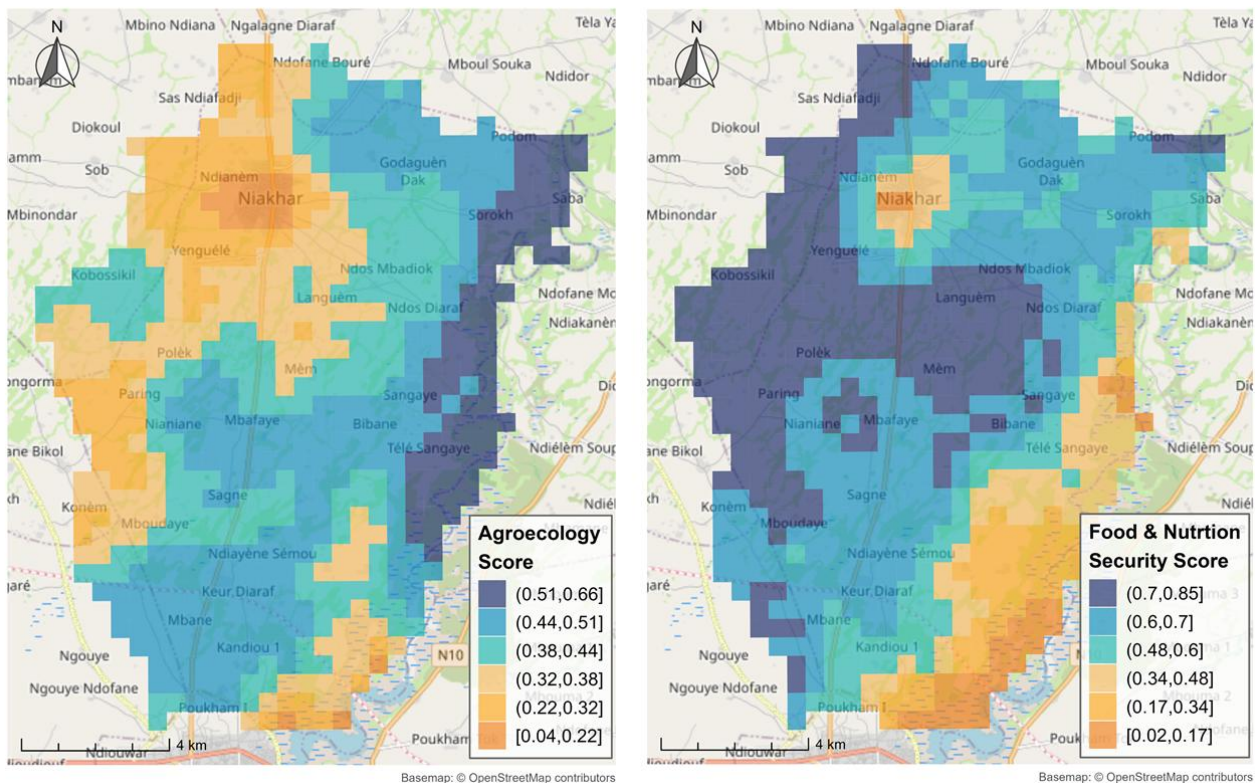


Figure 11. Aggregated indicators maps for Agroecology and Food and Nutrition Security

This trade-off is further illustrated in the relationship between both composite scores (Figure 11). The scatterplot reveals a weak but significant negative correlation (Pearson's $r = -0.082$, $p = 0.029$), with a dominant cluster of landscapes (57.5%, $n=409$) achieving high FSN performance (0.6–0.85). This concentration represents the north-western and central cropland zones where agricultural intensification delivers more food security outcomes without complete ecological collapse, benefiting from residual nutrient cycling and habitat provision from scattered trees (mean 2.9% shrub vegetation) and crop-livestock integration facilitated by bare soils and grasslands (mean 18.4%). These landscapes average 76% cropland coverage, reflecting intensive agricultural use balanced by retained ecological infrastructure.

Conversely, landscapes with high AE scores (>0.5) rarely exceed moderate FSN performance. Only 6.3% of landscapes ($n=45$) achieve balanced high performance in both dimensions (both scores >0.5), and truly "win-win" landscapes (AE >0.5 AND FSN >0.7) remain exceptionally rare (0.56%, $n=4$). These four outlier landscapes, clustered in the eastern portion of the study area (x : 356–357 km), exhibit distinctive compositional features: moderate cropland coverage (42–54%), elevated bare soil-grassland mosaics (21–30%), and slightly higher shrub vegetation presence (3.3–4.7%).

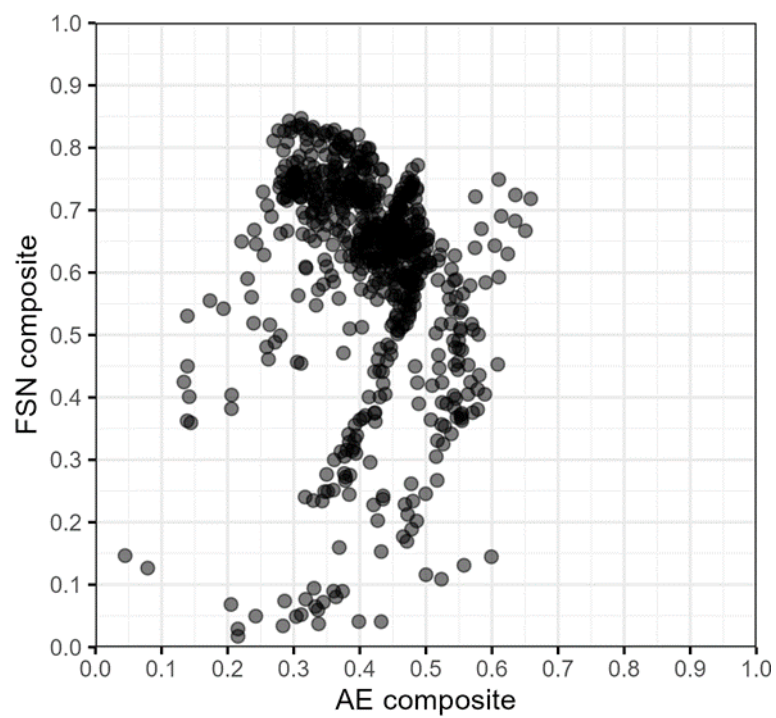


Figure 12. Relationship between agroecology and food security composite indicators across sampled landscapes

6. Conclusion

This report presents an initial exploratory assessment of the potential for using the methodology developed by Coquereau (2026) to estimate agroecology and food security indicators at the landscape scale in the commune of Niakhar. The maps and indicators generated in this report have not yet been calibrated, meaning that the results presented serve as a demonstration and do not represent actual measured values.

Nevertheless, this report provides insight into emerging trends within the Niakhar area. It highlights the existence of landscape heterogeneity, leading to theoretically variable degrees of agroecology and food security. The indicators were calculated based on strong assumptions of landscape autonomy and self-sufficiency, without taking into account the socio-economic constraints faced by farmers. This approach makes it possible to explore a “theoretical” level of agroecology and food security based solely on land-use composition, but it does not reflect real-world performance.

Comparing these theoretical results with actual field conditions could help inform discussions on the potential possibilities of landscape management to simultaneously improve food production and ecosystem health.

As this initial report is only a proof of concept, further in-depth work will now be required to redefine, together with stakeholders in Niakhar, indicators linked to the different principles that are meaningful in the context of the Senegalese groundnut basin. A substantial data collection effort in the area should then make it possible to calibrate the models for this specific context. The maps subsequently produced can be discussed with local stakeholders to explore landscape planning options and move toward greater sustainability.

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Towards assessment of the performances of multifunctional agroecology landscapes

This report explores the application of an innovative methodology for assessing agroecological and food security performance at the landscape scale in the municipality of Niakhar (Senegal). Based on detailed land use mapping (Dynamic World – Sentinel-2) and systematic spatial sampling, eight agroecology indicators and four food and nutrition security indicators were simulated. The results highlight significant spatial heterogeneity. The intensive agricultural areas in the northwest perform better in terms of food security (production and income), while the agro-pastoral mosaics in the southeast score higher in terms of agroecology (nutrient recycling, biodiversity, soil health). There appears to be tension between productive intensification and ecological multifunctionality. Win-win situations remain rare. The study constitutes an uncalibrated proof of concept based on simplifying assumptions. It opens up prospects for co-constructing contextualized indicators and orienting territorial planning towards more sustainable multifunctional agroecological landscapes.

