Multi-Index Geospatial Assessment of Land-Surface Transformation, Built-Up Growth, and other Land Surface Change as a Result of Anthropogenic Pressure in Atakunmosa West Local Government Area, Southwestern Nigeria

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ABSTRACT

The anthropogenic disturbances in tropical mineralized regions can impact not only the non-permeable and exposed earth surfaces but also the plant life and surface water. Thus, using a single index for interpretation could not be appropriate (Sherring, 2020). With this study, a multi-index geospatial method using Landsat 8 data was adapted to assess land surface changes in the Atakunmosa West governmental area in Osun state in Nigeria in 2016, 2019, 2022, and 2025. Eight yearly remote-sensing products were analyzed including Built-Up Index (BUI), Urban Index (UI), Bare Soil Index (BSI), Normalized Difference Built-Up Index (NDBI), Enhanced Vegetation Index (EVI), Modified Normalized Difference Water Index (MNDWI) and two ancillary binary indexed maps (NDBI2 and NDWI2), these were derived from the continuous NDBI and NDWI raster using a specified threshold. Pixels satisfying the classification criterion are assigned a value of 1, whereas the remaining pixels are assigned a value of 0. The Landsat data, collection 2 level 2, covering row and path 055/190 for the year 2016, 2019, 2022 and 2025 were filtered to less than 10% cloud cover and these were clipped to cover the research area using ArcGIS 3.5.3 package. Built-up and bare land increased sharply between 2016 and 2025: the maximum Urban Index value raised from 0.454 in 2016 to 0.715 in 2025, Normalized Difference Built-up Index value increased from 0.183 to 0.523, Bare Soil Index from 0.153 to 0.413, and Built-Up Index from 0.216 to 0.359. The maximum EVI values were high till 2022 (0.697) and fell down to 0.604 in 2025. MNDWI reached its maximum level in 2022 (0.241), while in 2025 it became 0.163). The coinciding high values of built-up, urban, and bare soil indexes showed the ongoing change of terrestrial areas under anthropogenic influence, while vegetation and water indexes showed different timings of their responses. The results demonstrate the value of integrated spectral diagnostics for distinguishing built/exposed-surface intensification, vegetation condition and hydrological reorganization in the studied landscapes. The integration of multiple spectral indices revealed potential surface disturbances and variations in vegetation and water-sensitive responses in Atakunmosa West.

Keywords: Landsat 8; Built-Up Index; Urban Index; Bare Soil Index; NDBI; EVI; MNDWI; anthropogenic pressure; hydrological change; southwestern Nigeria

INTRODUCTION

The rapid transformation of the land surface is becoming increasingly important throughout tropical areas within Nigeria, where settlement development and agricultural practices take place concurrently leading to negative environmental impacts as well as the extraction of minerals. The spectral response of these regions is extremely complex because many factors such as bare soil, deforestation and impervious surfaces occur in a

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small area. Therefore, the detection of land cover change should involve an analysis that will separate built environments from the terrestrial response of vegetation and water bodies instead of employing one land-use class or using a vegetation index.

The Atakunmosa West Local Government Area (LGA) in Osun State is located in the mineralized Ife-Ilesha belt of southwestern Nigeria, which possesses communities that have been engaged in artisanal mining. Numerous previous investigations concerning the mining regions of Ijeshaland have shown the impact of mining on vegetation ecosystems, soil characteristics, pollution and land surface change (Akinbiola et al., 2016; Eludoyin et al., 2017; Awomeso et al., 2017; Adesipo et al., 2020; Oluwafemi et al., 2021). The analysis of the data collected in Atakunmosa West supports the idea about the spatial and temporal nature of environmental degradation in mining areas (Owolabi et al., 2025).

Spectral indices render a physically meaningful way to delve into how vegetation respond to changes exert by human being. The NDBI increases the amount of developed and impervious areas due to its measurement of the difference between the reflectance values in short-wave and near-infrared regions of the spectrum (Zha et al., 2003).

While the Urban Index (UI) refers to urban areas and construction materials, the Bare Soil Index (BSI) refers to bare soil. On the other hand, Built-Up Index (BUI) utilizes information about both construction and vegetation, improving the possibility of distinguishing developed and vegetated zones.

Furthermore, EVI was created to be more sensitive to the canopy structure and decrease the influence of atmosphere and background (Huete et al., 2002). Moreover, MNDWI enhances water detection by replacing the near infrared band of the classical NDWI with the short-wave band (Xu, 2006). All the indices given can be used to determine whether the changing land surface is turning into more developed, more bare, less vegetated, or more hydrological one.

Multi-index approach is of paramount importance for mining landscapes because positive values of NDBI, BSI, BUI, and UI are not exclusively indicative of urbanization. Freshly excavated earth, rocks, and compacted ground exhibit a strong alteration in the response as well. On the contrary, indices connected to water reveal natural rivers, agricultural ponds, and filled mine pits. The interpretation of water-related indices depends on the combination of several indices and the knowledge about land use.

This research analyses multi-temporal land surface changes in Atakunmosa West LGA using Landsat 8 derived products in 2016, 2019, 2022, and 2025: BUI, UI, BSI, NDBI, NDBI2, EVI, MNDWI, and NDWI. The aims are:(i) to discover how built-up and exposed surfaces change over time in terms of their spectral responses; (ii) to analyse the land surface using the EVI vegetation index; (iii) to investigate changes with the aid of the MNDWI and NDWI indices; (iv) to combine all the identified indices and show regions and years where human activities promote land change. The difference between this and earlier land cover area research is that this study does not employ area statistics nor LULC change tables.

MATERIALS AND METHODS

Study area

Atakunmosa West Local Government Area is in south-west Nigeria between (Latitude of 7°13′-7°43′ N and Longitude of 4°32′-4°46′ E). The area falls in humid tropical region of Ife-Ilesha schist-belt consisting of agricultural, forest, settlement and mining surfaces. The location of Osun State in Nigeria is depicted in Figure 1 along with location of Atakunmosa west within Osun State and the study area boundary delineated for the satellite remote sensing.

The presence of cocoa based agriculture, secondary vegetation, settlement and small-scale mining in the area makes it ideal for measuring anthropogenic impact considering built or exposed surfaces, vegetation and water indices.

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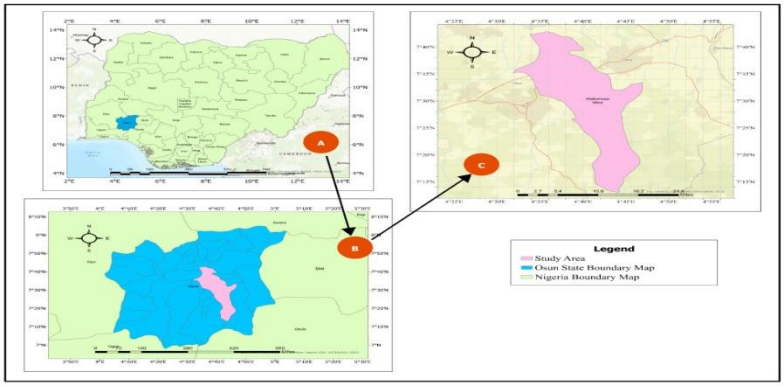


Figure 1. Location of Atakunmosa West Local Government Area, Osun State, Nigeria, showing the national, state and local study-area contexts.

Methods (Landsat 8 data and preprocessing)

The Study used index overlays and threshold-based index. For the years 2016, 2019, 2022, and 2025, Landsat 8, collection 2, Level 2 images covering path/row 190/055 with the acquisition date of 02/01/2016, 28/12/2019, 28/12/2022 and 22/01/2025, was acquired with less than 10% cloud cover to avoid the clouds and and its shadows. These show no seasonal variation variation in terms of rainfall as all of the data were acquired in uniform season to ensure uniformity and quality of the results. The spectral index generation process was conducted using raster calculator in Arc GIS Pro version 3.5.3 and subsequently clipped with the study area map boundary layer to match with the Atakunmosa West spatial boundary.

Spectral Indices and Interpretation

These comprise BUI, UI, BSI, NDBI, EVI and MNDWI, NDBI and NDWI are supplied as binary 0/1 derivatives. Table 1 presents conventional expressions used to interpret the indices.

Table: Spectra indices and its interpretations

Index	Conventional expression	Primary interpretation
BUI	NDBI - NDVI	Built/exposed surface enhancement relative to vegetation
UI	(SWIR2 - NIR)/(SWIR2 + NIR)	Urban/built-surface response
BSI	[(SWIR1 + Red) - (NIR + Blue)] / [(SWIR1 + Red) + (NIR + Blue)]	Bare or exposed soil
NDBI	(SWIR1 - NIR)/(SWIR1 + NIR)	Built-up/impervious or exposed-surface tendency
EVI	2.5(NIR - Red)/(NIR + 6Red - 7.5Blue + 1)	Vegetation condition and canopy greenness
MNDWI	(Green - SWIR1)/(Green + SWIR1)	Open-water enhancement
NDBI	Binary 0/1 derivative of supplied NDBI workflow	Thresholded built/non-built response
NDWI	Binary 0/1 derivative of supplied water-index workflow	Thresholded water/non-water response

For Landsat 8, the band correspondents are Blue = Band 2, Green = Band 3, Red = Band 4, NIR = Band 5, SWIR1 = Band 6 and SWIR2 = Band 7. A built-up/bare-surface positive reaction that indicates more anthropogenic realities or exposed-surface tendencies may be regarded as convincing only in the presence of spatial agreement between several indices.

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Temporal Spectral-Range Analysis

For each index, the minimum and maximum values for the four observation years are embeded in the legend of the maps with width calculated as R = Imax - Imin, where Imax and Imin are the highest and lowest mapped index values shown for that year. Inter annual change in the positive extreme was summarized as ΔImax = Imax,2025 - Imax,2016. These statistics describe the span and intensity of the spectral products; they do not represent pixel means or infer the proportion of the landscape above a threshold.

Spatial Comparison and Binary Products

The year-long index maps were contrasted visually for spotting the stagnant or newly coming up spatial clusters of BUI, UI, BSI and NDBI responses. EVI and MNDWI were analyzed for the same sites ascertaining whether human impact signals matched with vegetation or water-sensitive responses. NDBI2 and NDWI were used for qualitative indicator corroboration as threshold values, class-1 pixel counts and raster attribute statistics were unavailable.

Analytical Caution and Uncertainty

Landsat 8 with (30m) spatial resolution can produce mixed pixels where mining surfaces, vegetation and water occur together. Accordingly, causal attribution is based on the convergence of multiple index responses and the known mining context, not on any single spectral threshold.

RESULTS

Temporal Spectral Ranges

The indices were characterized by unique trends over time (Table 2). The built/infrastructure indices experienced the highest increase in positive extremes, as evidenced by their values in 2025. They were -0.260 on the negative end of the scale and 0.216 on the positive end of the scale in 2016. The UI indices experienced an increase in their 2016 peak of 0.454 to 0.715 in 2025, BSI went from 0.153 to 0.413, and NDBI from 0.183 to 0.523. On the other hand, the EVI showed an opposite trend reaching its maximum figure in 2022 (0.697) and coming down to 0.604 in 2025. The same trend may be observed in the values of the MNDWI: its maximum level was registered in 2022 (0.241), while 2025 recorded its minimum.

Table 2: Temporal Spectral range of the indices for the year under study

Index	2016 range	2019 range	2022 range	2025 range
BUI	-0.260 to 0.216	-0.694 to 0.041	-0.697 to 0.041	-0.602 to 0.359
UI	-0.372 to 0.454	-0.229 to 0.445	-0.334 to 0.577	-0.258 to 0.715
BSI	-0.149 to 0.153	-0.145 to 0.102	-0.165 to 0.152	-0.129 to 0.413
NDBI	-0.236 to 0.183	-0.273 to 0.113	-0.327 to 0.149	-0.282 to 0.523
EVI	-0.056 to 0.680	0.031 to 0.692	-0.110 to 0.697	-0.063 to 0.604
MNDWI	-0.392 to 0.134	-0.311 to 0.122	-0.342 to 0.241	-0.640 to 0.163

Table 3 summarizes the spectral range widths derived from the displayed minima and maxima. Between 2016 and 2025, the widest variations were recorded for BUI (from 0.476 to 0.961) and NDBI (from 0.419 to 0.805), whereas the width of BSI increased from 0.302 to 0.542. EVI is the only variable which shrank its range over the course of the whole period from 0.736 to 0.677.

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Table 3: Spectral Range width of the indices.

Index	Range width 2016	Range width 2019	Range width 2022	Range width 2025	Δ maximum 2016-2025
BUI	0.476	0.735	0.738	0.961	0.143
UI	0.826	0.674	0.911	0.973	0.261
BSI	0.302	0.247	0.317	0.542	0.26
NDBI	0.419	0.386	0.476	0.805	0.34
EVI	0.736	0.661	0.807	0.667	-0.076
MNDWI	0.526	0.433	0.583	0.803	0.029

Built-Up and Exposed-Surface Dynamics

The four indices of BUI, UI, BSI, and NDBI showed a non-linear progression of their extreme indexes, however, 2025 was the year with the largest peak value for each index (Figure 2). The BUI index decreased from 0.216 in 2016 to 0.041 in 2019 and the same index in 2022 and jumped up to 0.359 in 2025. Regarding the index of UI, it remained stable over the entire period mentioned and increased from 0.454 in 2016 to 0.577 in 2022 and finally, to 0.715 in 2025. BSI also exhibited a late growth, where its peak value increased from 0.152 in 2022 up to 0.413 in 2025. The best accomplishment of NDBI was demonstrated by the increase of this index from the value of 0.149% in 2022 up to the value of 0.523 in 2025.

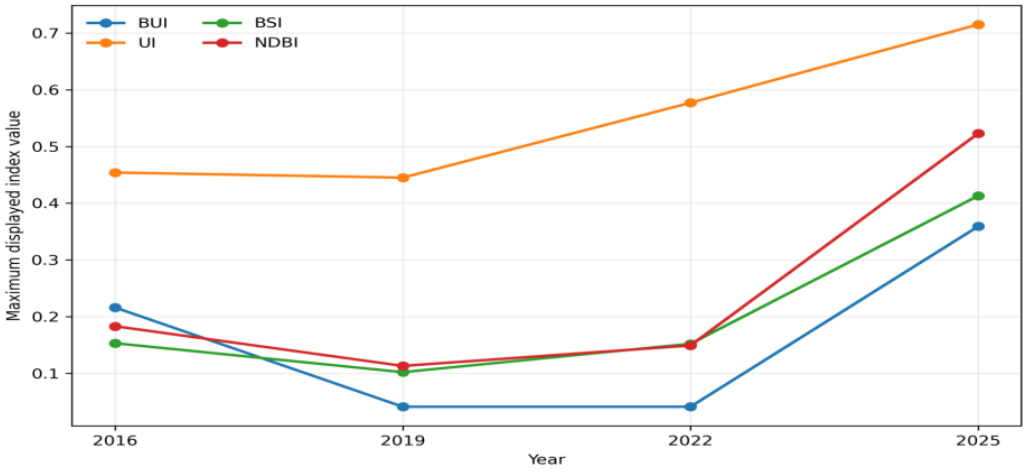


Figure 2. Maximum displayed values of BUI, UI, BSI and NDBI for 2016, 2019, 2022 and 2025. The values represent spectral extrema from the supplied map legends, not area-weighted means or mapped extent.

Geographically, the regions with greater incidences of classes were predominantly in the northwestern, western-central and chosen central path regions. The presence of these regions throughout BUI, UI, BSI and NDBI suggests that the observed pattern is not the result of just one index calculation. The maps for the year 2025 display the most noticeable convergence of high positive classes in these regions. Since BSI and NDBI also respond to bare rock and exposed soil and some man-made surfaces, the total response is interpreted as heightened human-made media activity rather than just normal urbanization.

Vegetation-Condition Response From EVI

EVI measurement was consistently high at maximum points in all years ranging from a maximum point of 0.680 in 2016 to a maximum of 0.604 in 2025 (Figure 3). Peak EVI value and the lowest value (-0.110) belong to the 2022 evaluation, which leads to the widest range of the EVI measure. The occurrence of such high EVI values demonstrates the essential difference between productive vegetation and spectrally stressed or non-vegetated surfaces. Nevertheless, by 2025 the EVI reached only 0.604, showing less range than it was observed before, and indicating that vegetation signal did not increase equally with the level of built/exposed surfaces.

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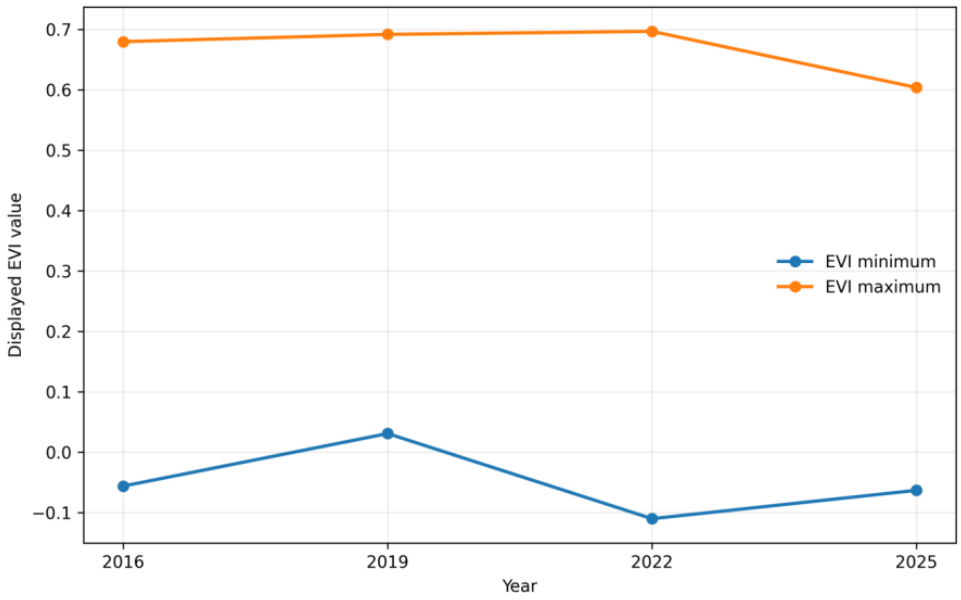


Figure 3. Minimum and maximum EVI values displayed across the four observation years. Extrema describe the range of vegetation response present in the supplied maps and should not be interpreted as landscape-average greenness.

Hydrological response from MNDWI and NDWI

EVI value was consistently high at maximum points in all years ranging from a maximum point of 0.680 in 2016 to a maximum of 0.604 in 2025 (Figure 3). Peak EVI value and the lowest value (-0.110) belong to the 2022 evaluation, which leads to the widest range of the EVI measure. The occurrence of such high EVI values demonstrates the essential difference between productive vegetation and spectrally stressed or non-vegetated surfaces. Nevertheless, by 2025 the EVI reached only 0.604, showing less range than it was observed before, and indicating that vegetation signal did not increase equally with the level of built/exposed surfaces. Figure 4. Shows Minimum and maximum displayed MNDWI values for 2016, 2019, 2022 and 2025.

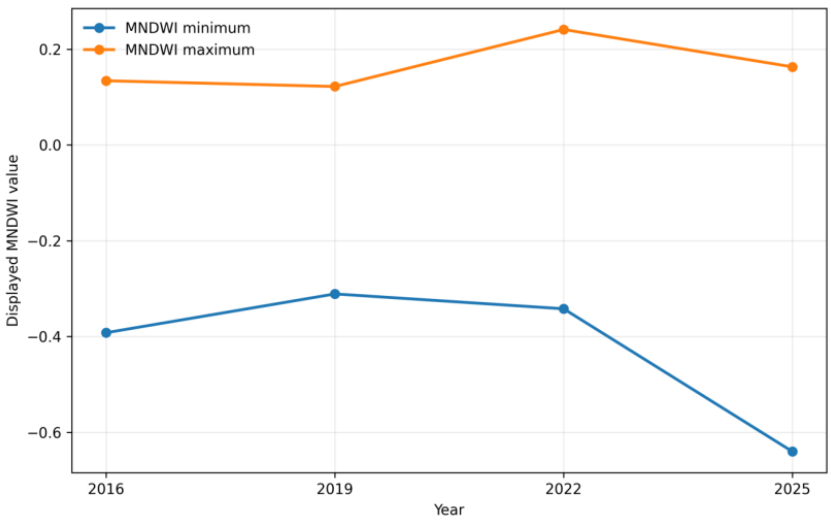


Figure 4. Minimum and maximum displayed MNDWI values for 2016, 2019, 2022 and 2025. The 2022 maximum is the strongest positive water-enhancing response, whereas the 2025 minimum produces the widest spectral range.

The NDWI maps provide a complementary binary representation of water-related pixels. Across the annual maps, class-1 features are spatially restricted relative to the non-water background and appear as channel-like or localized patches. This binary product is used only to support the location of water-sensitive features, not to estimate water area or percentage change. Figure 5 – 8 display the map showing the indexes.

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Multi-index spatial evolution, 2016-2025

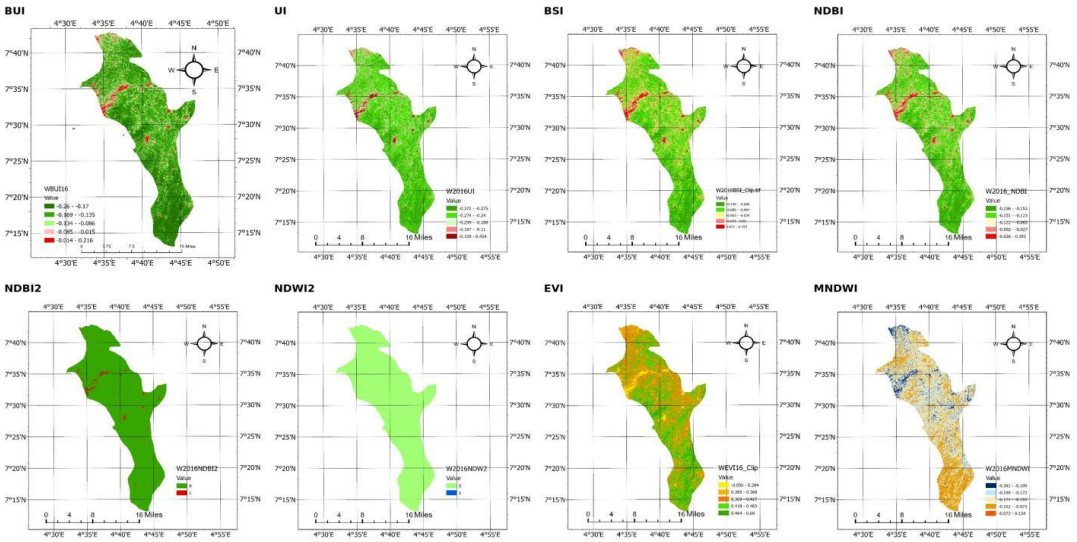


Figure 5. Landsat 8-derived multi-index products for Atakunmosa West in 2016: BUI, UI, BSI, NDBI, binary NDBI2, binary NDWI, EVI and MNDWI. Panels reproduce the annual geospatial outputs supplied.

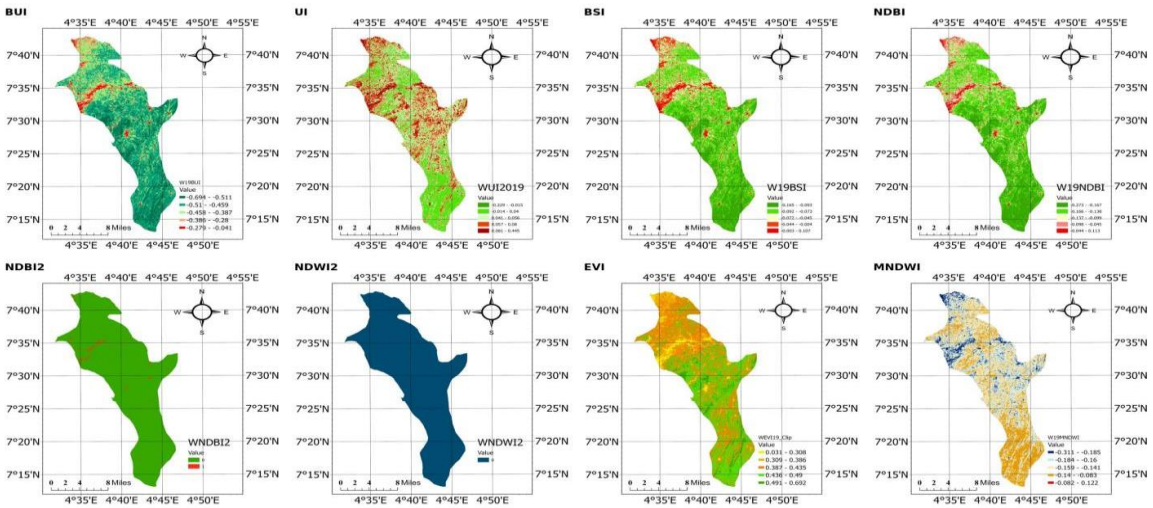


Figure 6. Landsat 8-derived multi-index products for Atakunmosa West in 2019: BUI, UI, BSI, NDBI, binary NDBI2, binary NDWI, EVI and MNDWI. Panels reproduce the annual geospatial outputs supplied.

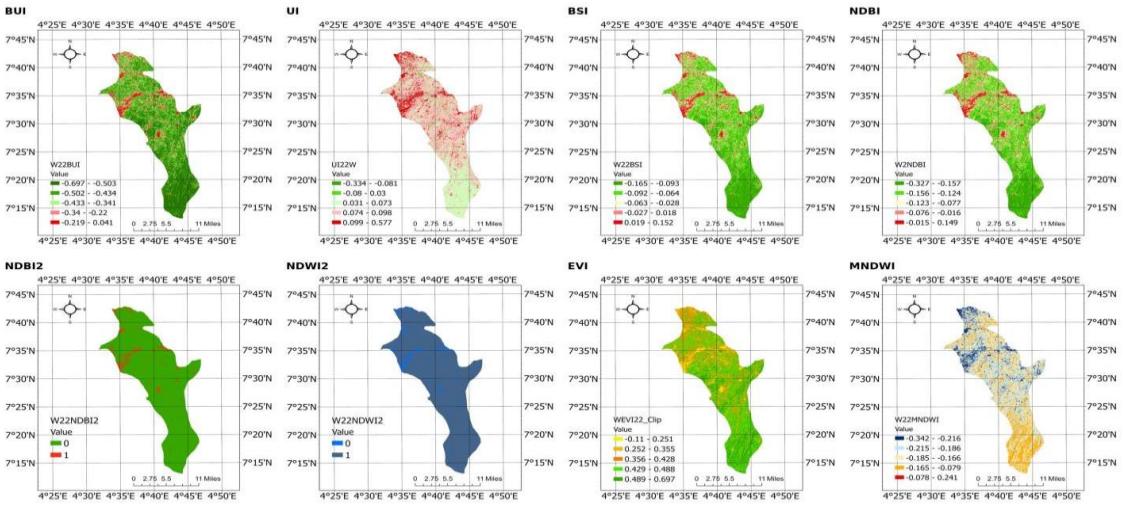


Figure 7. Landsat 8-derived multi-index products for Atakunmosa West in 2022: BUI, UI, BSI, NDBI, binary

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NDBI2, binary NDWI, EVI and MNDWI. Panels reproduce the annual geospatial outputs supplied.

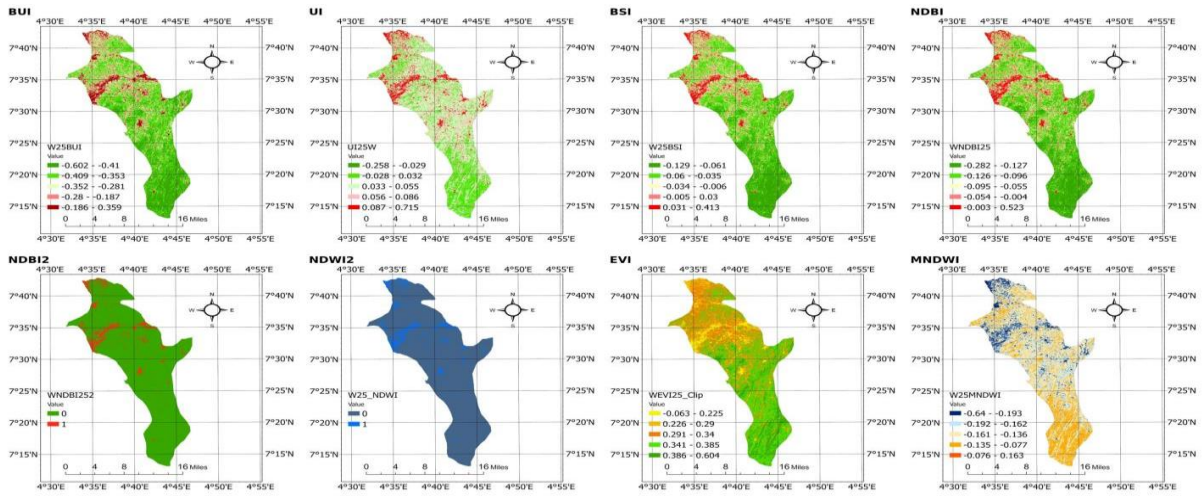


Figure 8. Landsat 8-derived multi-index products for Atakunmosa West in 2025: BUI, UI, BSI, NDBI, binary NDBI2, binary NDWI, EVI and MNDWI. Panels reproduce the annual geospatial outputs supplied.

The strongest built/exposed surface responses were localized in 2016 with high-value characteristics in the western and north-central disturbance belts. The results for 2019 indicate higher expansion prospects for high UI, BSI and NDBI classes in the northwest and central-west sectors with low-positive maximum for BUI. In 2022, UI became evident over a wider portion of the northern and central area whereas NDBI2 determined isolated built/exposed hotspots. This year gave the highest values of EVI and MNDWI highlighting the strong spatial heterogeneity of the area rather than the signal of uniform degradation. By 2025, maximum values of UI, BSI, BUI and NDBI were noted and their zones of high values were prominent in the north-west and centre-west corridor and some internal nodes. The decline of maximum values of EVI and the widening of MNDWI contrast demonstrate but the phenomena mentioned above were accompanied by different ecological reactions experienced in the region.

Integrated Spectral Trajectory of Anthropogenic Pressure

Based on the multi-index data, there appear to have been three separate phases. To begin with, the year 2016 can be classified as a lower baseline point that contains weak positive ground/exposed-surface signals. The period of 2019-2022 results in increasingly greater spatial variance where UI and MNDWI improve by 2022, EVI achieves its maximum value, and binary outputs show distinct disturbances and water-related features. Finally, the year 2025 provides extensive evidence for significant positive values of BUI, UI, BSI, and NDBI, as well as maximum wavelength ranges for BUI, NDBI, and MNDWI. This indicates that anthropogenic surfaces began to become more visible while the vegetation and water indicators changed randomly in terms of their spatial behavior.

DISCUSSION

Converging evidence of human-caused intensification of surfaces

The most significant finding is the convergence in the four disturbance-oriented indices showing the growing tendency for stronger positive extremes in the year 2025. UI increased to 0.715, NDBI to 0.523, BSI to 0.413, and BUI to 0.359. The essential point is that the indices are in close agreement as each acts differently with regard to surface materials. While NDBI and UI focus on built or impervious materials, BSI responds to exposed soil, and BUI emphasizes the difference between built and vegetated surfaces. Therefore, intensity of the indices is more convincing evidence of human surface transformation than any of the indices on its own.

The fact that the ranges of BUI and NDBI spectral numbers are getting wider indicates the increase of surface diversity. The diversity in landscapes affected by mining might be caused by a combination of exposed soil, excavated areas, compacted roads, settlements, regrowing surfaces, and remaining vegetation. This view is

supported by both field and remote-sensing research findings that found mining-related disturbance in Itagunmodi and the entire Ijeshaland gold belt (Akinbiola et al., 2016; Awomeso et al., 2017; Oluwafemi et al., 2021; Owolabi et al., 2025).

Built-Up Growth Should Not Be Equated With Urbanization Alone

Even though the title of the study indicates built-up development, the evidence obtained can be understood in a wider sense of constructed/exposed human surfaces. Positive results of NDBI and UI can suggest the presence of roofs, roads, and buildings, whereas BSI and NDBI can, at the same time, refer to bare land, striped earth, or stone. The occurrence of the high value of BSI, together with the high values of BUI, UI, and NDBI, in Atakunmosa West demonstrates that this "built" value is connected with excavation and exposed material rather than built environment alone. High-resolution images or real-life observations must be employed to distinguish these types of surfaces conclusively.

Vegetation Response Was Non-Synchronous With Surface Intensification

EVI did not follow the same pattern as other indices. Maximum values increased from 0.680 in 2016 to 0.697 in 2022 and then decreased to 0.604 by 2025. The EVI readings suggest that in 2022 there were places where highly productive vegetation was mixed with very stressed and even barren land. This phenomenon can be explained by the configuration of the tropical mining landscape where disturbances occur in patches and surrounding areas remain productive. The significance of a maximum EVI value for 2025 being lower indicates that changes in vegetation state occurred at least in some parts of the LGA which is supported by the findings of other indices.

Hydrological Change Reflects Reorganization Rather Than A Monotonic Trend

MNDWI results indicate that hydrological behavior has changed considerably, but not inevitably in a systematic fashion. The highest positive MNDWI value occurred in 2022, while 2025 is characterized by the greatest contrast in spectral values, as it decreased to a minimum of -0.640. The fact that MNDWI was developed specifically to enhance open water and suppress built-up land (Xu, 2006) means that changes mentioned above point to changing trends regarding contrast water to non-water bodies in the landscape. In mining, such events may mean the availability of natural waterways, water-bearing quarries, water-sumps, sediment pools, and other landscape features. Binary NDWI values allow seeing the locations that are the most suitable for the field work.

Value of a Multi-Index Framework

The non-synchronous behavior of the indices shows that a multi-index strategy is more effective than a single-index evaluation. High NDBI readings can create confusion in locations with large amounts of bare soil, BSI discerning areas with sets of bare surfaces while EVI determines if there is vegetation and MNDWI signals the presence of water. In a case where BUI, UI, BSI, and NDBI coincide spatially but EVI is growing weak, the proof of human activity on the surface gets stronger. If MNDWI or NDWI would also change, the presented solution will show places with possible transformation of land surface involving reorganization of water in this place.

Implications for Monitoring and Land Management

The positive built/exposed-surface response pattern of 2025 marks priority areas for up-to-date monitoring, notably in the northwestern and west-central areas where several indices intersect. These places are appropriate to implement high-resolution mapping. Water-sensitive hotspots flagged by MNDWI and NDWI need to be verified to check whether they indicate natural bodies of water, man-made agricultural ponds, or pit mining areas. The repetitive use of multi-index process with seasonal Landsat data allows making the screening process cost-effective for the detection of new disturbances prior to conducting more thorough on-ground research.

LIMITATIONS

Landsat data is limited to 30m resolution, which might miss-interpreted pixel, therefore higher resolution satellite data was is suggested for further investigation.

Finally, attribution to mining or other anthropogenic activities is inferential. The known mining context and multi-index convergence support the interpretation of anthropogenic pressure, but causal separation among mining, settlement, roads and agriculture requires independent spatial layers or field validation.

CONCLUSIONS

This research presents an assessment based on spectral index of land surface in Atakunmosa West with no requirement of land cover area information. The assessment from the period ranging from 2016 to 2025 indicates a growth in exposed/built surface responses. The indices recorded were; UI -0.715, NDBI -0.523, BSI -0.413 and BUI -0.359. In comparison with the 2016 records, the spectral indices BUI and NDBI expanded significantly. The vegetation and hydrological indices show two divergent trends; for the case of vegetation EVI index marking the highest value in the year 2022 before declining by 2025 and for the case of hydrology MNDWI values record the peak in 2022 but the lowest level in 2025. These trends show that anthropogenic surface intensification, hydrology manifestations and vegetation conditions could not be explained by one index only. The overlapping of the indices BUI, UI, BSI and NDBI in northwestern and central corridors together with zones of normal binary NDBI2 and NDWI responses highlights the priority zones for environmental monitoring.

Declarations

Funding: No external funding was received.

Conflict of Interest: The authors declare no conflict of interest.

Data Availability: The Landsat-derived spectral-index products analyzed in this study are available from the corresponding author subject to the data-sharing conditions of the research project.

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