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Multi-criteria assessment of the environmental sustainability of agroecosystems in the agricultural basin of northern Benin based on satellite data

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Plan

- Introduction
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Assessing Environmental Sustainability in Agricultural Landscapes

Growing agricultural products demand *(Lanz et al., 2018)* → Agricultural intensification, including a 25% expansion of agricultural land in developing countries *(Balmford et al., 2005)*

Agricultural intensification → Biodiversity loss, ecosystem degradation, environmental externalities difficult to monitor spatially *(Dirzo and Raven 2003)*

Current indicators (e.g., hemeroby index) partially capture human impacts *(Sukopp 1976)* → Need for integrated spatial assessment negative environmental externalities associated with agriculture and its intensification *(Hunt et al. 2019, Weiss et al. 2020)*

Building on the hemeroby concept *(Zhou et al. 2018, Wang et al. 2023)* , this study proposes a novel approach for multicriteria assessment of environmental sustainability in rural landscape based on satellite data: **The Landscape Environmental Sustainability Index (LESI)**.

Study area

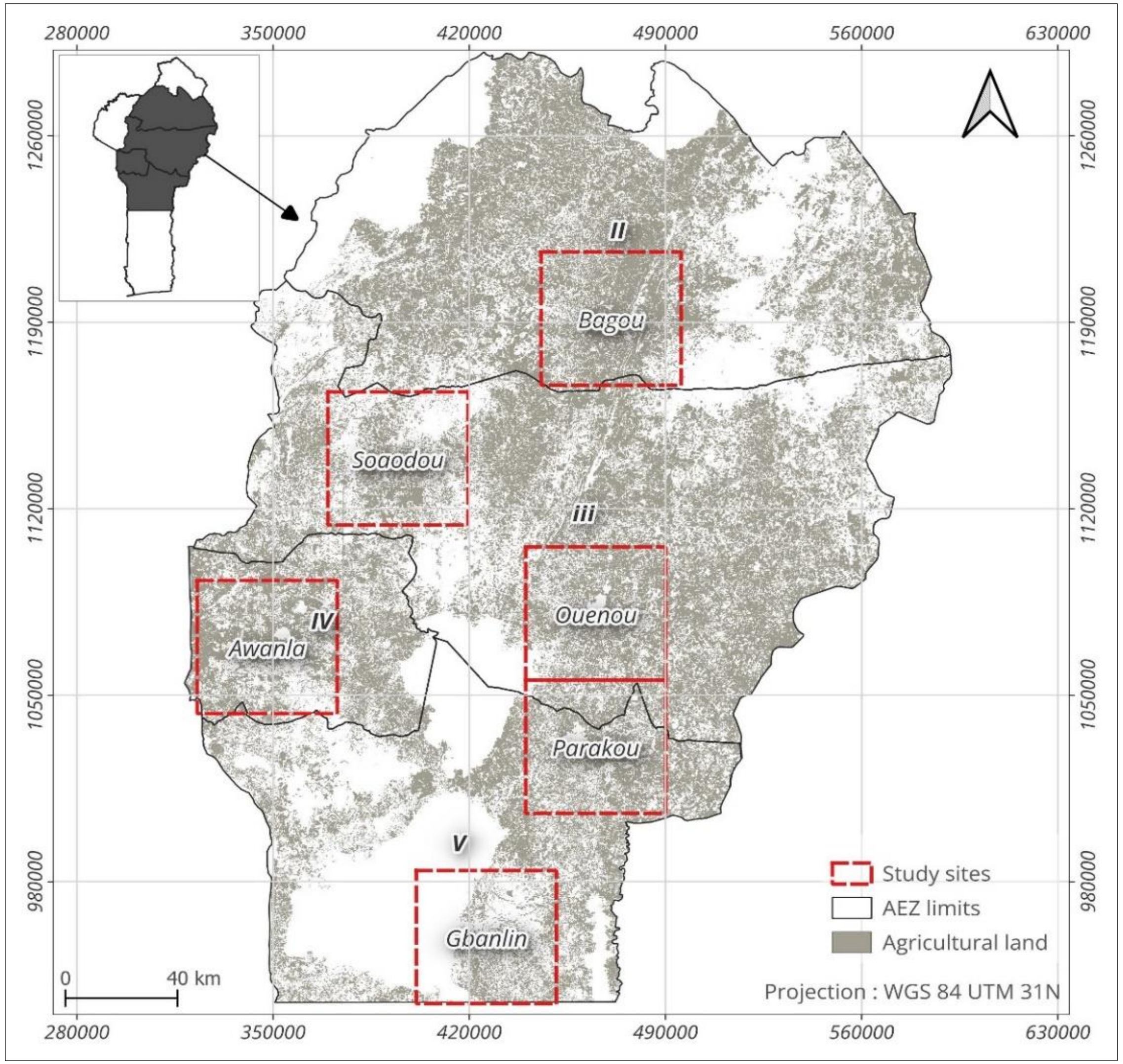


Fig. 1. Study area.

- 65,926 km² agricultural basin
- 4 agroecological zones (600–1400 mm rainfall)
- Dominant cash and food crops *(Chadare et al., 2018)*
- High levels of fertilizer and pesticide use *(PAPA/INRAB, 2017)*
- Dominant ferruginous tropical soils *(Aholoukpè et al., 2020)*

Data source

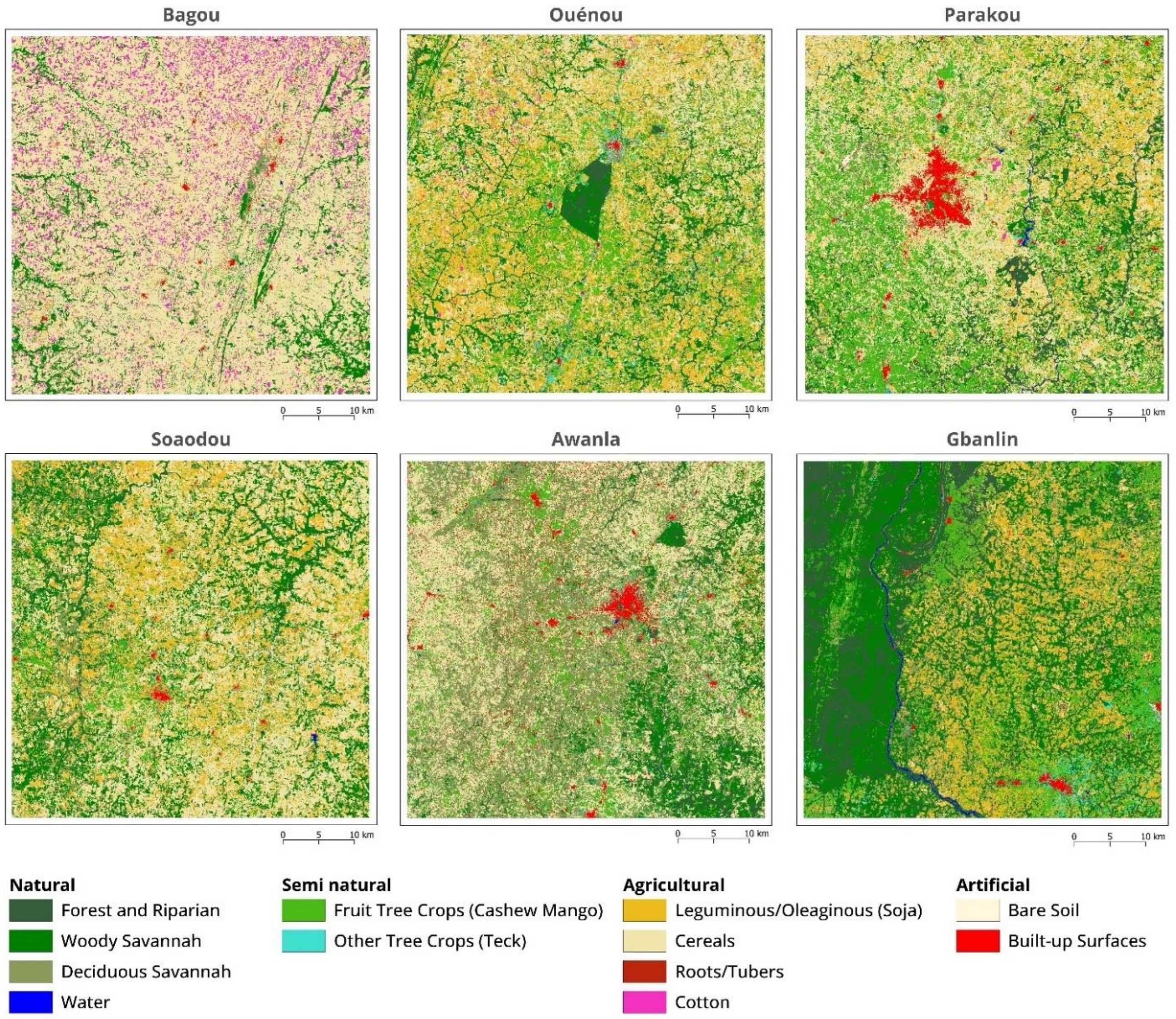


Fig. 2. Types of land cover in the 6 study sites.

- Satellite data used : SPOT 6/7 (1.5 m)Sentinel-2 time series (10 m)SRTM DEM (30 m)
- Field-based reference database; Object-based approach; Random Forest algorithm *(Stéphane et al. 2020)*
- 12-class land cover maps (2023 & 2024) Produced under OBSYDYA project
- Overall accuracy: 64–76%
- Fivefold cross-validation

LESI construction

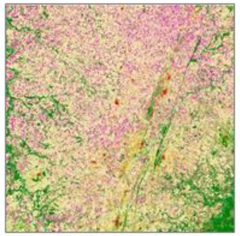
Land Cover map with 12 classes

Natural
- Forest and Riparian
- Woody Savannah
- Deciduous Savannah
- Water

Semi-natural
- Fruit Tree Crops (Cashew Mango)
- Other Tree Crops (Teck)

Agricultural
- Leguminous/Oleaginous (Soy)
- Cereals
- Roots/Tubers
- Cotton

Artificial
- Bare Soil
- Built-up Surfaces



50 km
Bagou site

Criteria group	9 criteria related to negative externalities Evaluated with scores on a 1 (null intensity) to 7 (maximal intensity) scale based on a literature review	Criteria weight (w_c)
Biosphere	Vegetation degradation	0.125
	Pressure on animal and vegetal biodiversity	0.125
Atmosphere	Greenhouse gases emissions	0.125
	Air pollution	0.125
Pedosphere	Soil erosion	0.083
	Degradation of soil productivity and characteristics	0.083
	Soil pollution	0.083
Hydrosphere	Water pollution	0.125
	Decrease of water resources available for man and ecosystems	0.125

Computation of **Human Disturbance Coefficient (HDC)** : each Land Cover class is evaluated according to 9 weighted criteria

$$\mathbf{HDC} = \sum_{i=1}^{9} w_{ci} * \text{Score}_{ci}$$

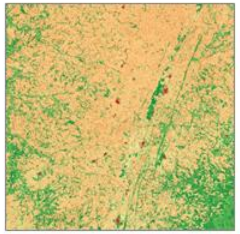
Human Disturbance Coefficient (HDC) map
Scale 1–7
3 symbologies

Computation of **Landscape Environmental Sustainability Index (LESI)** : aggregation of HDC by landscape cell of 1 km² by a surface weighted sum

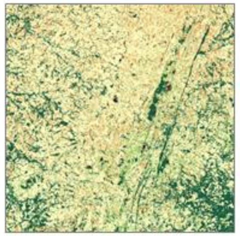
$$\mathbf{LESI} = \sum_{i=1}^{n} \frac{Si}{S} * \text{HDC}_i$$

1 landscape cell of HDC of 1 km²

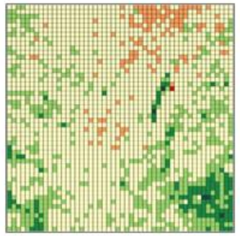
Landscape Environmental Sustainability Index (LESI) map
Scale 1–7
2 symbologies

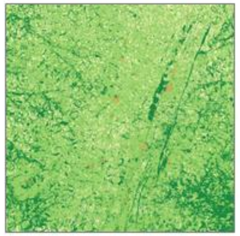


Scale of exact HDC values of land cover classes
- 1,75 (Deciduous savannah)
- 2 (Forest and riparian/Woody savannah)
- 2,25 (Water)
- 2,66 (Tree crops)
- 2,96 (Leguminous/Oleaginous (Soja))
- 3,21 (Roots/Tubers)
- 3,41 (Cereals)
- 3,95 (Cotton)
- 4,29 (Bare Soil)
- 4,79 (Built-up Surfaces)



Scale from 1.5 to 5 by 0.5
- [1.5 - 2.0]
-]2.0 - 2.5]
-]2.5 - 3.0]
-]3.0 - 3.5]
-]3.5 - 4.0]
-]4.0 - 4.5]
-]4.5 - 5.0]

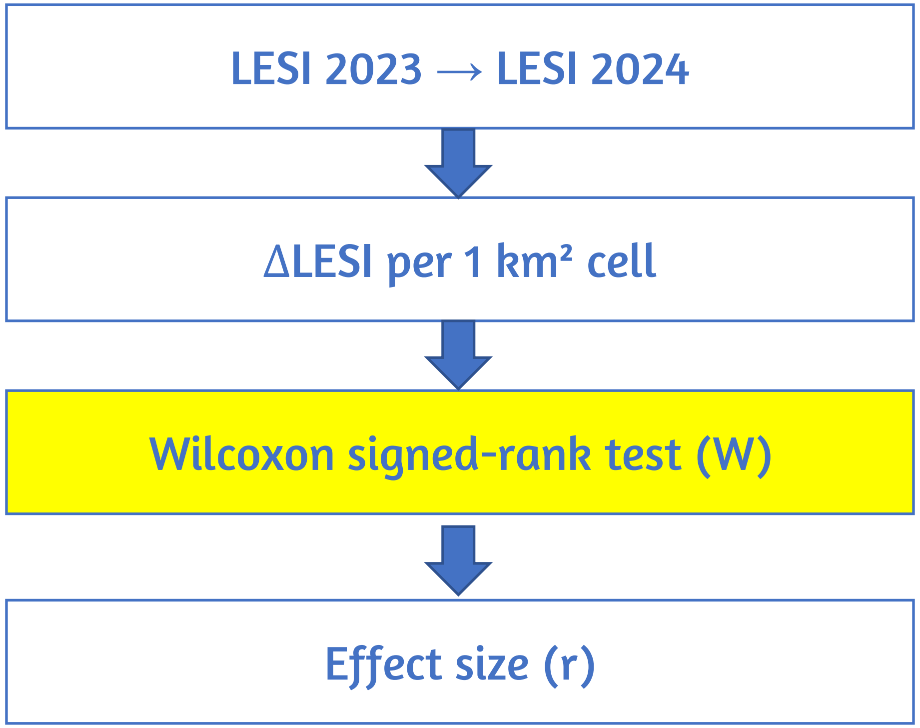




Scale from 1 to 7 by 1
- [1.0 - 1.5]
-]1.5 - 2.5]
-]2.5 - 3.5]
-]3.5 - 4.5]
-]4.5 - 5.5]
-]5.5 - 6.5]
-]6.5 - 7.0]

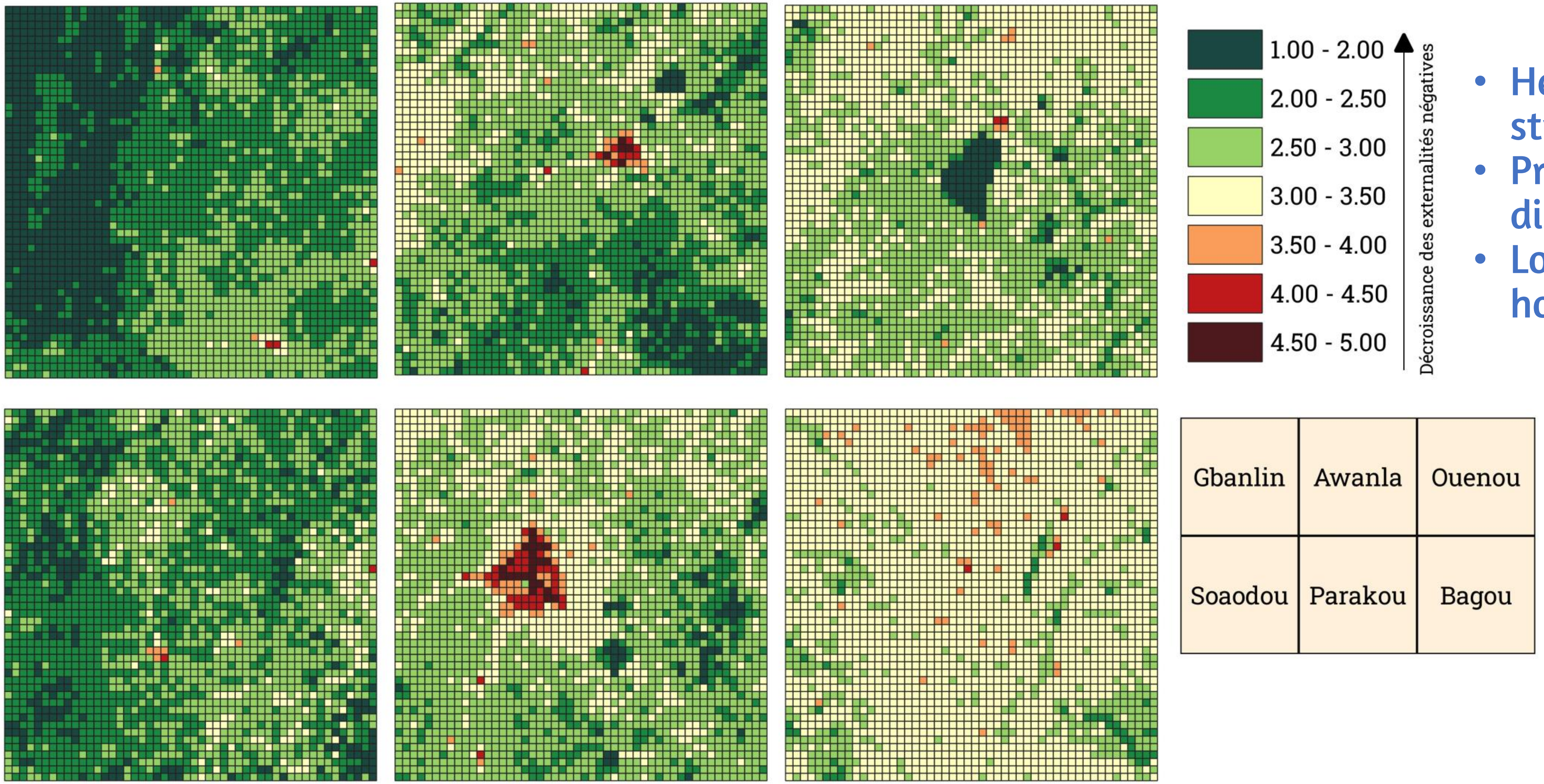
Fig. 3. Methodological framework for computing LESI.

Temporal Sensitivity Analysis of LESI (2023–2024)



- Cell-by-cell comparison (1 km²)
- ΔLESI calculation
- Wilcoxon signed-rank test *(Okoye and Hosseini 2024)*
- Effect size estimation

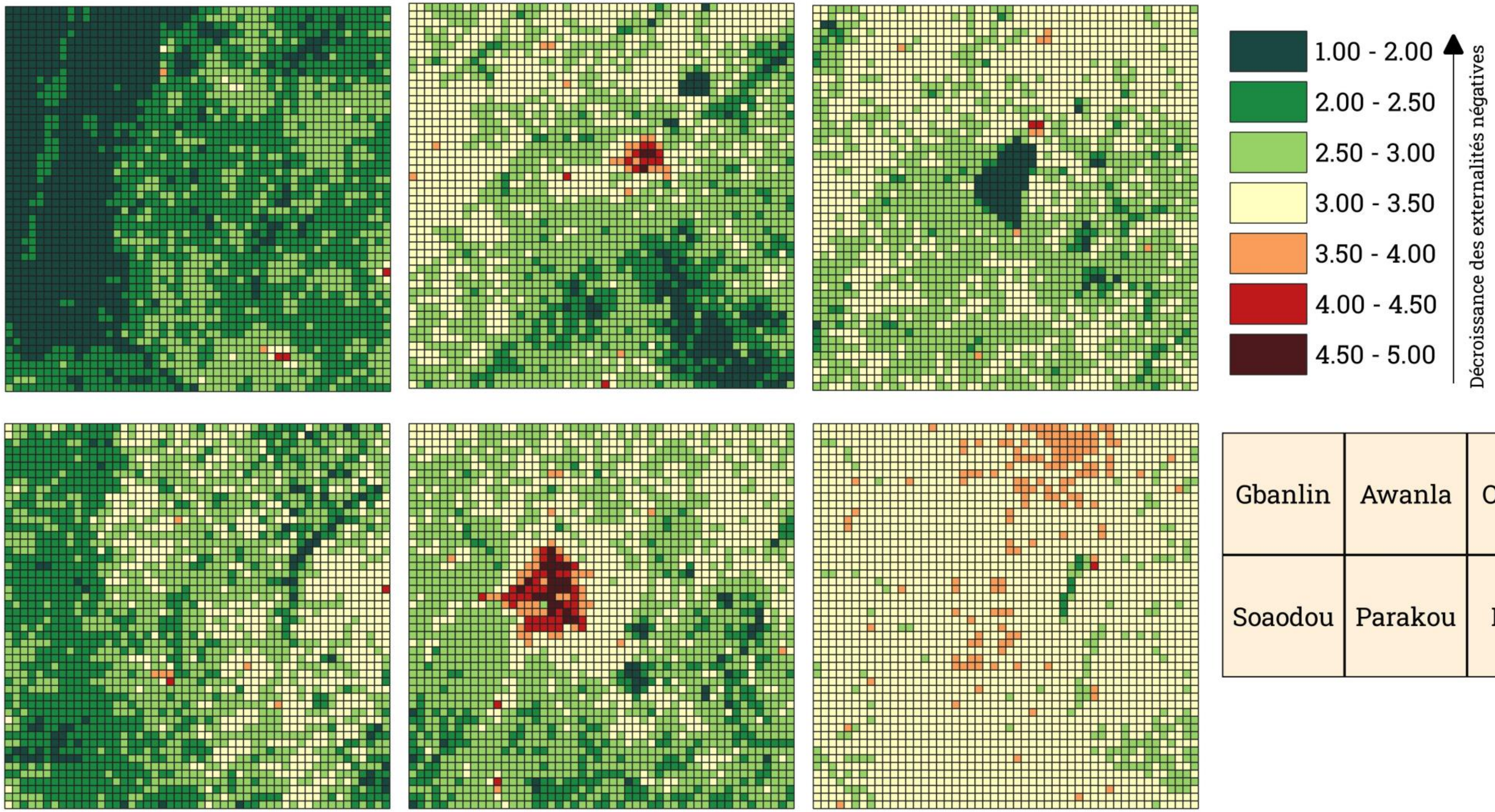
LESI 2023



- Heterogeneous spatial structure
- Predominantly low disturbance areas
- Localized high-pressure hotspots

Fig. 4. LESI 2023.

LESI 2024

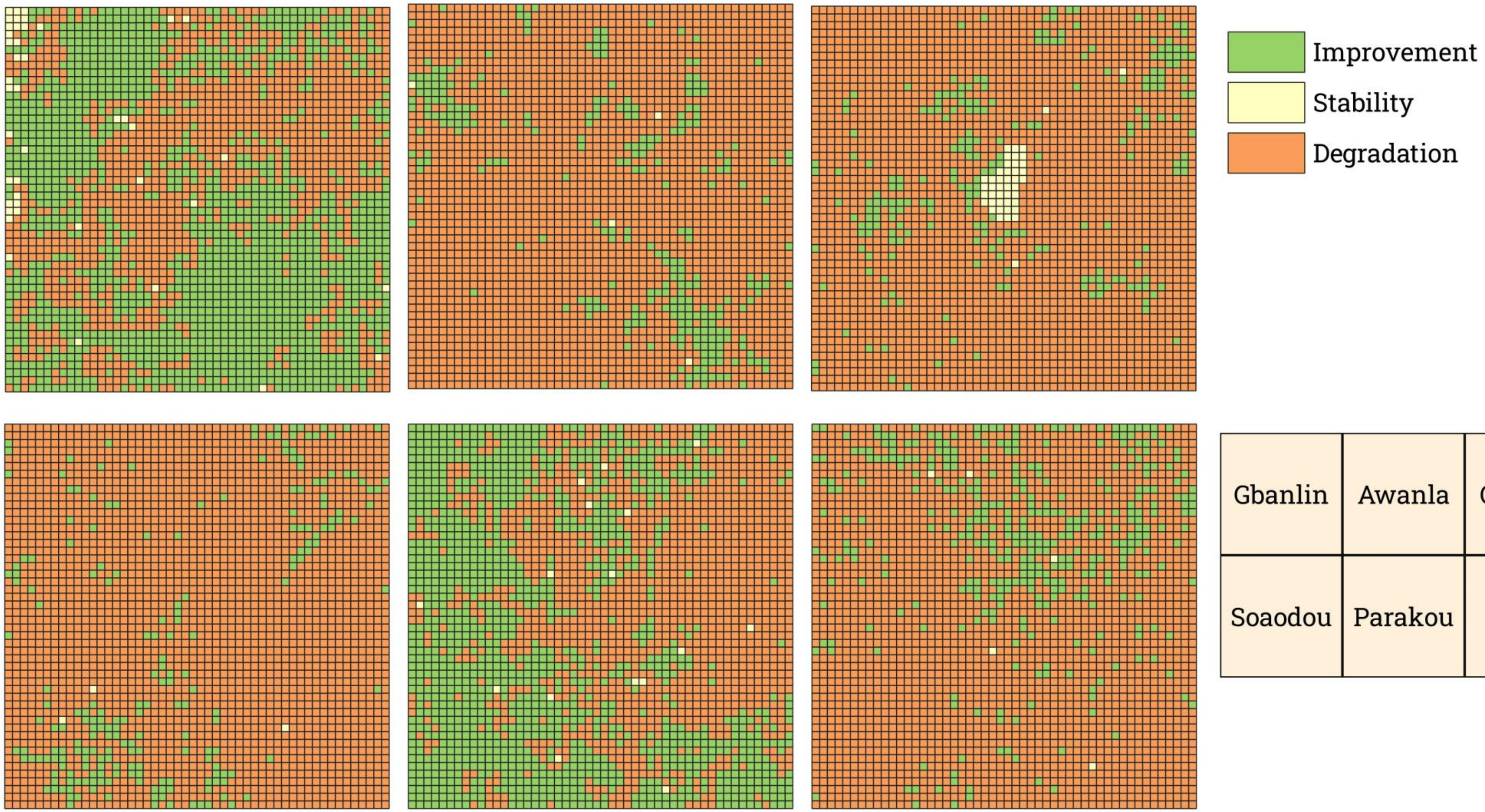


Gbanlin	Awanla	Ouenou
Soaodou	Parakou	Bagou

- Overall spatial pattern maintained
- Local expansion of disturbed areas
- Persistent inter-site variability

Fig. 5. LESI 2024.

ΔLESI (2024–2023)

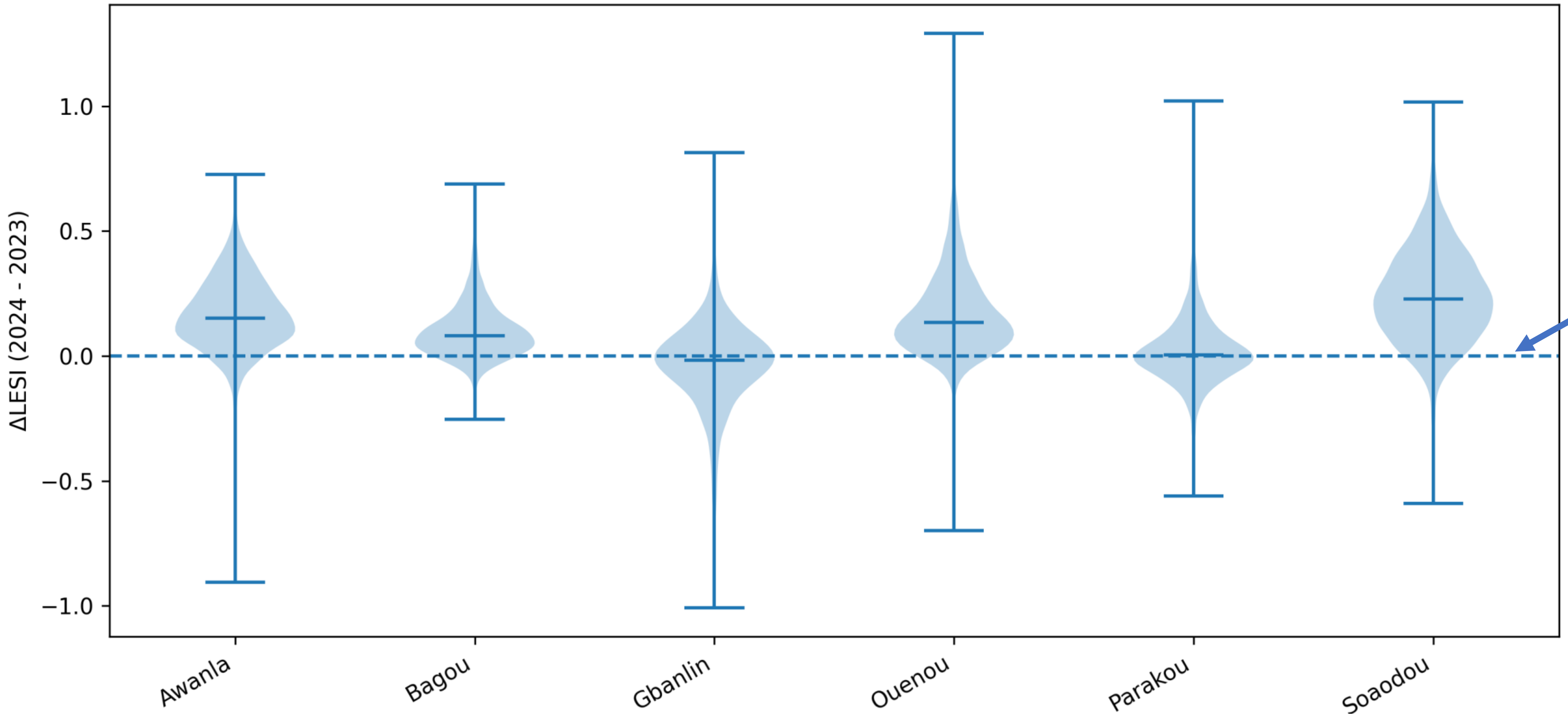


Gbanlin	Awanla	Ouenou
Soaodou	Parakou	Bagou

- Predominant degradation trend
- Localized improvements
- Confirmed temporal sensitivity

Fig. 6. LESI 2024.

Distribution of LESI Changes by Site



Dashed line
= no change

Fig. 7. LESI changes by site.

- ΔLESI distributions centered near zero
- Slight positive shift in several sites
- High intra-site variability
- Coexistence of improvement and degradation

Distribution of LESI Changes by Site

Site	Median ΔLESI	IQR ΔLESI	% ΔLESI>0 (Degradation)	% ΔLESI<0 (Improvement)	% ΔLESI=0 (Stability)	Wilcoxon test (W)	r (Effect size)
Awanla	0.152	0.186	88,92%	10,92%	0,16%	151724.0*	0.782**
Bagou	0.081	0.124	85,24%	14,56%	0,20%	203477.0*	0.753**
Gbanlin	-0.018	0.177	42,68%	55,60%	1,72%	1201249.0*	0.177*
Ouenou	0.135	0.195	89,24%	9,00%	1,76%	105278.0*	0.806**
Parakou	0.003	0.133	51,32%	48,04%	0,64%	1396562.5*	0.082
Soaodou	0.227	0.250	91,24%	8,64%	0,12%	104215.0*	0.808**

Table 1. Wilcoxon test results.

*In the table, * indicates statistical significance at the 1% level for the Wilcoxon test, while effect size is interpreted as weak (*) or strong (**)*

- Significant LESI changes detected in several sites + Predominantly high effect sizes
  → Confirms LESI temporal sensitivity

Interpretation of Environmental Dynamics

- Relative stability of LESI values between 2023 and 2024
- Strong spatial heterogeneity across landscape cells
- Predominant tendency toward increased anthropogenic pressure
- Local coexistence of improvement and degradation patterns

Methodological Implications and Study Limits

- LESI effectively detects short-term environmental changes
- Multicriteria framework integrating negatives externalities on hydrosphere, pedosphere, atmosphere and biosphere
- Potential tool for spatial monitoring of agricultural sustainability
- Results depend on land-cover data quality and weighting assumptions

Conclusion

- The LESI provides an integrated assessment of environmental sustainability in agricultural landscapes.
- Spatial analyses reveal heterogeneous but generally moderate environmental changes between 2023 and 2024.
- The index demonstrates sensitivity to short-term land-use dynamics.
- LESI offers a scalable tool for monitoring environmental sustainability using satellite data.

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Thank you for your attention

Questions

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