Assessment and Monitoring of Flood Inundation Along the River Niger Channel in Nigeria (2015–2023)

A Multi-Year Sentinel-1 SAR and Google Earth Engine Analysis

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Abstract: Riverine flooding along the River Niger is a recurrent hazard with substantial implications for settlements, agriculture, infrastructure and disaster management in Nigeria. This study assessed and monitored flood inundation along a 5 km corridor of the River Niger for the period 2015–2023 using Sentinel-1 Synthetic Aperture Radar (SAR), Google Earth Engine (GEE) and complementary geospatial datasets. Annual flood footprints were derived from pre-flood and flood-period Sentinel-1 observations using a backscatter-change workflow, speckle filtering, threshold classification, terrain and permanent-water masks, and connected-pixel refinement. The mapped flood extents were intersected with population, cropland and settlement datasets to estimate exposure and to construct an annual settlement-inundation matrix. Internal consistency checks were applied to the annual statistics and the full 817-settlement matrix. The largest mapped event occurred in 2018, when 1,000,009 ha were inundated, an estimated 394,951 people were exposed and 18,467 ha of cropland intersected the flood footprint. Other high-exposure years included 2015, 2020 and 2022. Analysis of the settlement matrix identified 310 of 817 settlement records as recurrent hotspots, defined as inundation in at least four of the nine years, while 14 settlement records were inundated in all nine years. The results reveal marked interannual variability but also persistent spatial recurrence in both upstream and downstream sections of the corridor. The study demonstrates the operational value of open Sentinel-1 data and cloud computing for repeatable flood surveillance and provides a spatial evidence base for early warning, anticipatory action, floodplain planning, agricultural preparedness and targeted resilience investments along the River Niger.

Keywords: *River Niger; Flood Inundation; Sentinel-1 SAR; Google Earth Engine; Population Exposure; Cropland Exposure; Inundation Frequency; Nigeria.*

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I. INTRODUCTION

➢ *Introduction*

Flooding is one of the most geographically widespread natural hazards and becomes a disaster where floodwater intersects exposed populations, livelihoods, assets and vulnerable infrastructure. Recent global assessments estimate that approximately 1.81 billion people are directly exposed to a 1-in-100-year flood, while satellite observations show that the proportion of people living in areas affected by observed inundation has increased since the beginning of the twenty-first century (Rentschler, Salhab, & Jafino, 2022; Tellman et al., 2021). These trends have strengthened the need for consistent, spatially explicit flood monitoring to support disaster risk reduction, climate adaptation and sustainable development.

Flood risk is not determined by hydrological hazard alone. Population growth, settlement expansion, agricultural intensification, floodplain occupation, drainage alteration and the condition of critical infrastructure can substantially increase the consequences of an event. In many low- and middle-income settings, these pressures interact with limited hydrometric coverage, fragmented risk information and constrained local response capacity. Consequently, retrospective mapping of where floods have repeatedly

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occurred is important not only for documenting past disasters but also for identifying places where preparedness and risk-reduction investments should be prioritised.

Nigeria experiences recurrent fluvial, pluvial and coastal flooding. Reviews of flood research and management in the country have consistently identified high exposure, uneven coping capacity, rapid urbanisation and gaps in integrated flood-risk analysis and governance (Komolafe, Adegboyega, & Akinluyi, 2015; Oladokun & Proverbs, 2016; Umar & Gray, 2023). The Niger–Benue system is especially important because it concentrates large populations, agricultural land, transport corridors, urban centres and strategic infrastructure along major floodplains. Earlier geospatial studies of the 2012 disaster demonstrated the value of Earth observation for delineating inundation and identifying exposed communities in the Niger–Benue basin and Kogi State (Aderoju et al., 2014; Nkeki, Henah, & Ojeh, 2013).

The growing availability of Earth-observation data has transformed flood assessment. Synthetic Aperture Radar (SAR) is particularly useful because microwave observations are largely independent of daylight and can penetrate cloud cover, which is a major advantage during the West African wet season. Sentinel-1 provides systematic C-band SAR observations, while Google Earth Engine enables scalable processing of large satellite archives (Gorelick et al., 2017; Torres et al., 2012). Multi-temporal SAR change detection has therefore become an established approach for rapid flood mapping, particularly when supported by permanent-water and terrain masks that reduce false detections (DeVries et al., 2020; Twele, Cao, Plank, & Martinis, 2016).

Recent Nigerian studies further demonstrate the increasing maturity of satellite-based flood intelligence. Odiji et al. (2024) mapped a decade of flood inundation and damage in the Niger–Benue confluence using multi-sensor imagery and GEE. Abu and Ibebuchi (2025) examined the 2022 Nigerian flood using remote-sensing products and climate data, Idowu et al. (2025) evaluated Earth-observation products for operational flood monitoring in a sparsely gauged Nigerian basin, and Adeyemi and Komolafe (2025) applied machine-learning and geospatial methods to flood-hazard prediction in the lower Niger basin. These studies provide important advances, but a corridor-wide, multi-year assessment that directly links annual flood extent to population exposure, cropland exposure and settlement-level recurrence remains valuable for prioritising persistent hotspots along the River Niger.

This research therefore applies a consistent geospatial workflow to assess annual flood inundation along the Nigerian River Niger corridor between 2015 and 2023. The study emphasises observable inundation and exposure rather than hydrodynamic simulation. By integrating annual Sentinel-1 flood footprints with population, cropland and settlement data, it provides both event-scale statistics and a nine-year recurrence perspective that can support early warning, anticipatory action, land-use planning and long-term resilience building.

➢ *Statement of Problem*

Communities and economic activities along the River Niger continue to experience recurrent flooding, yet flood-risk management is often informed by single-event assessments, post-disaster reports or geographically restricted studies. Such evidence is useful for emergency response but is less effective for distinguishing locations that are repeatedly exposed from those affected only during exceptional events. This distinction is critical because recurrently inundated settlements require different combinations of warning, land-use control, infrastructure protection, livelihood adaptation and relocation planning than areas with infrequent exposure.

A second problem concerns spatial and temporal consistency. Flood information in Nigeria is generated from multiple sensors, mapping approaches, administrative reports and field observations. Differences in acquisition dates, spatial resolution, classification methods and reporting units can make long-term comparison difficult. Reviews of flood risk analysis in Nigeria have noted persistent gaps in integrated datasets, modelling capability, institutional coordination and the translation of geospatial information into operational planning (Komolafe et al., 2015; Oladokun & Proverbs, 2016; Umar & Gray, 2023). A repeatable Earth-observation workflow applied over several years can reduce some of these inconsistencies and provide a common spatial basis for comparison.

A third gap is that flood extent alone does not describe potential impact. Two events with similar mapped area may affect very different numbers of people or hectares of cropland depending on where the water occurs. Conversely, a spatially smaller event can have high consequences if it intersects densely settled or agriculturally important areas. Recent work on the Niger–Benue system and the 2022 national flood has shown the value of integrating hazard and exposure information (Abu & Ibebuchi, 2025; Odiji et al., 2024), but there remains a need to extend this logic to a longer series across the River Niger corridor.

The central research problem addressed by this study is therefore the absence of a spatially consistent, multi-year evidence base that simultaneously characterises annual inundation, population exposure, cropland exposure and settlement recurrence along the River Niger in Nigeria. Without such evidence, recurrent hotspots may remain hidden within annual disaster statistics, weakening the ability of institutions to target preparedness and long-term risk-reduction measures.

➢ *Aim and Objectives*

The aim of this study is to assess and monitor flood inundation and exposure along the River Niger channel in Nigeria from 2015 to 2023 using Earth-observation and geospatial techniques.

The specific objectives are to:

- Map the annual flood inundation extent along the River Niger corridor from 2015 to 2023;

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- Estimate annual population and cropland exposure to the mapped flood inundation;
- Determine settlement-level inundation frequency across the nine-year study period; and
- Identify settlements with recurrent flood exposure for priority risk-reduction and preparedness action.

➢ *Justification of the Study*

The study is justified by the persistent human and economic consequences of flooding along the River Niger and by the need to move from event-by-event response toward risk-informed preparedness. A multi-year record provides information that cannot be obtained from a single flood map: it identifies whether an observed inundation is exceptional or part of a recurring spatial pattern. This is particularly relevant for settlements, farmland and infrastructure located on active floodplains, where repeated exposure can erode household assets, disrupt food production and generate cumulative recovery costs.

The use of Sentinel-1 SAR is also justified by the environmental conditions under which Nigerian floods occur. Persistent cloud cover during the wet season can constrain optical imagery, whereas SAR can provide observations under cloudy and low-light conditions. Google Earth Engine further enables consistent processing of multi-year satellite archives without requiring local storage of large volumes of imagery (Gorelick et al., 2017; Torres et al., 2012). This combination therefore provides a practical basis for both retrospective assessment and future operational monitoring.

The study additionally contributes to decision support. Population and cropland intersections translate flood footprints into exposure indicators, while settlement-frequency analysis converts nine separate annual maps into a prioritisation layer. These outputs are relevant to emergency management, hydrological and meteorological services, spatial planning authorities, agricultural agencies and local governments. They can inform contingency planning, early-warning dissemination, anticipatory action, resilient infrastructure investment and targeted community preparedness.

Scientifically, the research extends the growing Nigerian literature on flood mapping by applying a consistent nine-year framework beyond a single city, state or extreme event. It complements confluence-scale and national studies (Abu & Ibebuchi, 2025; Odiji et al., 2024) and provides a reproducible basis for future work incorporating flood depth, duration, forecasts, river-gauge observations and socio-economic vulnerability.

➢ *Study Area*

The River Niger is the principal river system of West Africa and is approximately 4,100–4,200 km long. It rises in the Guinea Highlands and flows through Mali and Niger, forms part of the Niger–Benin boundary, and enters Nigeria before discharging through the Niger Delta into the Gulf of Guinea. Within Nigeria, the river and its floodplain connect contrasting hydrological, ecological and socio-economic environments, including major agricultural areas, transport corridors, urban centres and deltaic wetlands.

This study focuses on the main River Niger corridor within Nigeria and applies a 5 km buffer around the mapped river channel as the analysis zone. The source settlement dataset covers river-adjacent areas in Kebbi, Niger, Kwara, Kogi, Edo, Anambra, Delta, Bayelsa and Rivers States. The corridor approach was adopted to maintain a consistent spatial frame across all years and to focus on settlements and land uses most directly associated with riverine inundation. The River Benue joins the Niger at Lokoja, and downstream flood behaviour reflects the combined influence of catchment rainfall, tributary inflows, river discharge, floodplain storage and deltaic drainage conditions.

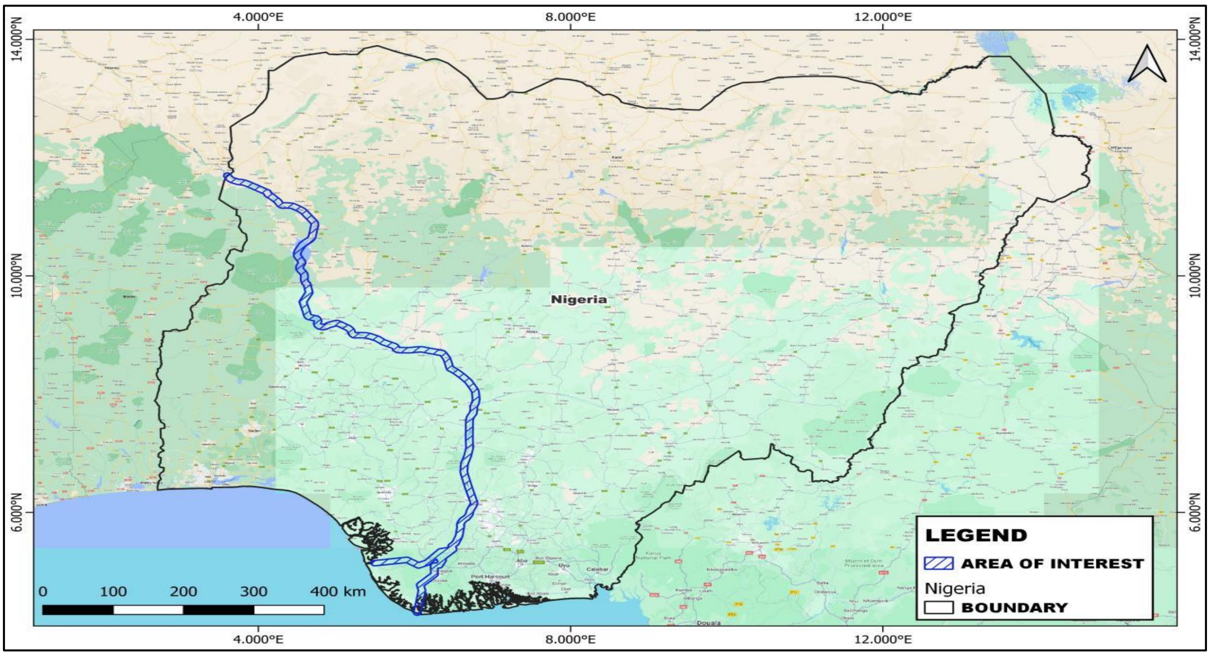

Fig 1 Study Area and 5 km River Niger Analysis Corridor in Nigeria.

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II. LITERATURE REVIEW

➢ *Flood Hazard, Exposure and Risk*

Floods occur when water exceeds the carrying capacity of channels, drainage systems or soils and spreads into areas that are normally dry. Their consequences depend on the interaction between hazard characteristics—such as extent, depth, velocity, duration and timing—and the spatial distribution of people, assets, ecosystems and livelihoods. For this reason, contemporary risk assessment distinguishes between the physical flood hazard and exposure or vulnerability. A satellite-derived flood footprint establishes where inundation occurred, while an exposure analysis identifies the people, cropland or settlements located within that footprint. It does not, by itself, prove physical damage or economic loss.

Global evidence shows that exposure is increasing in many flood-prone regions as population and development expand into hazard zones. Rentschler et al. (2022) estimated that 1.81 billion people are directly exposed to significant flood risk, while Tellman et al. (2021) demonstrated increasing population presence in areas observed to have flooded. These findings emphasise the importance of monitoring both the hazard footprint and the spatial distribution of exposed populations.

➢ *Flooding in Nigeria and the River Niger–Benue System*

Flooding is a recurrent environmental and development challenge in Nigeria. Its drivers vary geographically and include intense rainfall, river overflow, poor drainage, floodplain encroachment, land-cover change, coastal processes and limitations in infrastructure and risk governance. Komolafe et al. (2015) reviewed flood-risk analysis in Nigeria and highlighted the need for improved vulnerability assessment and more integrated approaches. Oladokun and Proverbs (2016) similarly identified institutional, technical and planning challenges in national flood-risk management, while Umar and Gray (2023) documented the occurrence, impacts and modelling approaches used across the country.

The Niger–Benue basin has received substantial attention because of the scale of its floodplain and the concentration of settlements and economic activities along the two rivers. Nkeki et al. (2013) used geospatial techniques to assess flood risk across the basin and identified substantial population exposure in downstream floodplain areas. Aderoju et al. (2014) assessed the 2012 Kogi State flood using geospatial data and demonstrated the value of satellite observations for identifying inundated and vulnerable communities. These studies established an important foundation for using remote sensing in flood assessment, but they were largely event-specific or spatially restricted.

More recent work has expanded the temporal and methodological scope. Odiji et al. (2024) mapped a decade of flood inundation and damage indicators around the Niger–Benue confluence using multi-sensor data and GEE, identifying major flood years including 2012, 2018, 2020 and 2022. Abu and Ibebuchi (2025) evaluated the 2022 national flood using remote-sensing products and climate data, while Adeyemi and Komolafe (2025) applied machine-learning-based geospatial analysis to flood-hazard prediction in the lower Niger basin. Together, these studies show that flood assessment in Nigeria is shifting toward multi-source, data-driven and spatially explicit approaches.

➢ *Remote Sensing and GIS for Flood Assessment*

Remote sensing provides synoptic and repeatable observations that are particularly valuable where ground measurements are sparse or difficult to access during disasters. Optical sensors can delineate open water using spectral indices and classification methods, but their usefulness during active flood periods can be reduced by cloud cover. SAR sensors overcome this limitation by transmitting microwave energy and measuring the returned signal, allowing observation through clouds and at night.

Flooded open surfaces generally exhibit reduced radar backscatter because specular reflection directs energy away from the sensor, although vegetation, urban structures, wind roughening and double-bounce interactions can complicate this relationship. Multi-temporal approaches therefore compare pre-event and event-period SAR observations and classify significant backscatter changes as candidate inundation. Twele et al. (2016) demonstrated a fully automated Sentinel-1 flood-mapping chain, while DeVries et al. (2020) showed the value of combining Sentinel-1 and Landsat observations in GEE for rapid and robust flood monitoring. Auxiliary information such as slope, permanent water and connectivity is commonly used to reduce false positives.

➢ *Sentinel-1 SAR and Google Earth Engine*

Sentinel-1 is a C-band SAR mission designed for systematic Earth observation (Torres et al., 2012). The mission's all-weather capability and regular acquisitions make it suitable for monitoring dynamic water conditions. In Google Earth Engine, the Sentinel-1 GRD collection is distributed after standard processing that includes orbit information, thermal-noise removal, radiometric calibration and terrain correction, with backscatter represented in decibels. These characteristics support consistent multi-year analysis when acquisition geometry and polarisation are controlled.

Google Earth Engine provides cloud-based access to satellite archives and geospatial datasets and allows analysis to be executed close to the data rather than through repeated local downloads (Gorelick et al., 2017). For flood studies, this makes it feasible to automate image filtering, compositing, change detection, masking, area calculation and intersection with exposure datasets across large regions and multiple years.

➢ *Population, Cropland and Settlement Exposure*

Flood impact assessment increasingly integrates hazard footprints with exposure datasets. Population grids such as the Global Human Settlement Layer (GHSL) provide spatially distributed population estimates, while land-cover products can identify cropland located within inundated

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areas. Such intersections are useful screening indicators but should be interpreted as exposure rather than confirmed damage, because actual losses depend on depth, duration, structural characteristics, crop phenology, preparedness and other vulnerability factors.

Settlement-level recurrence offers an additional dimension. By recording whether each settlement intersects the flood footprint in each year, a binary settlement-by-year matrix can be constructed and summed to derive inundation frequency. This approach distinguishes persistent hotspots from infrequently affected locations and is directly relevant to targeting early warning, preparedness and floodplain management.

- *Recent Operational Flood-Monitoring Approaches in Nigeria*

Operational use of Earth observation is particularly important in sparsely gauged basins. Idowu et al. (2025) evaluated satellite and Earth-observation products for catchment-scale flood monitoring and risk management in a sparsely gauged to ungauged Nigerian basin and showed that such products can provide useful complementary information for operational decision-making. Abu and Ibebuchi (2025) likewise demonstrated the value of integrating satellite-derived flood products with climatic information for national-scale flood assessment.

These developments indicate that the principal challenge is no longer only data availability but also consistency, reproducibility and the conversion of mapped inundation into decision-relevant information. A multi-year River Niger corridor analysis that connects annual extent to exposure and recurrence therefore contributes directly to this operational need.

- *Research Gap and Contribution of the Study*

The literature establishes the severity of Nigerian floods and the usefulness of geospatial methods, but three gaps remain relevant to the present research. First, many studies focus on individual flood events or specific urban/confluence areas rather than a consistent nine-year corridor-wide series. Second, flood extent is often reported without a parallel settlement-recurrence analysis that identifies locations repeatedly affected over time. Third, the distinction between mapped exposure and verified physical damage is not always made explicit, which can lead to over-interpretation of satellite intersection results.

This study addresses these gaps by applying a consistent Sentinel-1/GEE workflow to annual River Niger flood mapping from 2015 to 2023, quantifying population and cropland exposure, and deriving settlement-level inundation frequency from an 817-record matrix. The resulting evidence is designed to complement hydrological forecasts and field observations, not replace them, and to support spatial prioritisation for flood-risk reduction.

III. METHODOLOGY

- *Research Design*

The study employed a retrospective geospatial assessment of annual flood inundation along the River Niger corridor for nine flood seasons (2015–2023). The analytical design consisted of four linked components: (i) annual Sentinel-1 flood mapping; (ii) spatial refinement of the flood mask using terrain and permanent-water information; (iii) intersection of annual flood footprints with population and cropland data to estimate exposure; and (iv) intersection with settlement records to derive annual inundation status and multi-year recurrence. Google Earth Engine was used for satellite-data access and core raster processing, while QGIS was used for additional spatial analysis, cartographic presentation and quality checks.

- *Data Access, Selection and Sources*

Datasets were selected on the basis of temporal coverage, spatial resolution, operational accessibility and relevance to the study objectives. Sentinel-1 GRD imagery formed the principal flood-detection dataset. Population, cropland/land-cover, settlement, terrain and permanent-water datasets were used for refinement and exposure analysis. Not all auxiliary product version identifiers were available in the archived processing record; where exact version information is unavailable, this is stated explicitly rather than inferred.

Table 1 Datasets Used in the Flood Inundation and Exposure Workflow.

Dataset	Period / epoch	Resolution / format	Purpose	Source / reference
Sentinel-1 GRD SAR	Annual flood-season scenes, 2015–2023	~10 m; VV; descending acquisitions documented	Annual flood change detection	Copernicus Sentinel-1; Torres et al. (2012); GEE
GHSL / GHS-POP	Population layer used in original analysis	100 m raster reported in source	Population exposure estimation	European Commission JRC; Schiavina et al. (2022)
Cropland / land-cover	2020 product reported	10 m raster	Cropland exposure estimation	Global pre-classified land-cover product; exact ID not retained
Nigeria settlement points	2023	Vector points	Settlement inundation and recurrence	GRID3 Nigeria
Digital elevation model	Static	Raster	Slope masking (>5% excluded)	DEM source/version not retained in source manuscript
Global Surface Water	Long-term surface-water record	Raster	Permanent-water masking	JRC Global Surface Water; Pekel et al. (2016)
NigeriaSat-X imagery	2023 validation imagery	High-resolution raster	Visual cross-check where available	NASRDA

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➢ *Sentinel-1 Scene Selection and Preprocessing*

Sentinel-1 Ground Range Detected imagery was accessed through Google Earth Engine. Scenes were filtered to maintain consistent acquisition characteristics, with VV polarisation and descending orbit direction maintained consistently across the annual analysis. Controlling acquisition geometry reduces backscatter differences unrelated to flooding. The Earth Engine Sentinel-1 GRD collection is distributed after standard preprocessing that includes orbit-file application, thermal-noise removal, radiometric calibration and terrain correction. Atmospheric correction was not applied because it is an optical-image preprocessing procedure and is not required for calibrated SAR backscatter.

The source data table records representative flood-period acquisition dates of 20 September 2015, 26 September 2016, 21 September 2017, 28 September 2018, 23 September 2019, 29 September 2020, 24 September 2021 and 9 October 2022. A 2023 Sentinel-1 scene was included in the analysis, but its exact acquisition date is not retained in the source table. Pre-flood and flood-period images or mosaics were generated for each year and a speckle-reduction filter was applied before change detection. For full reproducibility, future archiving should retain exact image identifiers, orbit numbers, date windows, filter parameters and classification thresholds.

➢ *Flood Mapping Techniques*

Annual flood extent was derived using multi-temporal SAR backscatter change detection rather than an optical water index. Pre-flood and flood-period Sentinel-1 composites were compared to create a backscatter-change layer. A threshold was then applied to classify candidate inundation. This approach follows established Sentinel-1 flood-mapping practice in which a marked decrease or change in radar backscatter is used to identify newly inundated surfaces (DeVries et al., 2020; Twele et al., 2016).

Candidate flood pixels were refined to reduce common false positives. Areas with slope greater than 5% were excluded because widespread standing-water inundation is less likely on steep terrain. Permanent surface water was removed so that mapped area represented anomalous or newly inundated land rather than the normal river channel and persistent water bodies. The JRC Global Surface Water record provides a widely used basis for distinguishing persistent and episodic surface water (Pekel, Cottam, Gorelick, & Belward, 2016). Isolated detections with fewer than four connected neighbouring pixels were also removed. The resulting layer represented the annual refined flood footprint within the 5 km River Niger corridor.

➢ *Population and Cropland Exposure Assessment*

For each year, the refined flood footprint was spatially intersected with the population grid and cropland/land-cover layer. Population values within inundated pixels were summed to estimate the number of people spatially exposed to the mapped flood. Cropland intersecting the flood footprint was converted to hectares to estimate agricultural exposure. These indicators are reported as exposure rather than confirmed damage because the analysis does not directly measure flood depth, duration, structural loss, crop phenology or economic value.

➢ *Settlement Inundation Frequency and Hotspot Definition*

Settlement points within the 5 km analysis corridor were intersected with each annual flood footprint. A binary matrix was created in which YES indicated that a settlement record intersected the mapped flood footprint in a given year and NO indicated no intersection. The annual values were summed for each settlement to produce an inundation frequency from 0 to 9 years. For this study, a recurrent hotspot was defined as a settlement record inundated in at least four of the nine years (frequency ≥ 4). Duplicate settlement names were retained because they represent separate geospatial records in the settlement dataset unless independently verified as duplicates.

➢ *Data Analysis and Visualisation*

Annual inundation statistics were summarised by year and compared with population and cropland exposure. Settlement-frequency counts were tabulated for all values from 0 to 9 years, while recurrent hotspots were summarised by state. Annual flood maps and exposure charts were used to examine spatial and temporal variability. QGIS was used for cartographic refinement and presentation of spatial outputs.

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➢ *Analytical Flow Chart*

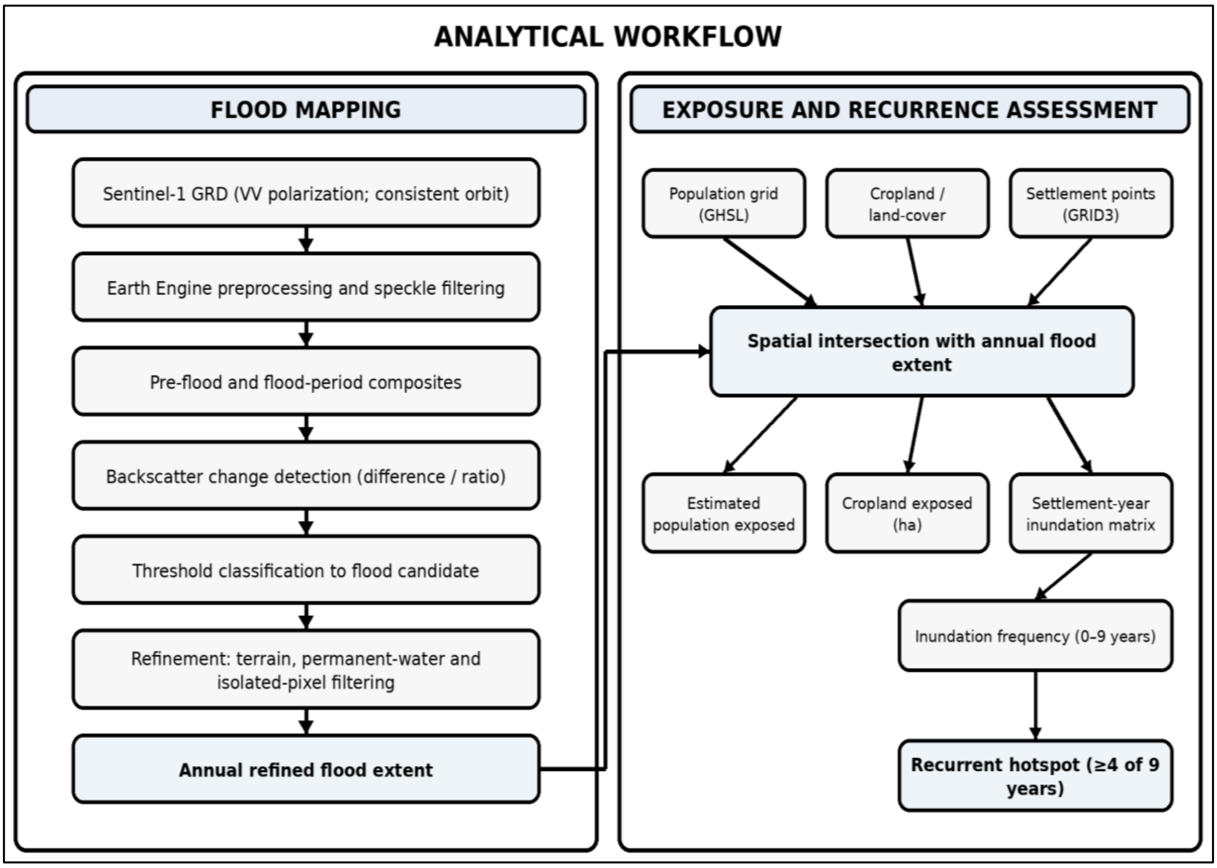

Fig 2 Analytical Workflow for Annual Flood Mapping, Exposure Estimation and Settlement-Recurrence Analysis.

➢ *Validation and Quality Assurance*

Mapped flood extents were visually checked against NigeriaSat-X imagery where available. A formal confusion matrix, reference-sample design and quantitative accuracy statistics were not available for the analysis; consequently, no unsupported accuracy values are reported. The outputs are therefore interpreted as a consistent screening and monitoring product rather than a formally accuracy-certified flood inventory.

Internal consistency checks were applied to the annual statistics and the complete settlement matrix. The 2018 flood extent used in the analysis is 1,000,009 ha, consistent with the year-specific 2018 output and its accompanying results record. Direct summation of the 817-settlement annual inundation matrix identified 310 settlement records with an inundation frequency of at least four years. These internally consistent values are used throughout the study.

➢ *Methodological Limitations and Reproducibility*

The study has several limitations. The numerical SAR classification threshold, the exact 2023 Sentinel-1 acquisition date, the DEM product identifier and the precise cropland product/version were unavailable in the archived processing record. These omissions constrain independent reproduction of the complete processing chain. In addition, a single population or land-cover epoch may not perfectly represent annual changes in population and agriculture across 2015–2023.

SAR flood mapping can also be affected by vegetation, urban double-bounce, wind-roughened water and differences in image geometry. The 5 km corridor deliberately focuses on river-adjacent inundation and may exclude flood impacts farther from the mapped main channel. Future implementations should archive the GEE script, image identifiers, orbit information, thresholds and auxiliary datasets; incorporate gauge and field observations; and report quantitative accuracy metrics.

IV. RESULT AND DISCUSSION

A. Results

➢ *Flood Extent along the River Niger Channel*

Flood extent varied markedly across the nine-year period. Annual maps show that inundation was not spatially uniform and that both upstream and downstream sections of the corridor experienced flood expansion in different years. The dominant event in the record was 2018, while 2015, 2020 and 2022 also showed substantial inundation. The complete annual map series is presented in Figure 3.

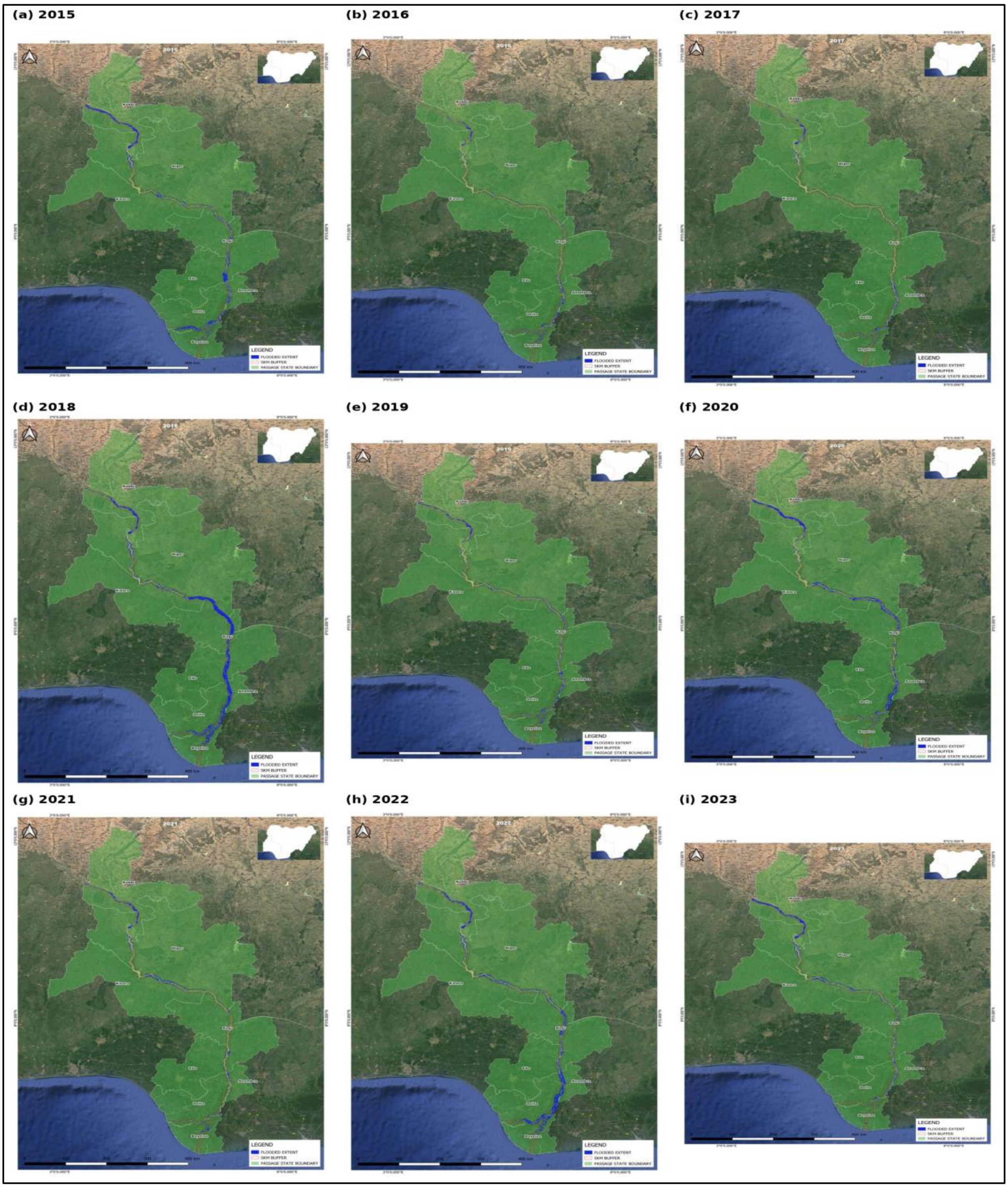

Fig 3 Annual Mapped Flood Extent Along the River Niger Corridor, 2015–2023. Blue Areas Indicate the Mapped Flood Footprint within the Study Corridor.

Table 2 Annual Flood Extent, Estimated Population Exposure and Cropland Exposure, 2015–2023.

Year	Flood extent (ha)	Estimated population exposed	Cropland exposed (ha)
2015	37,725	76,033	1,369
2016	10,089	11,601	0
2017	9,919	7,810	0
2018	1,000,009	394,951	18,467
2019	20,385	18,850	349
2020	42,245	72,712	761
2021	14,613	6,127	265
2022	47,781	108,772	970
2023	22,496	4,674	274

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In 2015, 37,725 ha were mapped as inundated, with an estimated 76,033 people and 1,369 ha of cropland exposed. Flood extent decreased sharply in 2016 to 10,089 ha and in 2017 to 9,919 ha, with substantially lower population exposure and no cropland intersection recorded in the annual exposure statistics for those two years.

The 2018 event was exceptional relative to the rest of the series. A total of 1,000,009 ha were mapped as inundated, an estimated 394,951 people were exposed and 18,467 ha of cropland intersected the flood footprint. The spatial pattern indicates extensive downstream inundation, including the Niger–Benue confluence and lower Niger floodplains. This year dominates the annual area series and represents the principal extreme event within the 2015–2023 analysis window.

Flood extent declined in 2019 to 20,385 ha, with 18,850 people and 349 ha of cropland exposed. In 2020, inundation expanded again to 42,245 ha and exposed an estimated 72,712 people and 761 ha of cropland. The 2021 event was comparatively smaller, at 14,613 ha, with 6,127 people and 265 ha of cropland exposed.

The 2022 event combined a relatively large mapped extent (47,781 ha) with the second-highest population exposure in the series (108,772 people). Cropland exposure was estimated at 970 ha. In 2023, mapped inundation decreased to 22,496 ha, with an estimated 4,674 people and 274 ha of cropland exposed. The comparatively low 2023 population estimate illustrates that inundated area alone is not a sufficient indicator of potential impact.

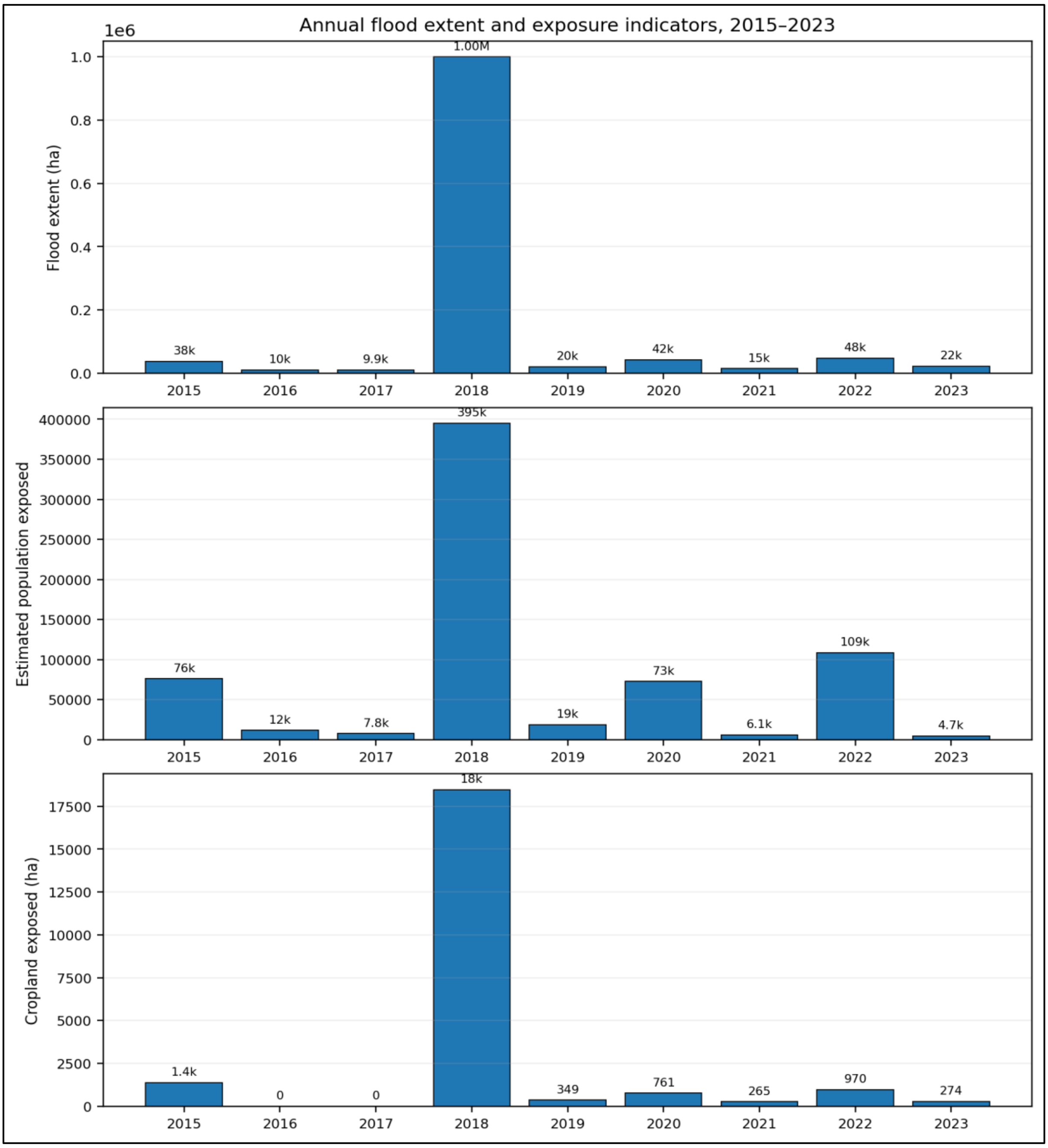

Fig 4 Annual Flood Extent, Estimated Population Exposure and Cropland Exposure, 2015–2023.

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- *Flood Impact on Population and Cropland*

Population exposure and cropland exposure broadly increased during larger flood years, but the relationship was not proportional. The 2018 event had the largest flood extent, population exposure and cropland exposure, indicating both an exceptionally large hazard footprint and substantial overlap with occupied and cultivated areas. By contrast, 2022 had a much smaller mapped area than 2018 but still exposed more than 108,000 people, demonstrating the importance of flood location relative to settlement density.

Cropland exposure was strongly concentrated in 2018, when 18,467 ha intersected the flood footprint. The values for the remaining years were below 1,400 ha, with 2016 and 2017 recording no cropland intersection in the annual exposure statistics. These values should not be interpreted as confirmed crop loss; they represent the spatial overlap between mapped inundation and the cropland layer.

- *Inundation Frequency Analysis*

The full settlement dataset contained 817 records within the 5 km River Niger corridor. Frequency analysis showed that 131 settlement records were not intersected by the mapped flood footprint in any of the nine years, while 139 were inundated once and 132 twice. At the recurrent end of the distribution, 310 settlement records were inundated in at least four years and therefore met the study's hotspot criterion. Fourteen settlement records were inundated in every year of the series.

Table 3 Distribution of Settlement Inundation Frequency Across the Nine-Year Study Period.

Years inundated	Settlement records	Share of 817 records (%)
0	131	16.0
1	139	17.0
2	132	16.2
3	105	12.9
4	87	10.6
5	65	8.0
6	65	8.0
7	41	5.0
8	38	4.7
9	14	1.7

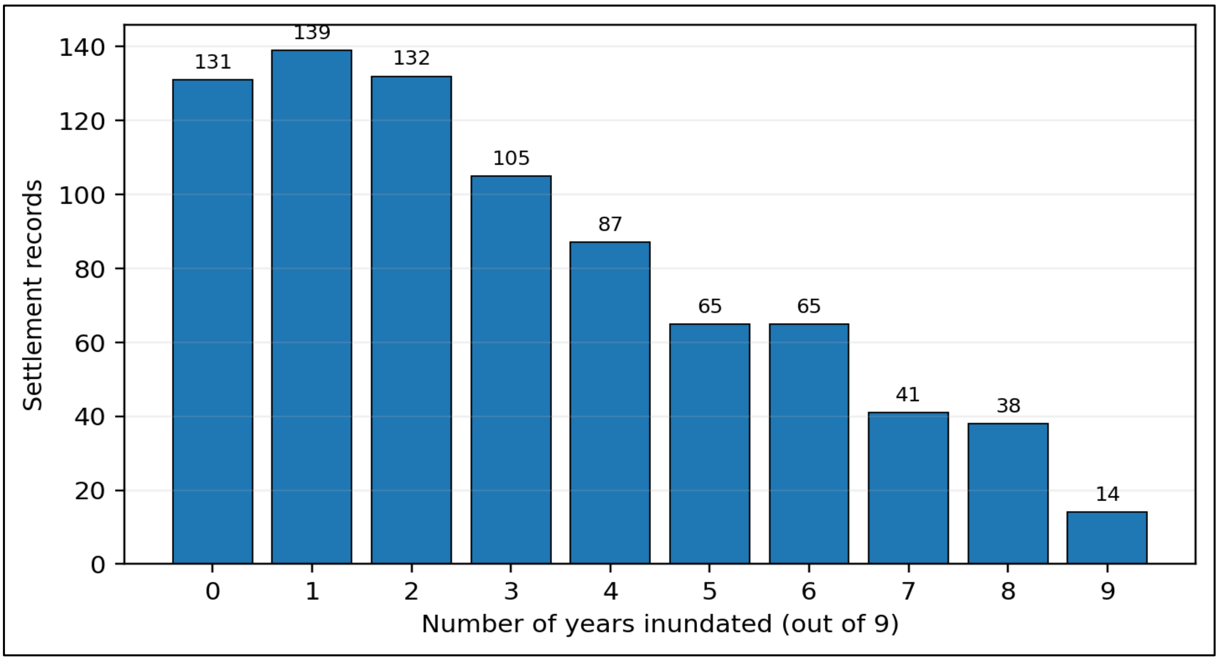

Fig 5 Settlement-Record Distribution by Number of Years Inundated, 2015–2023.

- *Geographic Distribution of Recurrent Hotspots*

Recurrent hotspots occurred in all nine states represented in the settlement dataset, but their prevalence varied substantially. Rivers State had the highest within-state hotspot share (15 of 17 records; 88.2%), followed by Anambra (28 of 38; 73.7%). Kebbi had 75 recurrent hotspot records, Delta 89 and Bayelsa 55, indicating large absolute concentrations of recurrent exposure. Kwara recorded one recurrent hotspot among 33 settlement records.

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Table 4 Recurrent-Flood Hotspot Records by State.

State	All settlement records	Hotspot records (≥4 years)	Hotspot share within state (%)
Anambra	38	28	73.7
Bayelsa	159	55	34.6
Delta	193	89	46.1
Edo	22	5	22.7
Kebbi	162	75	46.3
Kogi	97	21	21.6
Kwara	33	1	3.0
Niger	96	21	21.9
Rivers	17	15	88.2

Fourteen settlement records were inundated in all nine years: Tunga Gendini (Kebbi); Mazoji (Kebbi); Zamanagi (Kebbi); Bukunji (Kebbi); Bakin Ruwa (Kebbi); Hinanbiro (Kebbi); Kasabu (Niger); Tungan Bariki (Kebbi); Umunankwo (Anambra); Odugri (Rivers); Otoka (Delta); Richardgbene (Delta); Grey-Gbene (Bayelsa); Opuama (Bayelsa). These locations represent the most persistent intersections in the dataset and warrant priority verification and risk-management attention. Because duplicate or similar settlement names occur in the source layer, each entry should be treated as a geospatial record pending place-name validation.

B. Discussion

➢ *Interannual Variability and Major Flood Years*

The nine-year record reveals strong interannual variability rather than a simple monotonic trend. This is expected because River Niger flooding reflects the combined influence of rainfall, upstream catchment conditions, tributary inflows, channel storage, floodplain connectivity and the timing of satellite observations. The exceptional 2018 footprint is consistent with evidence from recent Niger–Benue research identifying 2018 as one of the major flood years of the last decade (Odiji et al., 2024). The strong 2022 population exposure is also consistent with the nationally significant character of the 2022 Nigerian flood documented by Abu and Ibebuchi (2025).

The results caution against inferring improved flood management solely from a smaller mapped area in a subsequent year. A lower annual footprint may reflect hydrometeorological conditions, image timing or spatial distribution rather than a permanent reduction in underlying risk. Flood-risk management should therefore combine annual event information with recurrence, exposure and vulnerability indicators.

➢ *Persistent Settlement Exposure*

The most important contribution of the settlement analysis is the distinction between episodic and recurrent exposure. Of 817 settlement records, 310 were inundated in at least four of nine years and 14 in every year. This shows that a substantial subset of the River Niger corridor experiences repeated spatial intersection with mapped floodwater. Such recurrence can generate cumulative livelihood losses and repeated displacement even when individual annual events are not nationally prominent.

The geographic distribution of hotspots also demonstrates that persistent risk is not confined to a single section of the river. Kebbi contains a large number of recurrent records in the upstream Nigerian reach, while Anambra, Delta, Bayelsa and Rivers show substantial recurrence downstream. This pattern supports differentiated, location-specific risk reduction rather than a uniform basin-wide intervention.

➢ *Population and Agricultural Exposure*

The exposure results reinforce the principle that hazard magnitude and impact potential are related but not identical. The 2018 event generated the maximum values across all three indicators, but 2022 produced the second-highest population exposure with an inundated area less than one-twentieth of the 2018 value. Population distribution therefore strongly influences potential consequences. Similar reasoning underpins recent flood-risk assessments that integrate Earth-observation hazard products with exposure and climate information (Abu & Ibebuchi, 2025; Rentschler et al., 2022).

Agricultural exposure is equally important because flood timing relative to crop growth and harvest can determine whether inundation is beneficial, tolerable or destructive. The present cropland intersection identifies where agricultural land overlapped floodwater but cannot establish yield loss. Future work should integrate crop calendars, flood duration and depth, crop type and post-event observations to convert exposure into more defensible agricultural damage estimates.

➢ *Operational Value of Earth Observation*

The study demonstrates the practical value of combining Sentinel-1 SAR with GEE for multi-year flood surveillance. SAR observations reduce dependence on cloud-free optical imagery, while GEE lowers the computational and storage burden of processing repeated annual scenes (DeVries et al., 2020; Gorelick et al., 2017). These advantages are particularly relevant in data-scarce environments where gauge networks alone may not provide a complete spatial picture of inundation.

Operationally, the retrospective recurrence layer can complement forecasts and early warnings. Historical hotspot settlements can be pre-identified before the flood season, while current rainfall, river forecasts, gauge observations and near-real-time SAR can determine when thresholds for

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preparedness or anticipatory action are reached. Idowu et al. (2025) similarly emphasise the value of Earth-observation products for operational flood monitoring in sparsely gauged Nigerian basins.

➢ *Implications for Flood-Risk Management*

The findings support a tiered risk-management approach. Recurrent hotspots should be incorporated into state and local contingency plans, warning dissemination protocols and community preparedness programmes. Development control and infrastructure planning should explicitly consider observed inundation recurrence, particularly where repeated settlement exposure overlaps critical roads, schools, health facilities or economic infrastructure.

Agricultural preparedness should prioritise recurrently inundated cropland through early harvest advisories, protected storage, resilient crop choices and appropriate risk-financing mechanisms. Institutional data sharing among agencies responsible for Earth observation, hydrology, meteorology, emergency management, agriculture and spatial planning would improve validation and create a common operational picture. These priorities align with longstanding calls for more integrated flood-risk management in Nigeria (Komolafe et al., 2015; Oladokun & Proverbs, 2016; Umar & Gray, 2023).

V. CONCLUSION AND RECOMMENDATIONS

➢ *Conclusion*

This study assessed and monitored flood inundation along a 5 km River Niger corridor in Nigeria over the nine-year period 2015–2023 using Sentinel-1 SAR, Google Earth Engine and complementary geospatial datasets. The approach produced a consistent annual flood record and connected each flood footprint to population, cropland and settlement exposure indicators.

The results show pronounced year-to-year variability. The 2018 event was the largest mapped flood in the series, with 1,000,009 ha inundated, an estimated 394,951 people exposed and 18,467 ha of cropland intersecting the flood footprint. The 2022 event also produced substantial population exposure, demonstrating that flood impact potential depends on the location of inundation as well as total area.

Settlement-frequency analysis provides the strongest evidence of persistent risk. Analysis of the full 817-record matrix identified 310 settlement records inundated in at least four of the nine years, while 14 were inundated in every year. Recurrent hotspots occur in both upstream and downstream sections of the corridor, confirming that flood risk along the River Niger is not limited to isolated extreme years or a single state.

The study therefore provides a spatial evidence base for distinguishing episodic exposure from persistent exposure. This distinction can improve the targeting of early warning, anticipatory action, land-use planning, infrastructure protection and community preparedness. At the same time, the absence of a retained numerical SAR threshold, incomplete 2023 scene metadata and the lack of formal map-accuracy statistics limit full reproducibility and should be addressed in subsequent implementations.

➢ *Recommendations*

- Institutionalise annual and near-real-time Sentinel-1 flood monitoring along the River Niger, with a documented and version-controlled GEE workflow.
- Prioritise the 310 recurrent hotspot settlement records for field verification, local risk profiling, early-warning targeting and contingency planning, with particular attention to the 14 records inundated in all nine years.
- Integrate satellite flood maps with river-gauge observations, hydrological forecasts, rainfall forecasts and dam/reservoir information to improve anticipatory action and event attribution.
- Strengthen floodplain development control and climate-resilient infrastructure planning in recurrently inundated settlement corridors.
- Link cropland exposure maps to crop calendars, flood duration and depth, crop type and post-event field data to estimate agricultural damage more accurately.
- Adopt formal validation protocols using independent reference data, stratified sampling and accuracy metrics for future annual flood products.
- Archive exact Sentinel-1 scene identifiers, orbit information, temporal windows, speckle-filter parameters, thresholds, DEM/product versions and exposure-layer versions to ensure scientific reproducibility.
- Promote inter-agency data sharing and common geospatial standards among organisations responsible for hydrology, meteorology, Earth observation, emergency management, agriculture and spatial planning.

➢ *Suggestions for Further Research*

Future research should extend the annual series beyond 2023; incorporate flood depth, duration and velocity; evaluate the influence of upstream hydrometeorological conditions and reservoir operations; and combine physical hazard with socio-economic vulnerability. A prospective operational system could couple historical recurrence with forecast rainfall, river discharge and near-real-time SAR observations to generate impact-based trigger products for anticipatory action.

LIST OF HOTSPOT COMMUNITIES

The study identified 310 recurrent hotspot settlement records that were inundated in at least four of the nine years from 2015 to 2023. Table 5 provides the state-level distribution; the complete settlement-by-settlement list, including frequency and inundated years, is presented in Appendix A. Settlement names are retained from the source GRID3 layer and should be field-verified before operational targeting.

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Table 5 Distribution of Recurrent-Flood Hotspot Records by State.

State	Recurrent hotspot records	Share of all 310 hotspots (%)
Anambra	28	9.0
Bayelsa	55	17.7
Delta	89	28.7
Edo	5	1.6
Kebbi	75	24.2
Kogi	21	6.8
Kwara	1	0.3
Niger	21	6.8
Rivers	15	4.8

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APPENDIX A

➢ *Recurrent-Flood Settlement Records (≥4 of 9 Years)*

This appendix lists the 310 settlement records that intersected the annual flood footprint in at least four of the nine years from 2015 to 2023. Names are retained from the settlement layer; duplicate or similar names may represent separate geospatial records and have not been collapsed. The frequency and inundated-year fields were derived directly from the 817-record annual matrix.

Record	State	Settlement	Frequency (years)	Years inundated
1	Kebbi	Tunga Gado	8	2015, 2016, 2017, 2018, 2019, 2021, 2022, 2023
2	Kebbi	Tunga Rogo	7	2015, 2016, 2017, 2018, 2019, 2021, 2023
3	Kebbi	Farankya	5	2015, 2018, 2021, 2022, 2023
4	Kebbi	Sabon Gari	6	2015, 2019, 2020, 2021, 2022, 2023
5	Kebbi	Sabon Gari	5	2015, 2018, 2019, 2020, 2022
6	Kebbi	Soda	6	2015, 2017, 2020, 2021, 2022, 2023
7	Kebbi	Kebbi	4	2015, 2019, 2020, 2023
8	Kebbi	Gorun Zaki	4	2015, 2021, 2022, 2023
9	Kebbi	Tunga Nagyera	6	2017, 2018, 2020, 2021, 2022, 2023
10	Kebbi	Bakin Goru	6	2015, 2018, 2020, 2021, 2022, 2023
11	Kebbi	Tuga Jideero Bode	4	2015, 2018, 2020, 2023
12	Kebbi	Tunga Baure	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
13	Kebbi	Toluwa	6	2018, 2019, 2020, 2021, 2022, 2023
14	Kebbi	Old Gendini	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
15	Kebbi	Tunga Gendini	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
16	Kebbi	Tunga Kwala	5	2015, 2018, 2020, 2021, 2023
17	Kebbi	Tunga Gowesu	5	2018, 2019, 2020, 2021, 2023
18	Kebbi	Tunga yalwan Borgu	5	2017, 2019, 2020, 2021, 2023
19	Kebbi	Buzere	5	2018, 2019, 2020, 2021, 2023
20	Kebbi	Tunga Rimi	4	2015, 2020, 2021, 2023
21	Kebbi	Tunga idi	6	2015, 2016, 2018, 2019, 2020, 2023
22	Kebbi	Zaria	6	2015, 2016, 2018, 2021, 2022, 2023
23	Kebbi	Mazoji	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
24	Kebbi	Gante	8	2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023
25	Kebbi	Tunga Sakke	4	2016, 2019, 2020, 2021
26	Kebbi	Tunga Tafo	6	2015, 2018, 2019, 2020, 2021, 2023
27	Kebbi	Alanjoni	7	2015, 2018, 2019, 2020, 2021, 2022, 2023
28	Kebbi	Tunga Jelebe	6	2017, 2018, 2019, 2020, 2021, 2023
29	Kebbi	Sabon gari	6	2015, 2018, 2019, 2020, 2021, 2023
30	Kebbi	Tunga Karwa	5	2016, 2018, 2019, 2020, 2021
31	Kebbi	Dutsin Mari	6	2016, 2018, 2019, 2020, 2021, 2023
32	Kebbi	Zamanagi	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
33	Kebbi	Inugu	4	2015, 2018, 2020, 2021
34	Kebbi	Bosa	4	2018, 2019, 2021, 2023
35	Kebbi	Homa	5	2018, 2019, 2020, 2021, 2022
36	Kebbi	Dan Zaki	6	2016, 2017, 2018, 2019, 2020, 2023
37	Kebbi	Tsamiya Tudu2	5	2017, 2018, 2019, 2020, 2021
38	Kebbi	Gebe	4	2018, 2019, 2020, 2023
39	Kebbi	Kaikami	5	2017, 2018, 2019, 2020, 2021
40	Kebbi	Samadobi	6	2017, 2018, 2019, 2020, 2021, 2023
41	Kebbi	Bukunji	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
42	Kebbi	Tungan dala	6	2015, 2016, 2018, 2020, 2021, 2023
43	Kebbi	Tungan Lauje	7	2015, 2018, 2019, 2020, 2021, 2022, 2023
44	Kebbi	Gweze	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
45	Kebbi	Bakin Ruwa	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
46	Kebbi	Lapo	4	2018, 2019, 2020, 2023
47	Kebbi	Bakin Sakace	6	2016, 2018, 2019, 2020, 2022, 2023
48	Kebbi	Tungan Bori	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
49	Kebbi	Tunga Guduwa	4	2018, 2021, 2022, 2023
50	Kebbi	Kasanu	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
51	Kebbi	Hilala	5	2018, 2019, 2020, 2021, 2023

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52	Kebbi	Matarito	7	2016, 2017, 2018, 2019, 2020, 2021, 2023
53	Kebbi	Ichan	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
54	Kebbi	Hinanbiro	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
55	Kebbi	Tungan Makeri	6	2016, 2017, 2018, 2019, 2021, 2023
56	Niger	Kasabu	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
57	Niger	Gbelegu	4	2017, 2018, 2020, 2021
58	Niger	Uhum	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
59	Kebbi	Sadawanka	6	2016, 2017, 2018, 2019, 2021, 2023
60	Kebbi	Akangala	5	2016, 2018, 2019, 2020, 2023
61	Kebbi	Jinjima	6	2015, 2017, 2018, 2021, 2022, 2023
62	Kebbi	Tungan bauche	7	2015, 2017, 2018, 2020, 2021, 2022, 2023
63	Kebbi	Tungan Maishagali	4	2016, 2018, 2021, 2023
64	Kebbi	Goya	7	2015, 2016, 2017, 2018, 2019, 2021, 2023
65	Kebbi	Suteku	5	2016, 2017, 2018, 2021, 2023
66	Kebbi	Tungan Bariki	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
67	Kebbi	Tungan Papa	8	2015, 2016, 2017, 2019, 2020, 2021, 2022, 2023
68	Niger	Mahuta	4	2017, 2018, 2021, 2023
69	Kebbi	Yerimawa	8	2015, 2016, 2017, 2018, 2019, 2021, 2022, 2023
70	Kebbi	Wata	5	2015, 2018, 2019, 2022, 2023
71	Niger	Ulakami	5	2017, 2018, 2019, 2021, 2023
72	Kebbi	foge	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
73	Kebbi	Annua	5	2016, 2017, 2019, 2021, 2023
74	Kebbi	Lopa	5	2016, 2017, 2019, 2021, 2023
75	Niger	Tungan Dangaje	6	2016, 2017, 2018, 2020, 2021, 2023
76	Niger	new Shagunnu	4	2015, 2017, 2018, 2021
77	Kebbi	Sangwa	6	2017, 2018, 2019, 2020, 2021, 2023
78	Kebbi	Shangwabiu	7	2016, 2017, 2018, 2019, 2020, 2021, 2023
79	Kebbi	Panni	7	2016, 2017, 2018, 2019, 2020, 2021, 2023
80	Niger	Gwaiya	7	2016, 2017, 2018, 2019, 2020, 2021, 2023
81	Niger	Bussa	6	2017, 2018, 2019, 2020, 2021, 2023
82	Niger	Minni	7	2016, 2017, 2018, 2019, 2020, 2021, 2023
83	Kebbi	Tungan Wakili	6	2016, 2017, 2018, 2019, 2021, 2023
84	Kebbi	Bussa	5	2017, 2018, 2019, 2020, 2021
85	Niger	Garayi	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
86	Kebbi	Tsofori Bussa	6	2017, 2018, 2019, 2020, 2021, 2023
87	Niger	Doro	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
88	Niger	Ubawa	6	2016, 2017, 2018, 2019, 2021, 2023
89	Niger	Old Malele	4	2017, 2018, 2021, 2023
90	Niger	Garafini	7	2016, 2017, 2018, 2019, 2021, 2022, 2023
91	Niger	Kaya	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2023
92	Niger	Tungar Ndachu Dagwa	5	2016, 2018, 2019, 2020, 2023
93	Niger	Lwafu	4	2016, 2017, 2018, 2023
94	Niger	Kaduna	5	2015, 2019, 2020, 2021, 2023
95	Niger	Muregi	4	2016, 2018, 2020, 2023
96	Niger	Gbako	4	2015, 2018, 2019, 2020
97	Kwara	Kadoune	5	2015, 2018, 2019, 2020, 2023
98	Kogi	Eggan	6	2015, 2017, 2018, 2019, 2020, 2023
99	Kogi	Kampe	4	2015, 2018, 2019, 2020
100	Kogi	Dare	7	2015, 2017, 2018, 2019, 2020, 2021, 2022
101	Kogi	Gurara	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
102	Kogi	Bogboru	4	2016, 2018, 2019, 2020
103	Kogi	Agodo	7	2015, 2017, 2018, 2019, 2020, 2021, 2023
104	Kogi	Koton Karifi	4	2015, 2018, 2019, 2022
105	Kogi	Adaha	4	2015, 2016, 2018, 2019
106	Kogi	Oshere	4	2015, 2019, 2020, 2022
107	Kogi	Adama	4	2018, 2020, 2022, 2023
108	Kogi	Lokoja	7	2015, 2016, 2018, 2019, 2020, 2022, 2023

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109	Kogi	Geregu	4	2015, 2018, 2021, 2022
110	Kogi	Ojigagala	6	2016, 2018, 2019, 2020, 2021, 2022
111	Kogi	Ofugbo	4	2015, 2018, 2019, 2022
112	Kogi	Ijonkuta	4	2015, 2017, 2018, 2022
113	Kogi	Adiagba	5	2015, 2018, 2019, 2020, 2022
114	Kogi	Ichichia	8	2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023
115	Kogi	Ichuchu	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022
116	Kogi	Odegune	7	2015, 2016, 2018, 2019, 2020, 2022, 2023
117	Kogi	Oje	5	2015, 2016, 2018, 2020, 2022
118	Kogi	Imbeka	7	2016, 2017, 2018, 2019, 2021, 2022, 2023
119	Edo	Okpatawo 1	5	2015, 2016, 2018, 2019, 2022
120	Edo	Amalu	4	2016, 2018, 2019, 2022
121	Edo	Anemene	4	2015, 2016, 2018, 2022
122	Edo	Eko-Okoh	4	2015, 2018, 2019, 2020
123	Edo	Ifeku Island	5	2015, 2016, 2017, 2018, 2019
124	Anambra	Odekpu	6	2015, 2017, 2018, 2019, 2021, 2022
125	Anambra	Odekpe	4	2015, 2018, 2019, 2022
126	Anambra	Iyiuku	6	2017, 2018, 2019, 2021, 2022, 2023
127	Anambra	Ibokye	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
128	Anambra	Ugu-Ozalla	7	2017, 2018, 2019, 2020, 2021, 2022, 2023
129	Anambra	Amusai	5	2015, 2017, 2018, 2020, 2022
130	Anambra	Ani-Nkwa-Anam	6	2015, 2017, 2018, 2020, 2021, 2022
131	Anambra	Omono	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
132	Anambra	Onono	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022
133	Anambra	Onisha	5	2015, 2016, 2018, 2022, 2023
134	Anambra	Idemili	6	2015, 2016, 2018, 2021, 2022, 2023
135	Anambra	Okpoko	4	2018, 2021, 2022, 2023
136	Anambra	Oyiowa-Odekpa	4	2015, 2016, 2018, 2022
137	Anambra	Iyowa Odekpa	5	2015, 2016, 2018, 2021, 2023
138	Anambra	Iyiowa Odekpa	4	2015, 2018, 2022, 2023
139	Anambra	Ouekbe	4	2015, 2018, 2019, 2022
140	Anambra	Odekpe	5	2015, 2017, 2018, 2020, 2022
141	Anambra	Oshita	7	2015, 2017, 2018, 2019, 2020, 2022, 2023
142	Anambra	Atani	6	2015, 2016, 2017, 2018, 2020, 2022
143	Anambra	Akili-Ozizor	6	2015, 2016, 2018, 2020, 2021, 2022
144	Anambra	Ogbakuma	8	2015, 2016, 2017, 2018, 2020, 2021, 2022, 2023
145	Anambra	Ogbakuma	6	2015, 2016, 2018, 2020, 2021, 2022
146	Anambra	Ogbekuma	6	2015, 2016, 2018, 2020, 2021, 2022
147	Anambra	Ochuche-Umudo	8	2015, 2016, 2018, 2019, 2020, 2021, 2022, 2023
148	Anambra	Umunankwo	7	2015, 2017, 2018, 2019, 2020, 2022, 2023
149	Anambra	Azogba	5	2017, 2018, 2019, 2020, 2022
150	Anambra	Umunankwo	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
151	Anambra	Ossomari	5	2016, 2018, 2020, 2022, 2023
152	Delta	Allah	4	2017, 2018, 2019, 2022
153	Delta	Asoko	6	2015, 2016, 2017, 2021, 2022, 2023
154	Delta	Okwe	4	2015, 2016, 2022, 2023
155	Delta	Oko	4	2015, 2017, 2020, 2022
156	Delta	Oko Amakom	6	2015, 2016, 2017, 2018, 2020, 2022
157	Delta	Obi Okpu	5	2017, 2018, 2020, 2022, 2023
158	Delta	Oko Anara	7	2015, 2016, 2017, 2018, 2020, 2022, 2023
159	Delta	Okogbele	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022
160	Delta	Abara	7	2016, 2017, 2018, 2019, 2020, 2022, 2023
161	Delta	Aballa Osimili	6	2016, 2017, 2019, 2020, 2022, 2023
162	Delta	Osimili	6	2016, 2017, 2018, 2020, 2022, 2023
163	Delta	Ossomari	7	2015, 2016, 2018, 2019, 2020, 2022, 2023
164	Delta	Awulu	8	2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023
165	Delta	Mili Uru	8	2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023
166	Delta	Utchi	4	2018, 2020, 2022, 2023

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167	Delta	Agwe	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
168	Delta	Umuobhi	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
169	Delta	Obe Otwu	6	2016, 2017, 2018, 2019, 2020, 2022
170	Delta	Umuochi Utchi	4	2018, 2019, 2020, 2022
171	Delta	Pata II	6	2016, 2017, 2018, 2019, 2020, 2022
172	Delta	Pata III	6	2016, 2018, 2019, 2020, 2022, 2023
173	Delta	Aseazaga	4	2018, 2020, 2022, 2023
174	Delta	Aguetiti IV	7	2017, 2018, 2019, 2020, 2021, 2022, 2023
175	Delta	Utchi	4	2018, 2020, 2022, 2023
176	Delta	Abara Uno	5	2018, 2019, 2020, 2022, 2023
177	Delta	Uguetiti II	5	2018, 2019, 2020, 2022, 2023
178	Delta	Odugiri	5	2018, 2019, 2020, 2022, 2023
179	Delta	Obagwe	5	2018, 2019, 2020, 2022, 2023
180	Delta	Abara Uno	5	2018, 2019, 2020, 2022, 2023
181	Delta	Ekuku	5	2017, 2018, 2019, 2020, 2022
182	Delta	Obeze	7	2015, 2017, 2018, 2019, 2020, 2022, 2023
183	Delta	Uchi	5	2018, 2019, 2020, 2022, 2023
184	Delta	Akasia	6	2016, 2018, 2019, 2020, 2022, 2023
185	Delta	Okpai Oluchi	6	2017, 2018, 2019, 2020, 2022, 2023
186	Delta	Okpai	4	2018, 2019, 2020, 2022
187	Delta	Akpobo	5	2017, 2018, 2019, 2020, 2022
188	Delta	Umugboma	6	2015, 2018, 2019, 2020, 2021, 2022
189	Rivers	Oworinnopia	4	2018, 2019, 2020, 2022
190	Rivers	Ogbeose	4	2018, 2019, 2020, 2022
191	Delta	Asemoke	4	2016, 2018, 2020, 2022
192	Delta	Iseede Egerega	4	2016, 2018, 2020, 2022
193	Delta	Keonokpo	5	2015, 2016, 2018, 2020, 2022
194	Delta	Ise Edeugbana	7	2016, 2017, 2018, 2019, 2020, 2021, 2022
195	Delta	Ise-Owulume	8	2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
196	Delta	Ise Abuato	4	2015, 2018, 2020, 2022
197	Rivers	Agwe	4	2015, 2020, 2021, 2022
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199	Rivers	Agwe	7	2015, 2016, 2018, 2019, 2020, 2022, 2023
200	Rivers	Oniku	6	2016, 2018, 2019, 2020, 2022, 2023
201	Rivers	Onu-iku	6	2016, 2018, 2019, 2020, 2022, 2023
202	Rivers	Ndoni	5	2015, 2016, 2018, 2020, 2022
203	Rivers	Ogbuku	4	2015, 2016, 2020, 2022
204	Rivers	Isafa	7	2015, 2016, 2018, 2019, 2020, 2022, 2023
205	Rivers	Obodo-ichekere-aku	6	2015, 2016, 2018, 2020, 2022, 2023
206	Rivers	Utu	7	2015, 2016, 2018, 2019, 2020, 2022, 2023
207	Rivers	Ogbaja	5	2015, 2016, 2018, 2019, 2023
208	Rivers	Utu	6	2015, 2016, 2018, 2020, 2022, 2023
209	Rivers	Adia wati ofu	5	2016, 2018, 2019, 2020, 2022
210	Delta	Ise-Edeogbana	5	2015, 2016, 2018, 2020, 2022
211	Delta	Emioko	4	2015, 2018, 2020, 2022
212	Delta	Ise-Abuato	5	2015, 2017, 2018, 2020, 2022
213	Delta	Abo	4	2015, 2018, 2020, 2022
214	Delta	Akarai Obodo	7	2015, 2017, 2018, 2020, 2021, 2022, 2023
215	Delta	Obodo-Ugbogu	4	2017, 2018, 2020, 2022
216	Delta	Okpo Okrika	6	2016, 2017, 2018, 2020, 2021, 2022
217	Delta	Ogbogen	4	2016, 2018, 2020, 2022
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220	Delta	Warri	5	2017, 2018, 2021, 2022, 2023
221	Delta	Warr irri	5	2017, 2018, 2019, 2020, 2021
222	Delta	Onya	5	2015, 2016, 2017, 2018, 2022
223	Delta	Dioliba Feuve	6	2015, 2016, 2018, 2021, 2022, 2023
224	Delta	Iwhrogboko	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022

225	Delta	Egbu	8	2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023
226	Delta	Ekeregbesi	4	2015, 2016, 2018, 2020
227	Delta	Iwele	6	2015, 2017, 2018, 2020, 2022, 2023
228	Delta	Asaba Ase	4	2015, 2017, 2018, 2022
229	Delta	Asaba assay	5	2015, 2018, 2020, 2022, 2023
230	Delta	Otoka	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
231	Delta	Sapele	7	2015, 2016, 2017, 2018, 2021, 2022, 2023
232	Delta	Emadia	4	2015, 2017, 2018, 2022
233	Delta	Egbeme	4	2017, 2018, 2021, 2022
234	Delta	Awopaka	5	2015, 2016, 2018, 2020, 2022
235	Delta	Abari	5	2015, 2017, 2018, 2020, 2022
236	Delta	Ofogbogbene	6	2015, 2018, 2019, 2020, 2022, 2023
237	Delta	Asabase	6	2015, 2017, 2018, 2021, 2022, 2023
238	Delta	David	4	2018, 2019, 2020, 2023
239	Delta	Arohwa	4	2015, 2018, 2019, 2022
240	Delta	Patani	4	2016, 2017, 2018, 2022
241	Delta	Angiama	7	2015, 2017, 2018, 2019, 2020, 2022, 2023
242	Delta	Richardgbene	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
243	Delta	Ogokurugbene	5	2015, 2016, 2018, 2021, 2023
244	Delta	Ogele	4	2018, 2019, 2020, 2022
245	Delta	Adorbu	4	2016, 2018, 2021, 2022
246	Delta	Kpakiama	5	2015, 2016, 2018, 2021, 2022
247	Delta	Alota	4	2015, 2016, 2018, 2022
248	Delta	Gbarogolo	4	2015, 2016, 2018, 2022
249	Delta	Osusugie	4	2015, 2016, 2017, 2018
250	Delta	Nikorogha	5	2015, 2017, 2018, 2021, 2022
251	Delta	Idegbene	4	2015, 2017, 2018, 2022
252	Delta	Ogriagbene	6	2015, 2016, 2017, 2018, 2021, 2022
253	Delta	Obidiegbene	4	2015, 2016, 2018, 2021
254	Delta	Edemogbene	6	2015, 2016, 2017, 2018, 2021, 2022
255	Delta	Ekumugbene	4	2015, 2016, 2018, 2021
256	Bayelsa	Ekpeniware	4	2015, 2016, 2018, 2022
257	Bayelsa	Ekpeniware	6	2015, 2016, 2018, 2021, 2022, 2023
258	Bayelsa	Ekpeniware	4	2016, 2018, 2022, 2023
259	Bayelsa	osikenike	6	2015, 2016, 2018, 2019, 2020, 2022
260	Bayelsa	Timbiko	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022
261	Bayelsa	Saniagi	5	2015, 2018, 2019, 2020, 2022
262	Bayelsa	Samabri Abueto	6	2016, 2017, 2018, 2019, 2020, 2022
263	Bayelsa	Igule Erohwa	8	2015, 2016, 2018, 2019, 2020, 2021, 2022, 2023
264	Bayelsa	Ewhoekone	6	2017, 2018, 2019, 2020, 2021, 2023
265	Bayelsa	Ikpede	6	2015, 2017, 2018, 2019, 2020, 2022
266	Bayelsa	Toropani	7	2016, 2017, 2018, 2019, 2020, 2022, 2023
267	Bayelsa	Angbariama	4	2015, 2017, 2018, 2022
268	Bayelsa	Perawari	4	2015, 2017, 2018, 2022
269	Bayelsa	Asidani	6	2015, 2017, 2018, 2019, 2020, 2022
270	Bayelsa	Odiowe-Gbene	7	2015, 2017, 2018, 2019, 2020, 2022, 2023
271	Bayelsa	Biriyegbene	4	2017, 2018, 2022, 2023
272	Bayelsa	Grey-Gbene	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
273	Bayelsa	Odi	5	2016, 2018, 2019, 2020, 2022
274	Bayelsa	Ibia	4	2015, 2017, 2018, 2022
275	Bayelsa	Ara	8	2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023
276	Bayelsa	Sampou	4	2017, 2018, 2020, 2022
277	Bayelsa	Amabebegbene	7	2015, 2016, 2017, 2018, 2019, 2020, 2022
278	Bayelsa	Ayokorama	4	2015, 2016, 2018, 2022
279	Bayelsa	Ayama	7	2016, 2017, 2018, 2019, 2020, 2021, 2023
280	Bayelsa	Igbainwari	7	2015, 2017, 2018, 2019, 2020, 2021, 2022
281	Bayelsa	Ayokorama	4	2015, 2016, 2018, 2022
282	Bayelsa	Okoloba Sabagria	7	2015, 2016, 2017, 2018, 2019, 2020, 2022

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283	Bayelsa	Polaku	5	2015, 2016, 2018, 2019, 2022
284	Bayelsa	Koroama	5	2015, 2016, 2019, 2020, 2022
285	Bayelsa	Agudama Ekpetiama	4	2015, 2018, 2021, 2022
286	Bayelsa	Tombia	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022
287	Bayelsa	Opuama	9	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
288	Bayelsa	Yenaka	8	2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022
289	Bayelsa	Fangbe	5	2015, 2016, 2017, 2021, 2022
290	Bayelsa	Obogoro	4	2015, 2018, 2021, 2022
291	Bayelsa	Akaba	4	2015, 2016, 2018, 2021
292	Bayelsa	Oweikorogba	5	2016, 2018, 2019, 2021, 2022
293	Bayelsa	Otwa	5	2015, 2016, 2017, 2021, 2022
294	Bayelsa	Agiama	6	2015, 2016, 2017, 2018, 2019, 2021
295	Bayelsa	Ekow	4	2015, 2018, 2019, 2020
296	Bayelsa	Obare	5	2015, 2017, 2018, 2019, 2022
297	Bayelsa	Sekingbene	7	2015, 2017, 2018, 2019, 2020, 2022, 2023
298	Bayelsa	Anisa l	7	2015, 2016, 2017, 2018, 2019, 2020, 2022
299	Bayelsa	Anisa ll	6	2015, 2016, 2017, 2018, 2019, 2020
300	Bayelsa	Sagbama	4	2015, 2017, 2018, 2019
301	Bayelsa	Ogolowa	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
302	Bayelsa	Precogbena	7	2015, 2017, 2018, 2019, 2020, 2021, 2023
303	Bayelsa	Agolomo	5	2018, 2019, 2020, 2021, 2022
304	Bayelsa	Tungbo	5	2015, 2016, 2018, 2020, 2022
305	Bayelsa	Angiama ll	4	2017, 2018, 2021, 2022
306	Bayelsa	Falafagbene	4	2015, 2016, 2018, 2020
307	Bayelsa	Ebedebri	8	2015, 2017, 2018, 2019, 2020, 2021, 2022, 2023
308	Bayelsa	Toru-Orua	6	2015, 2016, 2017, 2018, 2022, 2023
309	Bayelsa	Ogbodugbene	4	2015, 2016, 2018, 2022
310	Bayelsa	Odorubo	6	2015, 2017, 2018, 2019, 2020, 2022

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APPENDIX B
LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
GEE	Google Earth Engine
GHSL	Global Human Settlement Layer
GIS	Geographic Information System
GRID3	Geo-Referenced Infrastructure and Demographic Data for Development
GHS-POP	Global Human Settlement population grid
JRC	Joint Research Centre
LULC	Land Use/Land Cover
NASRDA	National Space Research and Development Agency
NEMA	National Emergency Management Agency
NiMet	Nigerian Meteorological Agency
NIHSA	Nigeria Hydrological Services Agency
QGIS	Quantum Geographic Information System / QGIS
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goal
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response