Supplementary material
Social–Ecological Archetypes of Land Degradation in the Nigerian Guinea Savannah: Insights for Sustainable Land Management
Ademola A. Adenle and Chinwe Ifejika Speranza

1.0 Correlations between drivers of land-degradation archetypes in the NGS

Figure S1. Correlation between the selected drivers of land degradation archetypes. Values and shade of intensities represent Spearman rank correlation coefficients between drivers. Negative correlations are shaded red; positive correlations are shaded green. The value and strength of the correlation is indicated by green or redcolour saturation, with perfect positive and perfect negative relationship spreading between 1 and -1 respectively. Many drivers did not correlate highly with one another (Figure S1), which shows their independence and a lack of multicollinearity. Taken together, most drivers have correlation values between 0.1 to 0.5 or –0.1 and –0.5, signifying a weak positive or weak negative relationship, or no relationship.

Figure S1: Correlation matrix between the selected drivers of land degradation archetypes.

Drivers and labels: Population density—Population_Den; elevation—Elevation; bulk density—Bulk-Den; distance to major town—Dis_town; slope—Slope; distance to major road—Dis_road; poverty—Poverty; male literacy—Literacy_M; female literacy—Literacy_F; fire occurrence density—Fire-Den; protected area—Protected_Area; livestock grazing intensity—Livestock_Den.

2.0 Training for the Self-Organizing Map (SOM)

In Figure S2, the evolution of the self-organized map shows that the stabilization for developing the archetypes occurred twice, first at the beginning of the iteration and finally at about 43 iteration steps for the neurons. Note that this final training process was determined after several maps size combinations for the dataset, which finally indicates the point of convergence with good quality of the clusters.

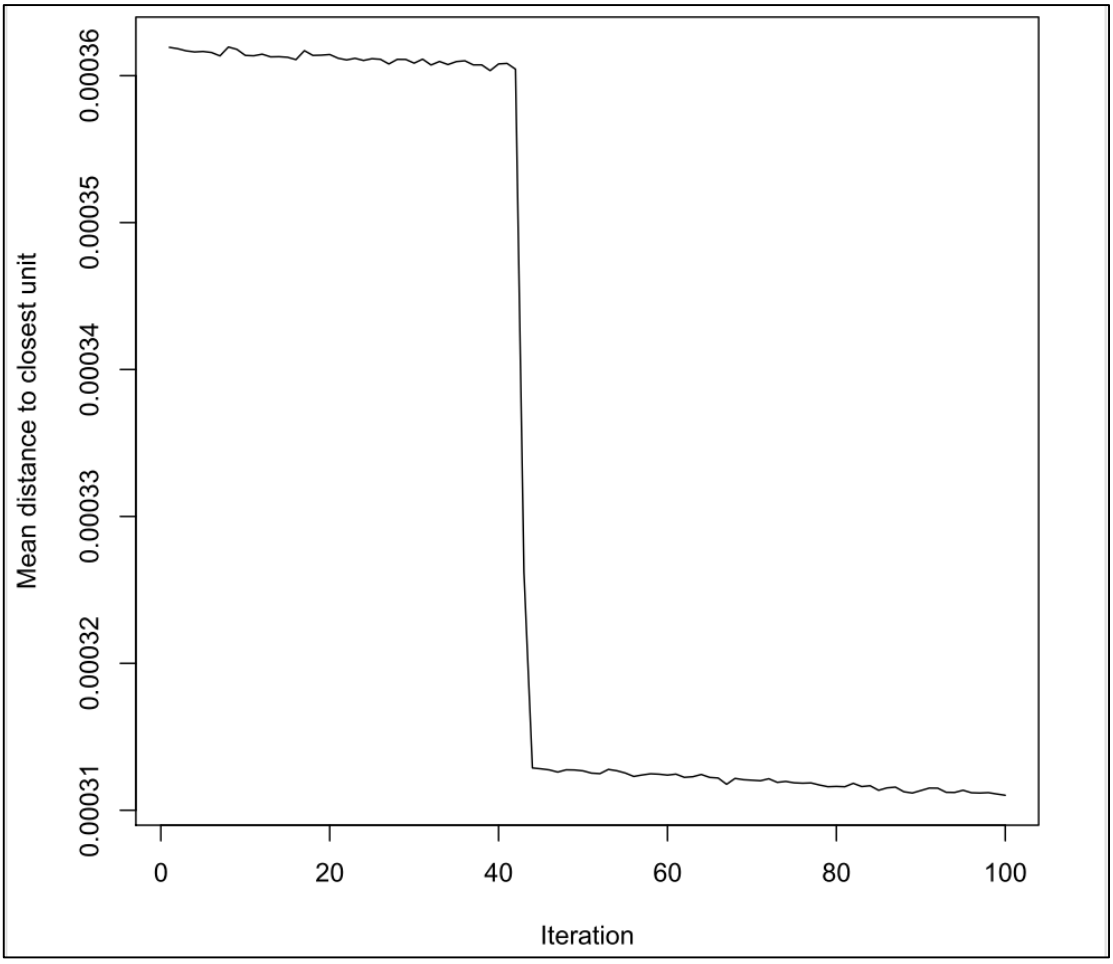

Figure S2: Training process for determining the nine cluster separations that are suitable for the land-degradation archetypes.

.

3.0 SOM Codes Plot

From the plot, the weight vectors of the nodes, which are also considered the codes of the cluster, is shown in Figure S3. The plot in each node indicates the aggregated profile of each neuron as synthesized by the magnitude of the selectecd drivers of land degradation after the datasets have been normalized.

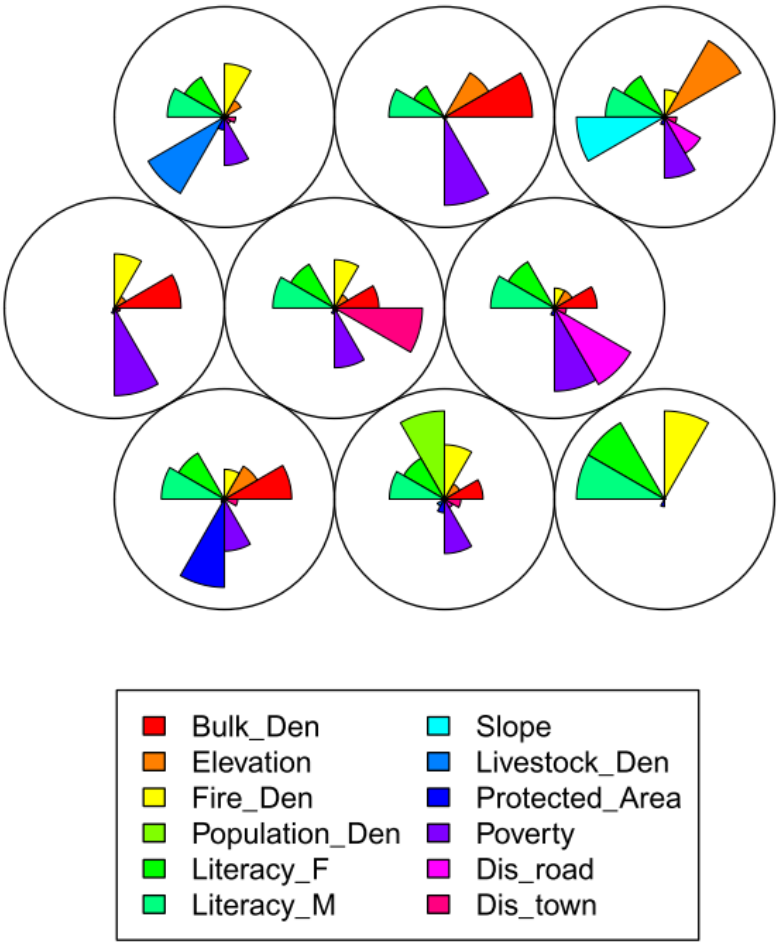

Figure. S3 : The plot showing the aggregated profile of each neuron as synthesized by the selected drivers of land degradation (3-by-3 mapping of the driver data).

Drivers and labels: Population density—Population_Den; elevation—Elevation; bulk density—Bulk-Den; distance to major town—Dis_town; slope—Slope; distance to major road—Dis_road; poverty—Poverty; male literacy—Literacy_M; female literacy—Literacy_F; fire occurrence density—Fire-Den; protected area—Protected_Area; livestock grazing intensity—Livestock_Den.

4.0 SOM Quality

Figure S4 shows the quality of the nine clusters; it shows the mean distance of the clusters to the units. A codebook is the best technical description and arrangement of the data that was collected for organizing the drivers cluster (Breard, 2017). Darker color ranges represent smaller mean distance while lighter color represents smaller mean distances. The larger the distances, the poorer the object representation in the codebook; and the smaller the distances, the better object representation in the codebook vector (Asan & Ercan, 2012). In Figure S4, six clusters (in deep red) have small distances, while the remaining three (in two light red, and one light yellow circles) have larger distances.

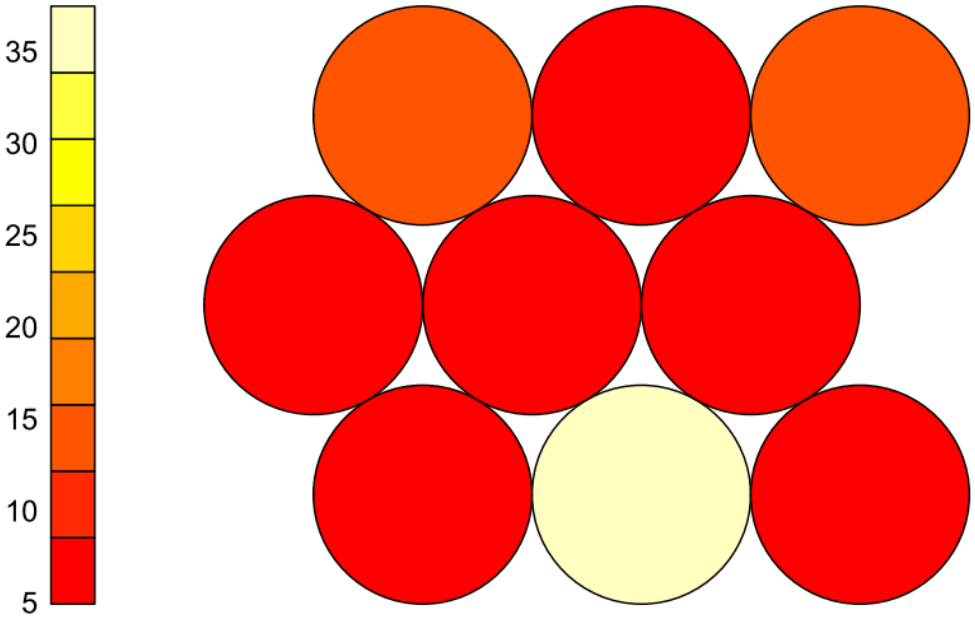

Figure S4: Quality of the nine clusters in the codebook.

5.0 SOM Neighbor Distances

Figure S5 shows the neighbor distances between the neurons for the clusters, it is also considered as the U-matrix plot. It shows natural boundaries, i.e the similarities and dissimilarities between the neurons of the clusters (Breard, 2017). The smaller the distance between the nodes of the cluster, the more the similarities; while the larger the distance, the more the differences between the cluster nodes (Asan & Ercan, 2012). As in the quality illustration (Figure S4), darker color ranges represent smaller distances, while lighter colors represent large distances. In Figure S5, six clusters (in deep red) are in close promixity, while the remaining three (light red, light yellow, and orange) have larger distances between them.

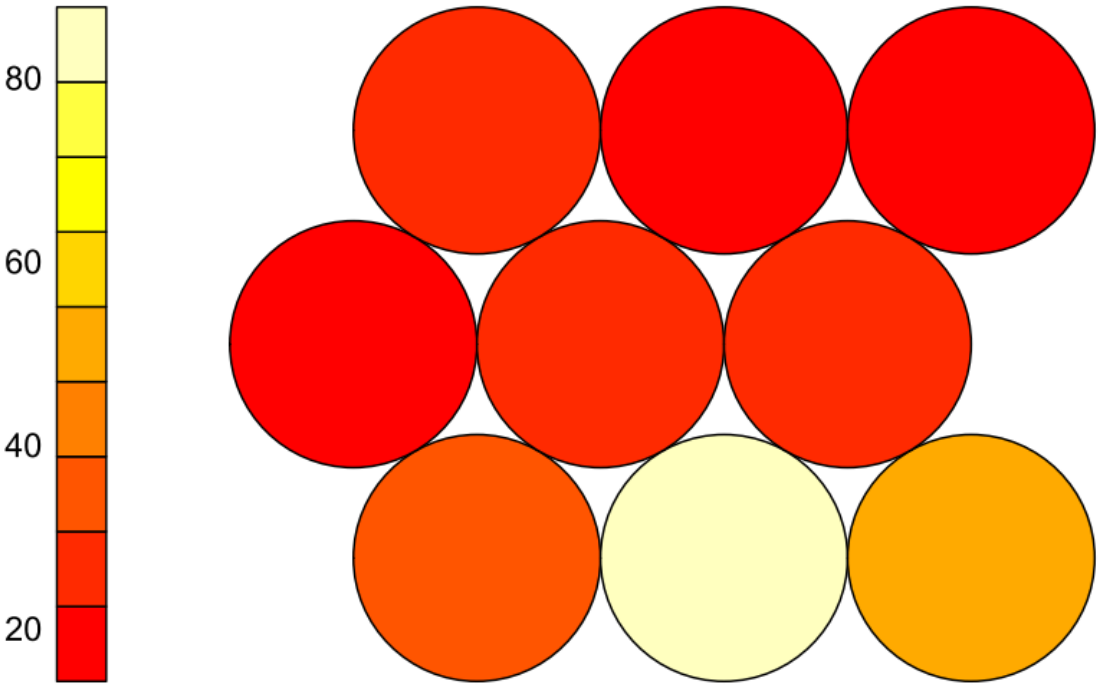

Figure S5: Neighbor distances between the neurons for the clusters.

6.0 Detailed description of archetypes based on state administrative units and land degradation status (See manuscript for relevant figures and tables)

NGSA 1: Archetype dominated by protected areas

This archetype (Figure 5; green in Figure 6) is the smallest of the LD driver cluster, covering 3.3% of the study area, with land-use practices (in particular protected areas) accounting for 70% dominance (Table 2; Figure 5). It occurs mainly in 11 out of the 25 states (Table S2; Figure 8) and is found in areas with many protected areas, moderately characterized by elevated terrain along with high bulk density (Figure 5), but with other sub-drivers such as fire and distance to major roads. The cluster also covers the least areas of degraded land, i.e 3.4%, 3.4%, and 2.8% of degraded, stable, and improved areas, respectively (Figure 7).

NGSA 2: Archetype dominated by very high-density population

In NGSA 2 (Figure 5; grey in Figure 6) socio-economic drivers (in particular, very high population density) dominate (84%) (Figure 5) and cover 15.3% of the NGS (Table 2) and with a minimal influence from livestock and fire activities. NGSA 2 exists as patches in 19 out of the 25 states, but dominates in southern NGS states such as the Federal Capital Territory (FCT), Kwara, Kogi, Benue, Plateau and Enugu (Table S2, Figures 6 and 8). It comprises 14.7%, 15.9%, and 15.2% degraded, stable, and improved areas, respectively (Figure. 7).

NGSA 3: Archetype dominated by moderately high information/knowledge access: NGSA 3 (Figure 5; blue in Figure 6), is the third-largest cluster and is characterized by socio-economic drivers (56%), in particular a moderately high level of both male and female literacy, and of fire occurrence activities, but with a low level of poverty (Table 2; Figure 5). It covers 12.4% of the NGS and mostly occurs in 20 out of the 25 states, spreading from the centre to the south-eastern part of the study area (Table S2; Figures 6 and 8). This archetype accounts for 12.4%, 12.6% and 11.9% of the overall degraded, stable, and improved areas, respectively (Figure 7).

NGSA 4: Archetype dominated by low literacy level and moderate–high poverty level

NGSA 4 (Figure 5; yellow in Figure 6), is the largest archetype, occupying 20.1% of the NGS (Table 2). Socio-economic factors (mainly low literacy levels and moderate-high poverty level) dominate this archetype by 66%. Other factors include minimal cases of fire and livestock activities, low elevation, low prevalence of protected areas (Figure 5). It occurs in 21 out of the 25 states in the NGS, predominantly in Kwara, Niger, and Oyo states, with patches spread from the south and north-west to the eastern border of the NGS (Table S2; Figures 6 and 8). NGS4 occupies the largest area of degradation, stable, and improved land status, i.e. 23.8%, 18.3%, and 16.0% respectively (Figure 7).

NGSA 5: Archetype dominated by rural remoteness

NGSA 5 (Figure 5; red in Figure 6), is one of the fifth largest clusters, representing 10.1% of the NGS (Table 2). Land-use management practices dominate (77%) in NGSA 5. These occur mostly in places far from major towns but with a moderately low prevalence of other drivers such as population density, protected areas, and flat terrain (Figure 5). NGSA 5 exists in small patches in

22 out of the 25 states across the study area (Table S2; Figures 6 and 8), and accounts for 10.5%, 10.0%, and 9.6% of total degraded, stable, and improved land status (Figure. 7) respectively.

NGSA 6: Archetype dominated by remoteness from a major road

Land-use management practices dominate (74%) the NGSA 6 (yellow in Figure 6; Figure 7), which is the second smallest archetype, covering 8.7 % of the NGS (Figure. 5; Table 2). NGSA 6 occurs at far distances away from major roads, has a low poverty level, a literacy level above the mean but with moderate–low fire and livestock activities (Figure 5). It exists as patches in 20 of the 25 states of the NGS, but is dominant in southern NGS states such as Oyo, Benue, Taraba, and Adamawa (Table S2; Figures 7 and 8). It is responsible for 9.1%, 8.4%, and 8.9% of total degraded, stable, and improved land status (Figure 7) respectively.

NGSA 7: Archetype dominated by very high livestock density: NGSA 7 (Figure 5;pink in Figure 6), is also a land-use- and management-practices-dominated (87%) archetype, with high livestock density and is equally (besides NGSA 5) the fifth-largest archetype, covering 10.1% of the NGS (Figure 5; Table 2). It is mainly characterized by a high prevalence of livestock activities (Figure 4), and predominantly found in Oyo, Taraba, Kaduna, and FCT with patches occurring in 20 states (Table S2; Figures 6 and 8). NGSA 7 is responsible for 9.5%, 10.5%, and 10.0% of the total degraded, stable, and improved areas, respectively (Figure 7).

NGSA 8: Archetype dominated by moderate poverty level and nearly level terrain:

NGSA 8 (Figure 5; light green in Figure 6), is the third smallest cluster, covering 9.4% of the NGS, and is fairly dominated by land-use management practices (47%), but also characterized by the mixed influence of social-environmental influence and drivers (Figure 5;Table 2), such as moderate elevation and moderate influence of bulk density and poverty (Figure. 5). This archetype exists in patches in 16 of the 25 states but dominantly in Kaduna, Adamawa, and FCT, including Tabara (Table S2; Figures 6 and 8). According to Figure 7, NGSA 8 accounts for 8.5%, 9.8%, and 10.7% degraded, stable, and improved areas, respectively.

NGSA 9: Archetype dominated by very rugged terrain and remote from a major road

This archetype (Figure 5; purple in Figure 6), is a small cluster occupying 10.5% of the NGS and is dominated by environmental drivers-78% (Figure 5;Table 2), with a characteristic moderate elevation and high slope and located far from a major road (Figure 5). It predominantly occurs in the south-western, the south-eastern, and the northern parts of the study area, with patches existing in 13 of the 25 states (Table S2; Figures 6 and 8) accounting for 8.1%, 11.2 %, and 14.8% of the total degraded, stable, and improved areas (Figure 7), respectively.

Table S1: Calculated Z-score normalized values of drivers characterizing the nine (9) distinctive archetypes of land degradation

	Environment variables			Socio-economic variables				Land-use management practices				
SOM Cluster	**Bulk_Den**	**Elevation**	**Slope**	**Literacy_F**	**Literacy_M**	**Poverty**	**Population_Den**	**Dis_road**	**Dis_town**	**Fire_Den**	**Livestock_Den**	**Protected_Area**
NGSA 1	0.2	0.4	-0.2	0.1	0.2	-0.1	-0.1	-0.3	0.0	-0.3	0.0	2.4
NGSA 2	0.0	-0.1	-0.2	0.0	0.0	0.0	4.0	0.0	0.1	0.2	0.2	0.1
NGSA 3	-0.3	-0.6	-0.2	1.0	0.8	-0.8	0.0	-0.3	-0.4	0.7	-0.2	-0.1
NGSA 4	0.2	-0.2	-0.2	-1.1	-1.4	0.4	-0.1	-0.2	-0.2	0.2	-0.2	-0.2
NGSA 5	0.0	-0.2	-0.2	0.1	0.2	0.0	-0.1	-0.2	1.9	0.1	-0.1	-0.2
NGSA 6	0.0	-0.1	-0.1	0.2	0.2	0.4	-0.1	2.2	-0.1	-0.4	-0.2	-0.1
NGSA 7	-0.3	-0.1	0.0	0.0	0.1	-0.1	-0.1	-0.1	-0.1	0.1	4.0	0.0
NGSA 8	0.4	0.8	-0.2	-0.3	0.0	0.4	-0.1	-0.3	-0.3	-0.8	-0.2	-0.3
NGSA 9	-0.3	1.8	3.9	0.0	0.1	0.1	0.0	0.9	-0.1	-0.3	-0.1	-0.1

The Z-score normalized values of drivers characterizing the nine archetypes of LD drivers. If the Z-scores = 0, this implies mean/low influence of a driver; Z-score $\leq \pm 1$ = moderate influence; $\pm 1 <$ Z-score $< \pm 2$ = high influence and Z-score $\geq \pm 2$ = very high influence, respectively.

Table S2: Archetypes and percentage share per state administration unit

State	NGSA 1	NGSA 2	NGSA 3	NGSA 4	NGSA 5	NGSA 6	NGSA 7	NGSA 8	NGSA 9	Outside NGS
Abia	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.5
Adamawa	0.0	0.0	0.0	0.2	0.7	2.1	5.7	10.5	10.9	70.0
Anambra	0.0	12.9	8.8	5.1	4.8	3.5	0.3	0.0	0.0	64.5
Bauchi	1.5	3.8	1.6	2.3	1.9	2.1	4.6	5.9	9.3	67.0
Benue	0.8	43.4	26.7	16.4	7.9	2.6	1.1	0.5	0.4	0.2
Cross River	0.4	7.1	2.0	0.6	0.2	0.0	0.0	0.0	0.0	89.8
Ebonyi	11.5	31.8	18.4	7.7	1.7	0.2	0.1	0.0	0.0	28.6
Edo	0.2	4.0	7.7	7.3	3.4	1.5	0.3	0.0	0.0	75.7
Ekiti	0.0	6.2	6.2	17.6	1.6	0.4	1.0	0.2	0.1	66.8
Enugu	9.8	52.6	18.3	7.6	3.9	2.6	0.6	0.1	0.3	4.2
FCT	0.3	7.3	9.7	12.1	13.7	16.4	12.5	13.4	14.7	0.0
Kaduna	2.0	2.9	2.2	6.8	10.0	12.7	19.3	22.4	21.7	0.0
Kano	0.2	0.1	0.2	0.3	0.3	0.5	1.1	2.9	13.0	81.4
Katsina	0.1	0.1	0.1	0.1	1.0	1.3	2.0	4.8	17.6	73.0
Kebbi	0.7	1.6	2.8	8.1	3.4	3.7	3.0	1.6	0.2	74.9
Kogi	0.3	48.0	26.6	16.0	6.3	1.8	0.7	0.2	0.0	0.0
Kwara	13.6	19.7	14.3	24.4	10.0	6.5	3.5	4.3	3.1	0.6
Nassarawa	0.9	19.3	18.0	18.6	12.3	6.9	8.6	9.7	5.7	0.0
Niger	3.6	7.9	10.9	40.5	12.4	8.8	8.2	4.8	1.4	1.5
Ogun	0.0	0.0	0.0	6.2	7.2	4.8	1.1	0.1	0.0	80.6
Ondo	0.0	0.1	1.2	5.9	2.1	3.2	1.6	0.8	0.1	84.8
Oyo	0.2	0.5	2.4	29.6	13.1	12.0	11.2	8.5	7.9	14.6
Plateau	5.7	12.5	10.0	7.3	5.5	6.3	8.3	7.8	7.4	29.3
Taraba	0.1	3.4	10.1	11.0	9.0	11.2	17.4	11.5	16.4	9.9
Zamfara	2.8	3.5	3.8	8.0	5.1	4.3	3.6	2.7	1.7	64.5

Table S 3: Archetypes and share of land status #

SOM Cluster	Degradation *(%)	Stable** (%)	Improvement*** (%)
NGSA 1	3.4	3.4	2.8
NGSA 2	14.7	15.9	15.2
NGSA 3	12.4	12.6	11.9
NGSA 4	23.8	18.3	16.0
NGSA 5	10.5	10.0	9.6
NGSA 6	9.1	8.4	8.9
NGSA 7	9.5	10.5	10.0
NGSA 8	8.5	9.8	10.7
NGSA 9	8.1	11.2	14.8
	100	100	100

Rainfall-corrected Normalized Difference Vegetation Index (NDVI) between 2003 and 2018 as a proxy for land-degradation status (Source Adenle, et.al 2020)

*Total degraded area in the NGS = 251,401 Km^2 (38%)

**Total stable area in the NGS = 91,258 Km^2 (14%)

***Total improved area in the NGS = 319,470 Km^2 (48%)

References

Adenle A. A., Eckert S., Adedeji O. I., Ellison D. and Ifejika Speranza C. 2020. "Human-induced land degradation dominance in the Nigerian Guinea savannah between 2003 – 2018," *Remote Sens. Appl. Soc. Environ.*, p. 100360, Jul. 2020, doi: 10.1016/j.rsase.2020.100360.

Asan, U. and Ercan, S. 2012. "An Introduction to Self-Organizing Maps. In Computational Intelligence Systems in Industrial Engineering"; Kahraman, C., Ed.; Atlantis Computational Intelligence Systems; Atlantis Press: Paris, 2012; Vol. 6, pp. 295–315 ISBN 978-94-91216-76-3.

Breard, G.T., 2017 "Evaluating Self-Organizing Map Quality Measures as Convergence Criteria" (2017). Open Access Master's Theses. Paper 1033. https://digitalcommons.uri.edu/theses/1033