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Forest Mapping Geospatial Analysis for Security Assessment in Benue State, Nigeria

Dr. Henry Nanlok[1], Dr. Omomoh Emmanuel[1], Gwamzhi Ponsah Emmanuel[1], Pwajok David Jang[1], Yahnan Miri[1], Songtak Nimdir[1] & Titus James Tumba[1]

[1]Zonal Advanced Space Technology Application Laboratory (ZASTAL), Langtang, Nigeria

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ABSTRACT

Forest cover is increasingly recognised in Nigeria as a factor security analysts must account for, since dense or poorly monitored vegetation can provide cover, mobility and concealment for armed actors operating alongside conventional drivers of conflict. This study presents a geospatial forest-mapping analysis of Benue State, Nigeria, undertaken to support the state's security assessment by characterising forest cover alongside an independent, event-level record of insecurity. Benue lies within a forest–savanna transition zone where agricultural expansion, settlement growth and rural livelihood pressure have driven measurable forest-cover decline over the past two decades, and it has become one of Nigeria's most conflict-affected states, with recurrent farmer–herder clashes prompting the state's Open Grazing Prohibition and Ranches Establishment Law of 2017. This study applies a Google Earth Engine (GEE) workflow to extract binary forest/non-forest cover across Benue State from the ESA WorldCover 10 m 2021 (v200) land-cover product, cross-referenced with GRID3 Nigeria Settlement Extents (v3.1, 2024) to characterise the spatial relationship between forest cover and settlement patterns. Classification reliability was evaluated against 100 independent reference points, yielding an overall accuracy of 94.0% and a Kappa coefficient of 0.88, indicating strong agreement between the WorldCover-derived tree-cover layer and ground-referenced land cover. To examine the insecurity dimension, 1,482 conflict events recorded for Benue State between January 2010 and May 2025 were extracted from the Armed Conflict Location & Event Data Project (ACLED) database and disaggregated by event type, sub-event type, actor and Local Government Area (LGA). Of these, 1,252 events (5,394 fatalities) were coded as political violence, with the annual rate of politically violent events rising from approximately 32 per year before the November 2017 Open Grazing Law to approximately 128 per year afterward, and with 617 events (3,863 fatalities) directly implicating herder or pastoralist-linked actors. Makurdi, Guma, Logo, Ukum, Agatu, Buruku and Gwer West LGAs together accounted for the majority of recorded fatalities. The geography of forest cover and the geography of insecurity are related here descriptively rather than through a pixel-level statistical overlay, and the resulting picture is consistent with the broader Nigerian literature linking forested and poorly governed terrain to sustained armed-group activity, and with prior site-specific evidence of accelerated forest loss in several of the same conflict-affected LGAs. As a security assessment, the study identifies forest and semi-natural vegetation cover as a plausible, literature-consistent contributing factor to the persistence of insecurity in specific Benue State LGAs, and proposes a quantitative spatial-statistical extension of the present mapping and conflict-analysis foundation as the next stage of this assessment.

1. Introduction

Forests provide carbon sequestration, biodiversity habitat, hydrological regulation and rural livelihood support, yet they remain under sustained pressure from agricultural conversion, settlement expansion and fuelwood extraction across the tropics, and Sub-Saharan Africa in particular exhibits deforestation dynamics driven predominantly by smallholder agriculture and informal land use rather than industrial-scale clearance (Assede et al., 2023, as cited in Anule et al., 2026). Nigeria is among the countries experiencing the fastest rates of forest loss in Africa, and within the country's Middle Belt region, including Benue State, forest decline has been repeatedly linked to agricultural expansion and fuelwood dependence associated with rural livelihoods (Bombom & Yemisi, 2024). Site-level remote-sensing evidence for Benue State bears this out: a multi-temporal classification of twelve communal and reserved forests across the state found forest cover falling by as much as 58.9 percentage points between 2005 and 2020 at the most affected sites, with agricultural conversion identified as the dominant transition pathway, even though a small number of sites showed relative stability or slight regeneration (Anule et al., 2026).

In parallel with this land-cover change, forested and weakly governed terrain has become an increasingly prominent feature of Nigeria's internal security landscape. Investigative geospatial reporting has documented how armed groups in north-western and north-central Nigeria exploit forest reserves such as Kamuku, Falgore, Kuyambana and the cross-border Rugu forest complex as operating bases from which to launch attacks, citing the difficulty state security forces face in patrolling dense, road-poor forest terrain and the resulting slow response times to reported attacks (HumAngle, 2025; Review of African Political Economy [ROAPE], 2026). Analysts have argued more generally that ungoverned forest spaces provide corridors for logistics and communication that are difficult for security forces to interdict, and that forest governance failures compound, rather than merely coincide with, the underlying drivers of banditry and communal violence (ROAPE, 2026). While this literature is concentrated on Nigeria's north-west and north-east, the underlying logic, that dense, weakly monitored vegetation cover confers an operational advantage on armed non-state actors, has clear relevance to Benue State's own forest-savanna mosaic and its distinct, but comparably severe, conflict profile.

Benue State's dominant conflict dynamic is the sustained confrontation between settled crop-farming communities and transhumant or semi-settled livestock herders, a conflict pattern common across Nigeria's Middle Belt but historically most acute in Benue (Bombom & Yemisi, 2024). In response to a documented 46 attacks attributed to suspected herders between February 2013 and May 2017, resulting in more than 1,541 deaths, the Benue State Government enacted the Open Grazing Prohibition and Ranches Establishment Law on 22 May 2017, which took effect on 1 November 2017 and required herders to establish fenced ranches in place of open, itinerant grazing (Guardian, 2020; Kwaja & Ademola-Adelehin, 2018). The law was welcomed by many crop-farming communities as an antidote to recurrent conflict but was contested by herder organisations, who characterised it as discriminatory and economically disruptive, and independent monitoring by the Search for Common Ground identified a range of residual economic, socio-cultural and legal risks capable of sustaining or re-igniting tension even after enactment (Kwaja & Ademola-Adelehin, 2018). State officials have publicly maintained that the law reduced the frequency of herder attacks relative to the pre-2017 period (Guardian, 2020; ThisDay, 2020), a claim this study is, in part, positioned to test empirically using an independent, event-level conflict dataset.

Despite the depth of qualitative and legal-institutional literature on both Benue's forest-cover dynamics and its farmer–herder conflict, no published study known to the authors has attempted to bring these two strands together within a single, geospatially explicit framework using contemporary cloud-based Earth observation tools. Google Earth Engine (GEE) has become the platform of choice for this kind of analysis because it hosts petabyte-scale, analysis-ready satellite archives and performs computation on Google's servers rather than the analyst's own hardware, substantially lowering the barrier to state-level land-cover mapping in data- and infrastructure-constrained settings (Gorelick et al., 2017). The ESA WorldCover 10 m 2021 (v200) global land-cover product, derived from Sentinel-1 and Sentinel-2 imagery and independently validated to an overall global accuracy of 76.7%, provides a freely available, GEE-native basis for extracting forest cover at fine spatial resolution (European Space Agency [ESA] WorldCover Consortium, 2022; Zanaga et al., 2022). Combining this layer with the GRID3 Nigeria Settlement Extents dataset, a high-resolution, building-detection-based settlement product developed to support subnational planning (Center for International Earth Science Information Network [CIESIN], 2024), allows forest distribution to be examined directly against the pattern of human settlement it surrounds.

This study presents a geospatial forest-mapping analysis intended to support a security assessment of Benue State, built on two linked components. The first is to produce and validate a current, GEE-derived forest/non-forest cover layer for Benue State and describe its spatial relationship to mapped settlement extents. The second is to characterise, using event-level data from the Armed Conflict Location & Event Data Project (ACLED), the spatiotemporal pattern of insecurity across the state's Local Government Areas (LGAs) between 2010 and 2025, including the observable change in conflict frequency around the 2017 Open Grazing Law, and to examine whether the geography of that insecurity coincides with the geography of forest cover. The specific objectives are to: (i) extract and map binary forest cover for Benue State from ESA WorldCover 2021 v200 in GEE; (ii) validate the resulting classification against independent reference points; (iii) integrate the forest layer with GRID3 settlement extents to describe their spatial relationship; (iv) quantify the frequency, fatality burden, actor composition and LGA distribution of conflict events in Benue State from 2010 to 2025 using ACLED, as the empirical core of the security assessment; and (v) assess the correspondence between forest-cover geography and conflict geography, identifying the LGAs where this convergence is strongest as priority areas for security attention and for the further spatial-statistical analysis needed to establish the relationship quantitatively.

2. Study Area

Benue State lies in Nigeria's North Central geopolitical zone, popularly regarded as part of the country's Middle Belt, and is bordered by Nasarawa State to the north, Taraba State to the east, Kogi State to the west, Enugu, Ebonyi and Cross River States to the south, and the Republic of Cameroon along a short international boundary to the south-east (Wikipedia, 2026). The State was created on 3 February 1976 and derives its name from the Benue River, Nigeria's second-largest river after the Niger, which traverses the state from east to west (Wikipedia, 2026). Commonly cited government and encyclopaedic sources place the State's total area at approximately 34,059 km² (Anule et al., 2026; Wikipedia, 2026); the administrative boundary layer used for the present GIS analysis, drawn from GRID3, computes a slightly smaller area of approximately 30,860 km², a discrepancy attributable to differences in boundary vintage, generalisation and coordinate-system handling between sources rather than to any change in the State's actual extent. Benue comprises 23 Local Government Areas, organised into three senatorial districts (North-East, North-West and South) and inhabited predominantly by the Tiv, Idoma and Igede ethno-linguistic groups. The State recorded a population of 4,253,641 at the 2006 census, with a 2022 estimate of approximately 6.14 million (Wikipedia, 2026).

The State experiences a tropical wet-and-dry climate with a single rainy season and a distinct dry season, supporting a mosaic of cultivated land, natural and semi-natural woody vegetation, wetlands, water bodies and built-up areas. Agriculture, including the cultivation of yam, rice, cassava, maize, sorghum and soya bean, is the dominant land use and the mainstay of the rural economy, a role reflected in Benue's popular nickname as Nigeria's "Food Basket of the Nation" (Wikipedia, 2026). This agrarian character is central to the present study for two reasons: it is the principal proximate driver of the forest-cover conversion documented for the State's remaining communal and reserved forests (Anule et al., 2026; Bombom & Yemisi, 2024), and it places large numbers of farming households in direct, sustained spatial contact with transhumance corridors and grazing land used by pastoralist herders, the central axis of the State's conflict profile (Bombom & Yemisi, 2024; Kwaja & Ademola-Adelehin, 2018).

The administrative boundary of Benue State defined the spatial extent of both the forest-cover extraction and the settlement-mapping components of this study. Figure 1 shows the mapped distribution of settlement extents across the State, derived from GRID3 Nigeria Settlement Extents (v3.1), together with the road and drainage network, illustrating the concentration of settlement around Makurdi (the state capital, at the confluence of local road and river networks), Otukpo, Adikpo, Katsina-Ala and Zaki-Biam.

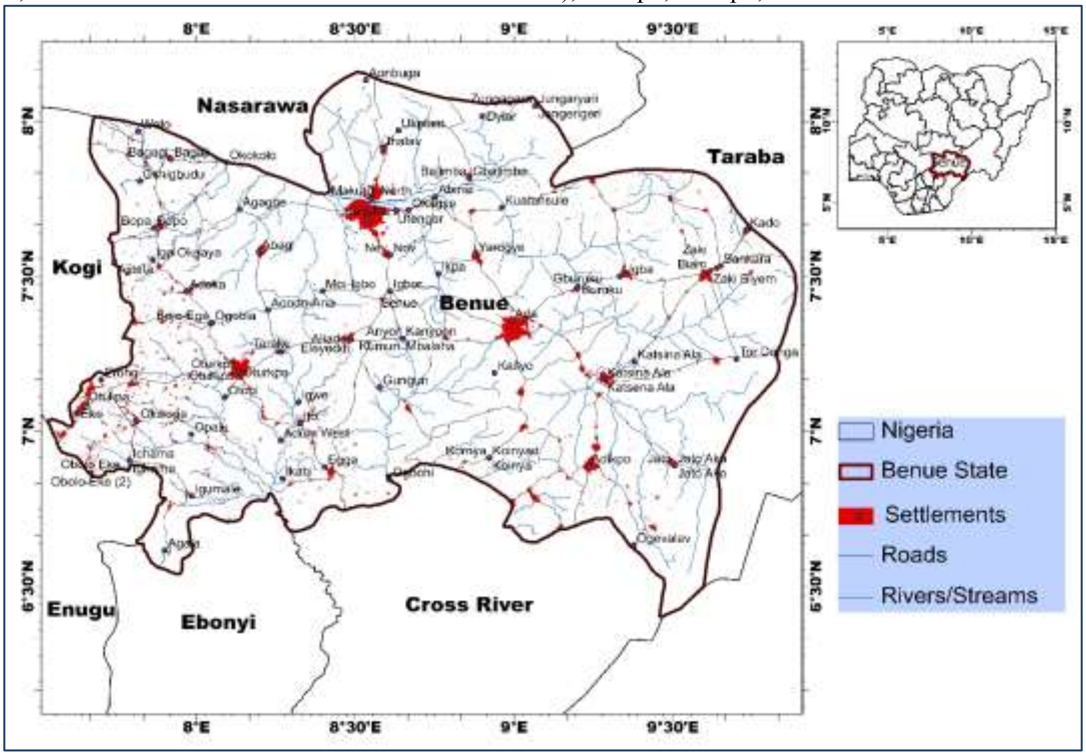

Figure 1: Distribution of mapped settlement extents (GRID3 Nigeria Settlement Extents v3.1) across Benue State, shown with the road and river/stream network and the surrounding state boundaries. Source: GRID3 Nigeria Settlement Extents v3.1; author's analysis.

3. Methodology

3.1 Overall Approach

The study integrates two independently processed data streams within a common Benue State boundary: (i) a remotely sensed forest/non-forest cover layer, extracted and validated following the workflow described in Sections 3.2–3.4, and (ii) an event-level insecurity dataset, compiled and analysed following the workflow described in Section 3.5. Both streams were spatially referenced to Local Government Area, the finest administrative unit at which conflict events in the source dataset are consistently geocoded, to permit comparison at a common spatial scale. Section 3.6 states explicitly the point at which the two streams could, and could not, be formally integrated within the scope of the data and processed outputs available at the time of writing.

3.2 Data Sources

Table 1 summarises the principal datasets used in the analysis.

Table 1: Datasets used in the geospatial and conflict-event analysis. Source: Author's compilation, 2026

Dataset	Product / Version	Reference Period	Resolution	Source / Provider
Land cover	ESA WorldCover 10 m, v200	2021	10 m	European Space Agency (via Google Earth Engine, collection ESA/WorldCover/v200)
Settlement extents	GRID3 NGA Settlement Extents, v3.1	2024	Polygon; ~100 m grid	CIESIN, Columbia University / GRID3 programme
Administrative boundary	GRID3 Nigeria administrative boundaries	2024	Vector	GRID3
Conflict / insecurity events	ACLED event-level records for Nigeria (Benue subset)	3 Jan 2010 – 29 May 2025	Point (event-level)	Armed Conflict Location & Event Data Project (ACLED)

The land-cover input for this study is the ESA WorldCover 10 m 2021 (v200) product, accessed via the Google Earth Engine data catalogue (collection ESA/WorldCover/v200). This is currently the most recent global WorldCover release: ESA has issued a 2020 map (v100) and a 2021 map (v200), generated with different algorithm versions and not directly interchangeable (ESA WorldCover Consortium, 2022; Zanaga et al., 2022); the 2021 v200 edition was used throughout the present analysis.

3.3 Forest-Cover Extraction

Forest cover was derived from the existing ESA WorldCover 2021 v200 classification rather than through an independent supervised or unsupervised classification exercise; the procedure therefore constitutes class extraction and reclassification of an established land-cover product, not a new land-cover classification (cf. Gorelick et al., 2017 for the underlying GEE processing model). All processing was carried out in the Google Earth Engine cloud-based platform, which was selected because it hosts the WorldCover archive natively and performs computation on Google's infrastructure without requiring local download or storage of the source raster (Gorelick et al., 2017).

The WorldCover image collection was imported into GEE and clipped to the Benue State administrative boundary obtained from GRID3. The Tree Cover class (WorldCover class value 10) was isolated to represent forest cover; all remaining WorldCover classes, cropland, built-up area, grassland, shrubland, bare or sparsely vegetated surfaces, permanent water bodies, herbaceous wetland and moss/lichen, were reclassified into a single non-forest category. This produced a binary forest/non-forest raster at the native 10 m spatial resolution, exported in GeoTIFF format for subsequent cartographic and spatial-analytical work. Nearest-neighbour resampling was used throughout to preserve the integrity of the categorical classification, consistent with standard practice for categorical land-cover data. The resulting forest layer was interpreted strictly as a WorldCover-defined tree-cover proxy rather than as a national or statutory definition of forest, since national forestry definitions may incorporate additional criteria relating to minimum mapping unit, canopy height, management intent or legal reservation status that WorldCover does not capture.

Settlement information was obtained from the GRID3 Nigeria Settlement Extents dataset (version 3.1, released July 2024), developed by CIESIN, Columbia University, as part of the GRID3 programme (CIESIN, 2024). The settlement-extents product represents mapped, building-detection-derived settled areas as polygon features rather than official administrative or gazetted settlement boundaries, and was clipped to the Benue State boundary and transformed into the coordinate reference system used for the wider analysis. The processed forest raster and the settlement-extents layer were subsequently imported into ArcGIS Pro for spatial integration and cartographic production. Forest cover was symbolised in green and settlement extents in red; the final map layout (Figure 2) was produced at a scale of 1:1,000,000 with a coordinate graticule, north arrow, scale bar and legend, following conventional cartographic standards.

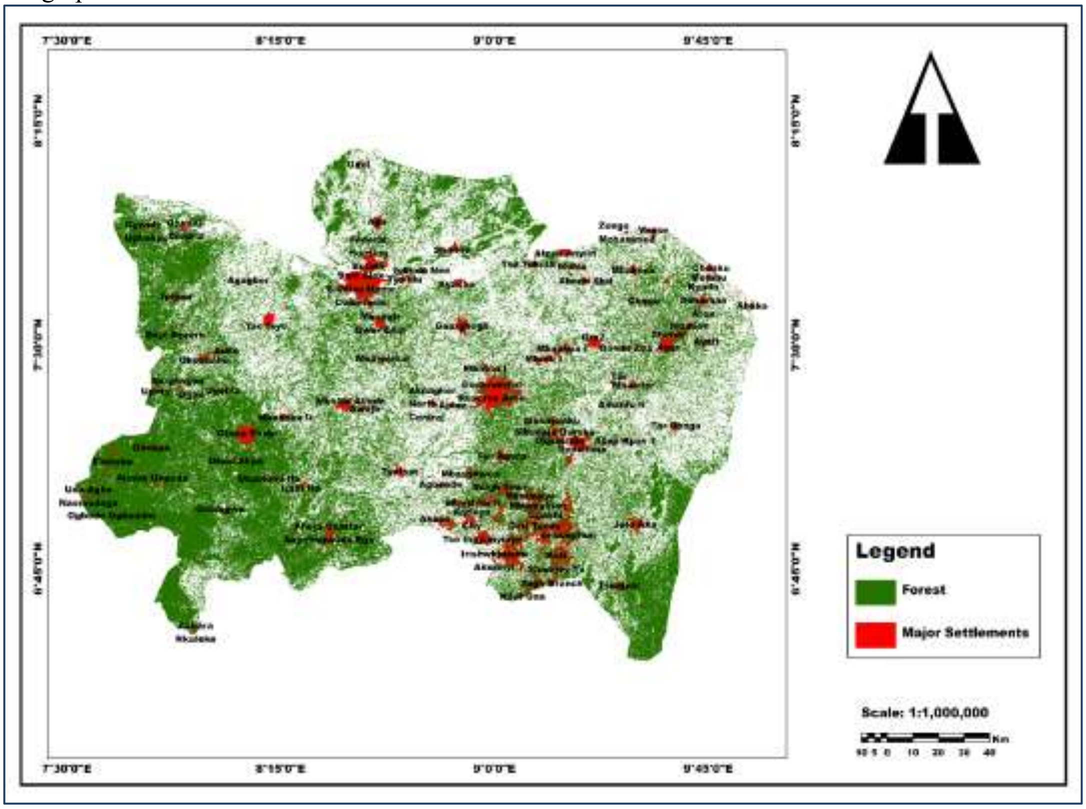

Figure 2: Distribution of ESA WorldCover-derived tree-cover (forest, green) and GRID3-derived major settlement extents (red) across Benue State. Source: ESA WorldCover 2021 v200; GRID3 Nigeria Settlement Extents v3.1; author's analysis.

3.4 Accuracy Assessment

Classification reliability was assessed using 100 independent reference points (50 forest, 50 non-forest), interpreted from high-resolution imagery and compared against the binary WorldCover-derived layer using a standard confusion-matrix approach, reporting overall accuracy, per-class producer's and user's accuracy, and the Kappa coefficient of agreement. Results are reported in Section 4.1.

3.5 Insecurity and Conflict-Event Data

Insecurity was characterised using event-level records from the Armed Conflict Location & Event Data Project (ACLED), a non-profit research initiative that codes political violence, demonstrations and strategic-development events worldwide from local, national and international media, non-governmental organisation reporting and other secondary sources, using a standardised codebook applied by trained regional researchers and subject to a multi-stage review process (Raleigh et al., 2010; ACLED, 2019). Records for Nigeria covering 3 January 2010 to 29 May 2025 were filtered to the 23 Local Government Areas of Benue State, yielding 1,482 events. Each event carries a disorder type (Political violence, Demonstrations or Strategic developments), an event type and sub-event type, actor and associated-actor fields, a geocoded location and administrative hierarchy, a fatality count, and a free-text description drawn from the underlying source report.

For the purposes of this study, "insecurity" is operationalised as the subset of events coded under the Political violence disorder type (Battles, Violence against civilians and Explosions/Remote violence), which excludes non-violent Demonstrations, Riots and Strategic developments and provides a more direct measure of armed insecurity than the full event set. Within this subset, events implicating herder, pastoralist or Fulani-linked actors were further identified by a keyword search of the actor and associated-actor fields (terms: "Fulani," "herder," "pastoral") to approximate the farmer–herder conflict dimension specifically; this is a coding heuristic applied for this study and not an ACLED-native classification, and it will misclassify events in which actor fields are recorded under different terminology (for example, named communal militias without an explicit herder/Fulani descriptor). Events were aggregated by year, by LGA and by sub-event type, and compared across the period immediately preceding (January 2010 – October 2017) and following (November 2017 – May 2025) the effective date of the Benue State Open Grazing Prohibition and Ranches Establishment Law, to provide an independent, data-driven check on official claims regarding the law's effect on herder-attributed violence (cf. Guardian, 2020; ThisDay, 2020).

3.6 Analytical Framework for Relating Forest Cover to Insecurity

The forest-cover layer (Section 3.3) and the conflict-event dataset (Section 3.5) share a common spatial reference, the Benue State LGA framework, which allows the two to be examined side by side. This study relates them through a descriptive, literature-triangulated comparison: the LGAs identified as insecurity hotspots through the ACLED analysis (Section 4.3) are read against the spatial pattern of forest and semi-natural vegetation cover visible in Figure 2 and against independently published, site-level forest-cover evidence for the same LGAs (Anule et al., 2026). This approach was chosen deliberately over a pixel-level statistical overlay (for example, correlating exact zonal forest-cover percentages with conflict density), which would require a further, more resource-intensive stage of geoprocessing and is identified in Section 6 as the natural next stage of this research programme rather than as part of the present study's scope.

4. Results and Discussion

4.1 Forest/Non-Forest Classification Accuracy

The accuracy assessment indicated a high level of agreement between the binary forest/non-forest classification derived from ESA WorldCover 2021 v200 and the independent reference dataset. Of the 50 reference forest points, 48 were correctly classified as forest and 2 as non-forest; of the 50 reference non-forest points, 46 were correctly classified and 4 were misclassified as forest (Table 2).

Table 2: Confusion matrix and accuracy statistics for the binary forest/non-forest classification. Source: Author's accuracy assessment, 2026

Classified class	Reference forest	Reference non-forest	Row total	User's accuracy
Forest	48	4	52	92.3%
Non-forest	2	46	48	95.8%
Column total	50	50	100	—
Producer's accuracy	96.0%	92.0%	—	—

The overall classification accuracy was 94.0%, with a Kappa coefficient of 0.88, indicating strong agreement beyond chance and comparing favourably with the 76.7% global overall accuracy independently reported for the underlying ESA WorldCover 2021 v200 product (ESA WorldCover Consortium, 2022). The relatively balanced producer's and user's accuracies across the forest and non-forest classes indicate that classification performance was not strongly biased toward either class, and the modest number of commission errors in the forest class (4 non-forest points misclassified as forest) and omission errors in the non-forest class (2 forest points misclassified as non-forest) support the suitability of the binary layer for the descriptive spatial analysis presented in Section 4.2. This state-level accuracy is also broadly consistent with the accuracy range (74–98% overall accuracy across twelve individual forest sites and four epochs) reported for supervised forest classification elsewhere in Benue State using higher-resolution imagery (Anule et al., 2026), suggesting that the coarser but freely available WorldCover product performs acceptably for state-scale screening purposes even though it cannot resolve the narrow, fragmented forest patches that site-level studies using sub-metre imagery are able to detect.

4.2 Spatial Distribution of Forest Cover and Settlement

Figure 2 shows the mapped distribution of forest cover and major settlement extents across Benue State. Visually, forest cover is concentrated and relatively contiguous across the western, south-western and parts of the north-central State, and becomes progressively sparser and more fragmented toward the central, eastern and south-eastern areas, where settlement extents are denser and more numerous. Settlement clusters are visibly concentrated around Makurdi and a corridor of secondary towns extending south-east through Otukpo, Adoka and Otobi, and north-east through Gboko, Katsina-Ala and Zaki-Biam, an urban and market-town pattern consistent with Benue's road network and its function as a regional agricultural trade corridor.

This description is based on visual interpretation of the classified forest layer rather than tabulated zonal statistics; a per-LGA quantification of forest area and percentage cover was outside the scope defined for the present study (Section 3.6) and is proposed in Section 6 as a direct extension of the mapping work reported here.

4.3 Spatiotemporal Patterns of Insecurity in Benue State, 2010–2025

Of the 1,482 conflict events recorded for Benue State between January 2010 and May 2025, 1,252 (84.5%) were coded under the Political violence disorder type, comprising 740 direct attacks, 354 armed clashes, 81 abductions or forced disappearances, 65 incidents of mob violence, 8 incidents of sexual violence, and 4 further events (remote explosive/landmine incidents and instances of government forces regaining territory). These 1,252 events recorded a combined 5,394 fatalities. A further 179 events were coded as demonstrations (peaceful protests, violent demonstrations and protests with intervention) and 51 as strategic developments, and are excluded from the fatality-focused analysis that follows.

The annual frequency of political-violence events rose sharply around the introduction of the Open Grazing Prohibition and Ranches Establishment Law. In the period from January 2010 to October 2017 (immediately preceding the law's effective date), Benue State recorded 253 political-violence events (2,002 fatalities), an average of approximately 32.3 events and 255.6 fatalities per year. In the period from November 2017 to May 2025, the state recorded 999 political-violence events (3,392 fatalities), an average of approximately 127.8 events and 434.0 fatalities per year (Figure 3). This roughly four-fold increase in the annual event rate, and a broadly one-and-a-half-fold increase in the annual fatality rate, runs counter to public claims that the law reduced the incidence of herder-attributed attacks relative to the pre-2017 period (Guardian, 2020; ThisDay, 2020). It is, however, consistent with independent monitoring that identified a range of unresolved economic, socio-cultural and legal risks capable of sustaining conflict after the law's enactment (Kwaja & Ademola-Adelehin, 2018), and with the broader observation that legislative bans on open grazing may reconfigure rather than resolve the underlying competition for land and water between farming and herding communities (Bombom & Yemisi, 2024). It should also be noted that ACLED's own event-collection intensity and media-sourcing coverage of Nigeria improved over the 2010s, which may account for some, though on the scale observed here not plausibly all, of the increase.

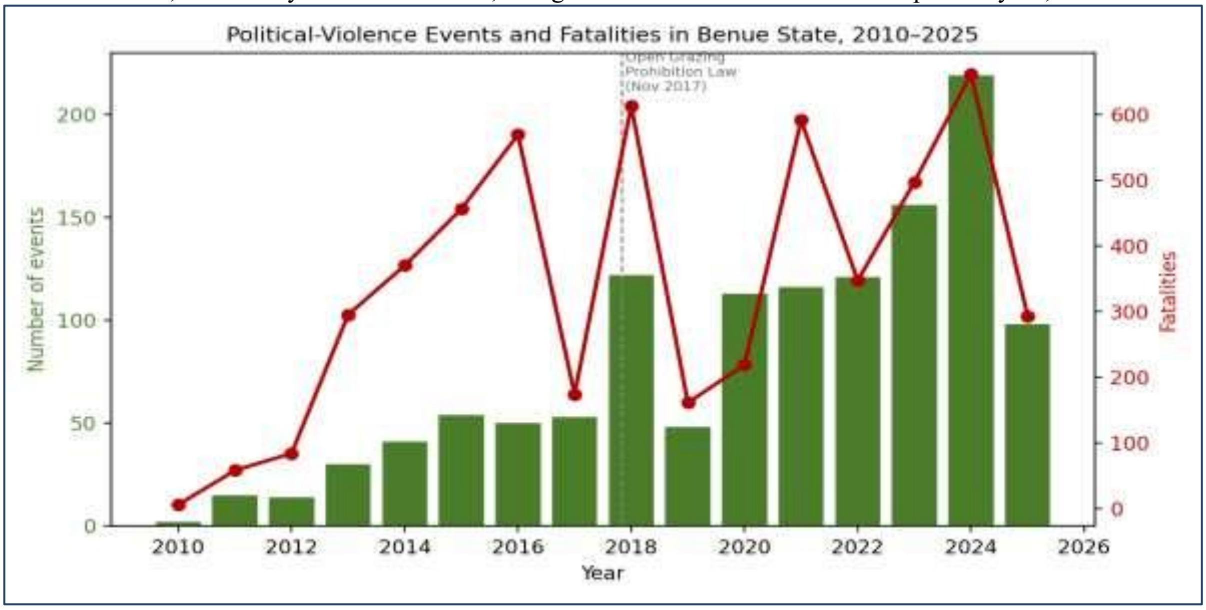

Figure 3: Annual number of political-violence events (bars) and associated fatalities (line) recorded for Benue State, 2010–2025 (ACLED). The dashed line marks the effective date of the Open Grazing Prohibition and Ranches Establishment Law (1 November 2017). The apparent decline in 2025 reflects a partial year of data (through 29 May 2025) rather than a substantive reduction. Source: ACLED, 2026.

Events involving herder, pastoralist or Fulani-linked actors, identified using the keyword approach described in Section 3.5, accounted for 617 of the 1,252 political-violence events (49.3%) and 3,863 of the 5,394 fatalities (71.6%), confirming that farmer–herder-related violence constitutes both the majority of insecurity incidents and a disproportionate share of the associated fatalities in Benue State over the study period. Sub-event coding shows that direct attacks (740 events) and armed clashes (354 events) dominate the political-violence total, with abduction/forced disappearance (81 events) constituting a smaller but non-trivial category consistent with the kidnapping-for-ransom dimension increasingly reported alongside farmer–herder violence elsewhere in Nigeria's forested and semi-forested terrain (HumAngle, 2025).

Table 3 ranks the seven LGAs with the highest recorded fatalities from political violence over the study period.

Table 3: Local Government Areas with the highest political-violence fatalities in Benue State, 2010–2025 (ACLED). Source: ACLED, 2026

LGA	Political-violence events	Fatalities	Share of state fatalities (%)
Agatu	96	869	16.1
Guma	169	762	14.1
Ukum	98	502	9.3
Makurdi	172	450	8.3
Buruku	67	446	8.3
Logo	126	445	8.2
Gwer West	102	413	7.7

These seven LGAs together account for 3,887 fatalities, or 72.1% of the state total, indicating a strongly concentrated rather than evenly distributed conflict geography. Makurdi's high event count partly reflects its role as the state capital and largest urban centre, where a wider range of political-violence sub-types (including urban criminal violence and civil-unrest-adjacent incidents) are recorded in addition to farmer–herder incidents; the remaining six LGAs, Agatu, Guma, Ukum, Buruku, Logo and Gwer West, are predominantly rural, riverine or semi-forested LGAs that recur throughout the Nigerian and Benue-specific literature as farmer–herder conflict flashpoints (Bombom & Yemisi, 2024; Kwaja & Ademola-Adelehin, 2018).

4.4 Forest Distribution and the Geography of Insecurity: A Descriptive Assessment

Consistent with the analytical framework set out in Section 3.6, forest distribution and conflict geography are related here descriptively rather than through a pixel-level statistical overlay, and the comparison is informative even at this level. Guma and

Kwande are both represented among the twelve forest sites independently assessed for cover change in Benue State, with Mbasaan forest in Guma LGA showing a slight net gain in cover between 2005 and 2020 (+3.08 percentage points) while forests elsewhere in the state declined sharply (Anule et al., 2026); Guma is simultaneously the second-highest LGA for conflict fatalities in the present ACLED analysis (Table 3) and has been repeatedly identified in humanitarian and media reporting as hosting large populations of persons displaced by farmer–herder violence, often into the vicinity of remaining bushland and forest reserve areas. Logo, Ukum and Buruku, three of the remaining top-seven fatality LGAs, lie along the Benue River floodplain in the state's north, an area characterised by extensive riverine bushland, seasonal wetland and grazing corridors rather than the dense reserved forest of the state's south-west, but sharing the general property of providing extensive semi-natural vegetation cover in which itinerant armed actors and displaced pastoralist herds can move with reduced visibility to security forces. This pattern is broadly consistent with the wider Nigerian evidence that forested and semi-forested terrain confers an operational advantage on armed non-state actors independent of the specific conflict driver involved, whether banditry in the north-west (HumAngle, 2025; ROAPE, 2026) or farmer–herder violence in the Middle Belt (Bombom & Yemisi, 2024).

This comparison should be read as descriptive and hypothesis-generating rather than as evidence of a statistical or causal relationship between forest cover and conflict incidence. A fully quantitative test would require LGA-level forest-cover zonal statistics, a comparable measure of conflict density normalised by LGA population and area, and an appropriate spatial-statistical test (for example, a bivariate or spatial-lag regression, or a spatial autocorrelation statistic such as Moran's I) capable of distinguishing a genuine spatial association from confounding factors such as population density, road access, or proximity to interstate transhumance routes. The forest–insecurity relationship proposed here is accordingly best understood as a plausible, literature-consistent hypothesis motivated by convergent qualitative evidence, rather than as a statistically demonstrated finding.

5. Conclusion

This study combined a Google Earth Engine-based extraction of forest cover from ESA WorldCover 2021 v200, validated to 94.0% overall accuracy ($\kappa = 0.88$) against independent reference points, with an event-level analysis of 1,482 ACLED-recorded conflict events in Benue State between 2010 and 2025, as a geospatial forest-mapping contribution to the state's security assessment. The insecurity analysis is the component for which this study is able to report genuine, independently verifiable quantitative findings, and which forms the empirical core of that assessment: political-violence events in Benue State rose from an average of approximately 32 per year before the November 2017 Open Grazing Prohibition and Ranches Establishment Law to approximately 128 per year afterward, with farmer–herder-linked actors implicated in roughly half of all political-violence events and more than seventy percent of associated fatalities, and with conflict fatalities strongly concentrated in seven of the state's 23 LGAs. The forest-mapping component successfully produced and validated a current, state-wide binary forest-cover layer and a settlement-cover comparison map, describing a landscape in which forest and semi-natural vegetation cover is concentrated in the western, south-western and north-central parts of the state and thins toward the more densely settled centre, east and south-east. The correspondence between the state's principal conflict-affected LGAs and areas of documented or visually evident forest and riverine bushland is consistent with the hypothesis that forest and semi-natural vegetation cover contributes to the persistence of insecurity in Benue State, a hypothesis well supported for other Nigerian regions by existing literature and now given a state-specific, geospatial and event-data foundation by this study. A fully quantitative statistical test of that relationship, building directly on the mapping and conflict-analysis foundation established here, is identified as the principal next step for this line of research.

6. Recommendations

Building on these findings, the following recommendations are proposed:

- Complete the forest-cover zonal statistics. The exported GeoTIFF forest layer should be processed to produce LGA-level area, percentage-cover and patch-size statistics using GEE's reduceRegion or an equivalent GIS zonal-statistics operation, as the necessary precursor to any quantitative forest–insecurity analysis.
- Conduct a formal spatial-statistical overlay. Once forest-cover statistics are available, LGA-level forest cover should be tested against conflict-event density and fatality rate (normalised by population and/or land area) using an appropriate bivariate or spatial-regression approach, with spatial autocorrelation (e.g., Moran's I) assessed to distinguish genuine clustering from confounding factors such as population density or road access.
- Disaggregate the herder/farmer actor classification. The keyword-based actor classification used in Section 3.5 should be replaced or supplemented with a manually reviewed classification of actor roles, to reduce misclassification of events in which farmer or herder involvement is implicit in the location and notes fields but not stated in the coded actor terms.
- Track forest-cover change, not only current extent. Given documented multi-decadal forest loss at several individual sites in Benue State (Anule et al., 2026), the single-date WorldCover extraction used here should be supplemented with a multi-year GEE time series (for example, using annual WorldCover composites or a Landsat/Sentinel-2 change-detection approach) to determine whether conflict-affected LGAs are also experiencing above-average rates of forest loss, rather than simply above-average current forest extent.
- Field and key-informant validation of the forest–insecurity hypothesis. Given the sensitivity and evolving nature of the security situation, any inference that specific forest or bushland areas function as staging grounds for armed actors should be corroborated through security-agency records, displacement-tracking data and community-level key-informant interviews before being used to inform operational security or land-management decisions.
- Institutional integration. Should the quantitative relationship be confirmed, forest-cover monitoring outputs of the kind produced here should be shared with Benue State's security and emergency-management agencies and with the National Space Research and Development Agency (NASRDA) as an input to early-warning and resource-allocation planning, alongside the state's existing farmer-herder conflict mitigation mechanisms.

7. Limitations

The following limitations apply to the analysis presented and should be taken into account in any use of its findings:

- Descriptive rather than tabulated forest-cover statistics. Forest distribution is characterised through classification accuracy and visual/spatial description of the mapped layer (Sections 4.1–4.2) rather than through tabulated LGA-level area, percentage-cover or patch-size statistics.
- No formal statistical test of the forest–insecurity relationship. The correspondence discussed in Section 4.4 is descriptive and literature-supported, not the output of a spatial-statistical test, and should not be read as demonstrating a causal or statistically confirmed spatial relationship.
- Single-date land cover. ESA WorldCover 2021 v200 represents land cover as at 2021 only; forest cover, settlement extent and the underlying conflict drivers have almost certainly continued to change since that date and since the 2024 GRID3 settlement vintage used here.
- Actor-classification heuristic. The identification of herder/farmer-linked conflict events relied on a keyword search of ACLED actor fields (Section 3.5) rather than a manually reviewed classification, and will under- or over-count events depending on how consistently actor identity is recorded in underlying source reporting.
- Reporting and coverage effects. ACLED's event coverage of Nigeria has evolved over the 2010–2025 period; part of the observed rise in recorded events, particularly in the earliest years of the series, may reflect improving source coverage rather than a purely underlying increase in violence, though the scale of the post-2017 increase is unlikely to be a coverage artefact alone.
- WorldCover accuracy is global, not Benue-specific in origin. The 76.7% global validation figure for ESA WorldCover 2021 v200 (ESA WorldCover Consortium, 2022) is not a Benue-specific accuracy estimate; the 94.0% accuracy reported in Section 4.1 is specific to this study's own 100-point reference sample and should not be assumed to generalise uniformly across all land-cover classes or all parts of the state.

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Data Availability Statement

The ACLED conflict-event data used in this study are publicly available from the Armed Conflict Location & Event Data Project (https://acleddata.com) subject to ACLED's standard attribution policy. ESA WorldCover 2021 v200 is freely available via the Google Earth Engine data catalogue (collection ESA/WorldCover/v200) and via the ESA WorldCover viewer (https://esa-worldcover.org). GRID3 Nigeria Settlement Extents v3.1 is available from CIESIN, Columbia University, under a CC BY-SA 4.0 licence. The processed forest-cover GeoTIFF and the ACLED extract and analysis code underlying Section 4.3 are available from the corresponding author upon reasonable request.