Sentinel-1 SAR and Google Earth Engine-Based Flood Inundation Mapping and Land-Cover Impact Assessment in the Upper Brahmaputra Valley, Assam, India: A Case Study of the July 2026 Flood Event

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Abstract*—Flood inundation is a recurrent hazard in the Brahmaputra Valley of Assam, where intense monsoonal rainfall, dynamic river channels, low-gradient floodplains and extensive agricultural land combine to increase exposure. This study develops a reproducible Google Earth Engine (GEE)-based framework for mapping the July 2026 flood event across Sivasagar, Charaideo and Jorhat districts in the Upper Brahmaputra Valley using Sentinel-1 Ground Range Detected (GRD) synthetic aperture radar (SAR) imagery. The workflow uses a homogeneous Sentinel-1 subset, temporal compositing, backscatter-based flood extraction, permanent-water masking, spatial cleaning, and overlay with ESA WorldCover 2021 and elevation data. GEE is used to automate image filtering, compositing, raster classification and district-wise zonal statistics, thereby improving processing efficiency and reproducibility. The supplied analysis indicates that inundation was concentrated in low-lying riverine and agricultural landscapes, with Sivasagar showing the largest mapped flood footprint, followed by widespread inundation in northern Jorhat and comparatively fragmented inundation in Charaideo. Agricultural land and wetlands constituted the principal affected land-cover categories. The study is contextualized using Kalita's assessment of flood chronology, river behaviour, inundation and human response in Morigaon, which demonstrates the broader relevance of floodplain dynamics and community vulnerability in Assam. The present work extends this regional perspective through an event-specific SAR mapping workflow. Importantly, SAR-derived inundation represents observed flood extent at the acquisition period and should not be interpreted as flood probability, depth or long-term risk without additional hydrological and vulnerability modelling.

***Index Terms*—Sentinel-1 SAR, Google Earth Engine, flood inundation, Brahmaputra Valley, Assam, floodplain, land-cover impact, remote sensing, GIS, disaster management**

I. Introduction

Floods are among the most frequent and damaging hydro-meteorological hazards, producing impacts that extend from temporary inundation to agricultural losses, disruption of transport and settlements, ecosystem disturbance and prolonged livelihood stress. In flood-prone river basins, the ability to obtain spatially consistent information during an active event is central to emergency response and post-event assessment.

The Brahmaputra Valley in Assam is particularly susceptible to seasonal flooding because of high monsoonal rainfall, a highly mobile alluvial river system, extensive floodplain surfaces and dense human use of low-lying land. Flood behaviour is also shaped by tributary interactions, drainage congestion, bank erosion and local topographic variation. Kalita's study of Morigaon documents recurrent flood events and relates inundation to river behaviour, rainfall, tributary processes, infrastructure conditions and human response, highlighting the need to consider floods as coupled physical and social processes (Kalita, 2025–26).

Conventional field surveys remain important for detailed damage assessment, but their spatial coverage can be constrained during hazardous conditions. Optical satellite imagery provides valuable multispectral information but is often compromised by monsoon cloud cover. Sentinel-1 SAR is particularly suitable for flood observation because microwave radar can acquire imagery through cloud and in darkness and is widely used for emergency flood mapping (European Space Agency, 2026).

The Google Earth Engine Sentinel-1 collection provides calibrated, terrain-corrected GRD backscatter in decibels and allows users to construct homogeneous subsets by polarization, instrument mode, orbit direction and resolution. Earth Engine documentation identifies these metadata filters as important because the archive contains heterogeneous acquisition configurations (Google Earth Engine, 2024). The platform therefore provides an efficient environment for event-scale flood mapping and repeatable spatial statistics.

The objectives are to: (i) delineate event-specific flood inundation from Sentinel-1 SAR; (ii) compare the spatial distribution of inundation among Sivasagar, Charaideo and Jorhat; (iii) quantify affected land-cover classes using ESA WorldCover; (iv) examine the relationship between inundation, elevation and floodplain setting; and (v) establish a reproducible validation and uncertainty framework for operational use.

II. Study Area

The study region comprises Sivasagar, Charaideo and Jorhat districts in the Upper Brahmaputra Valley of Assam, India. The landscape is dominated by low-gradient alluvial plains, river channels, tributary corridors, wetlands and extensive agricultural areas. The monsoon season, particularly June to September, accounts for a large proportion of annual rainfall and coincides with the period of greatest flood exposure.

The three districts differ in their spatial relationship with the Brahmaputra and associated tributaries. Sivasagar contains extensive low-lying agricultural and wetland areas associated with the Dikhow, Disang and related drainage systems. Charaideo contains a mixture of agricultural floodplains, river corridors and locally elevated surfaces. Jorhat includes a broad northern floodplain connected to the Brahmaputra and riverine landscapes adjoining Majuli.

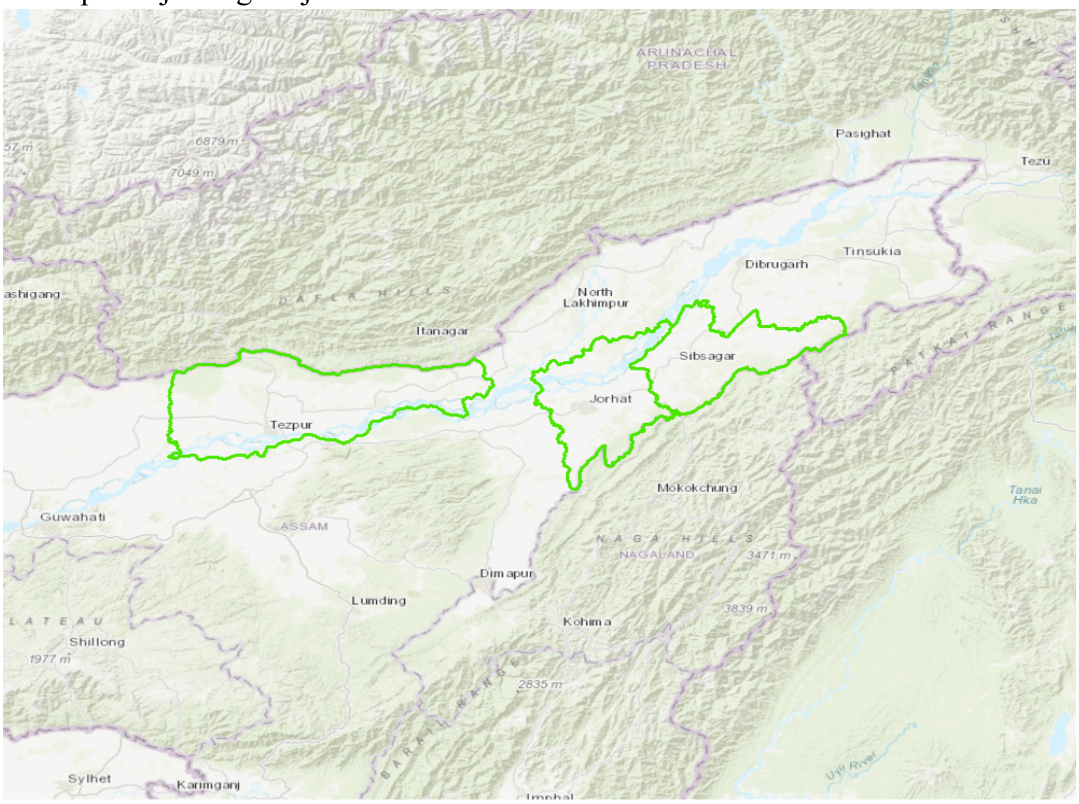


Figure 1. Study Region and Conceptual Floodplain Setting

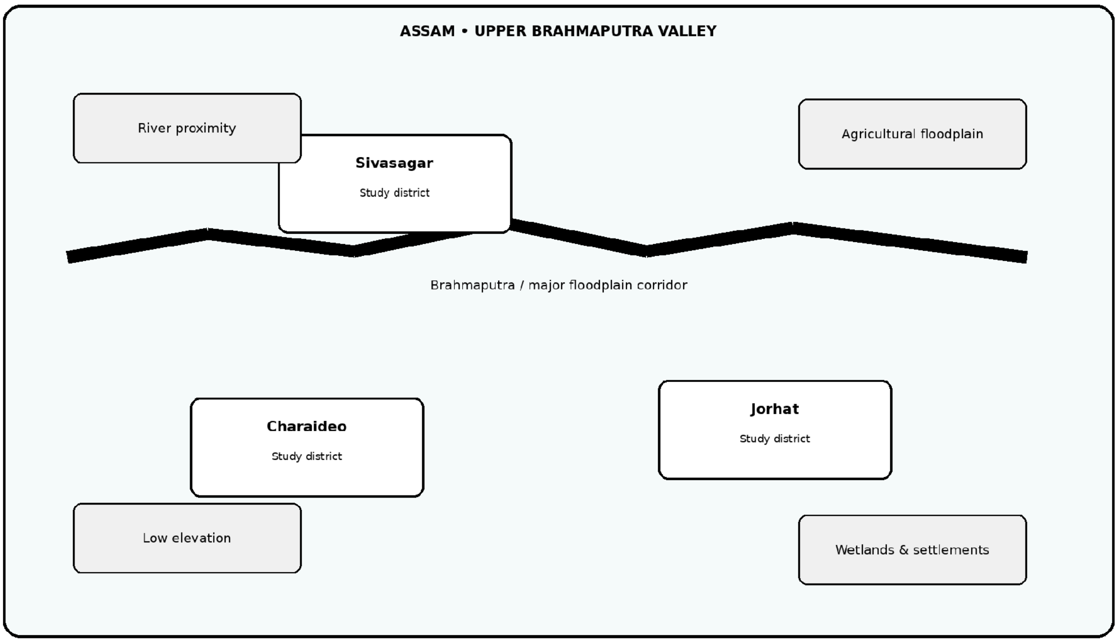


Figure 1. Conceptual representation of the study region and principal floodplain controls. For journal submission, replace the schematic with a GIS-generated map using official Survey of India boundaries, drainage, scale bar, north arrow and coordinate grid.

III. Materials and Methods

The research adopts a cloud-based geospatial workflow in Google Earth Engine. The method consists of defining the study area; constructing a homogeneous Sentinel-1 GRD collection; generating pre-flood and flood-period composites; extracting flood water from SAR backscatter change and/or a validated threshold; masking permanent water; removing isolated classification noise; intersecting the flood layer with ESA WorldCover and SRTM elevation; calculating district-wise and land-cover-wise statistics; and validating the resulting flood mask using independent reference observations.

3.1 Satellite and Ancillary Data

Dataset	Source / GEE collection	Characteristics	Purpose	Reference
Sentinel-1 GRD	COPERNICUS/S1_GRD	C-band; IW; 10 m class; VV/VH	Flood detection	ESA / GEE
ESA WorldCover 2021	ESA/WorldCover/v200	10 m land cover	LULC impact statistics	Zanaga et al., 2022
JRC Global Surface Water	JRC/GSW1_4/GlobalSurfaceWater	Water occurrence	Permanent-water mask	Pekel et al., 2016
SRTM DEM	USGS/SRTMGL1_003	30 m elevation	Elevation context	Farr et al., 2007
Survey of India boundaries	SOI	District polygons	Clipping and zonal statistics	Survey of India
Reference observations	Independent imagery/field/reports	Event-specific	Validation	Study-specific

3.2 Google Earth Engine Sentinel-1 Collection Construction

Sentinel-1 GRD scenes were accessed from the COPERNICUS/S1_GRD collection in Google Earth Engine. To minimize differences caused by acquisition geometry, a homogeneous subset should be defined by instrument mode, polarization, spatial resolution and orbit direction. The GEE documentation identifies these metadata filters as important when constructing comparable Sentinel-1 composites (Google Earth Engine, 2024).

For the July 2026 event, the final manuscript should report the exact pre-flood and flood-period acquisition windows, the number of scenes retained in each window, polarization, orbit direction and acquisition dates. These values must be taken directly from the final GEE run.

3.3 SAR Processing in GEE

The Sentinel-1 GRD collection in Earth Engine is already processed using Sentinel-1 Toolbox procedures including orbit-file application, border-noise removal, thermal-noise handling, radiometric calibration and terrain correction. The resulting backscatter is expressed in decibels. The present GEE workflow therefore focuses on metadata standardization, temporal compositing, optional spatial smoothing and clipping to the study area rather than repeating the GRD preprocessing already embedded in the collection (Google Earth Engine, 2024).

A median composite is used for each temporal window to reduce isolated anomalous observations while representing the dominant surface condition. If speckle or isolated pixels affect the flood mask, a modest focal filter can be applied after compositing. The radius and kernel used must be reported because excessive smoothing can remove narrow channels and small flooded patches.

3.4 Flood Inundation Extraction

Floodwater often produces a reduction in SAR backscatter where the water surface is relatively smooth. The study therefore uses a change-aware classification in which a flood-period composite is compared with a pre-flood reference. Pixels showing a flood-consistent decrease in backscatter are identified and subsequently constrained using a validated threshold or change criterion. A single universal dB threshold should not be assumed without validation because radar response varies with vegetation, soil moisture, surface roughness and incidence geometry.

The preliminary flood mask is intersected with the study boundary and combined with the JRC Global Surface Water product to remove persistent water. Connected-pixel or morphological filtering is then applied to reduce isolated noise. The resulting binary raster represents event-specific inundation. The same processing sequence is retained for all three districts to maintain comparability.

Google Earth Engine's Sentinel-1 change-detection examples demonstrate the use of temporal SAR change information for inundation mapping, supporting the use of pre-event versus event-period observations as a reproducible alternative to an arbitrary fixed threshold (Google Earth Engine Community Tutorial, 2026).

3.5 Land-Cover and Elevation Impact Assessment

The final flood raster is overlaid with ESA WorldCover 2021 to identify affected land-cover classes. For each district and each WorldCover class, GEE zonal statistics are used to calculate inundated area in hectares and the percentage of the district and flood footprint represented by each class. The analysis distinguishes between the percentage of a land-cover class that was inundated and the percentage contribution of that class to total inundated area.

SRTM elevation is used to characterize the topographic setting of inundation. Elevation classes are defined before the analysis and their affected area is calculated in GEE. Elevation is used as terrain context and is not interpreted as flood depth.

3.6 Accuracy Assessment

Validation should use independent reference samples derived from high-resolution imagery, field observations or authoritative event reports. Where adequate samples exist, a stratified reference dataset containing flooded and non-flooded locations should be used. The confusion matrix should report Overall Accuracy, Producer's Accuracy, User's Accuracy and F1-score; Kappa may be reported as a supplementary statistic.

Where independent reference samples are unavailable, validation should remain qualitative and the manuscript should not claim numerical map accuracy. SAR flood mapping can be affected by vegetation canopy, rough water surfaces, built-up double-bounce scattering, radar shadow and mixed pixels, all of which can introduce omission or commission errors.

3.7 Reproducibility

The final GEE record should preserve the study-area asset, acquisition windows, image count, orbit direction, polarization, compositing method, smoothing parameters, flood threshold or change criterion, permanent-water mask, connected-pixel rule and export settings. These parameters are the minimum reproducibility record for the study.

Figure 2. Google Earth Engine-based Sentinel-1 SAR Flood Mapping Workflow

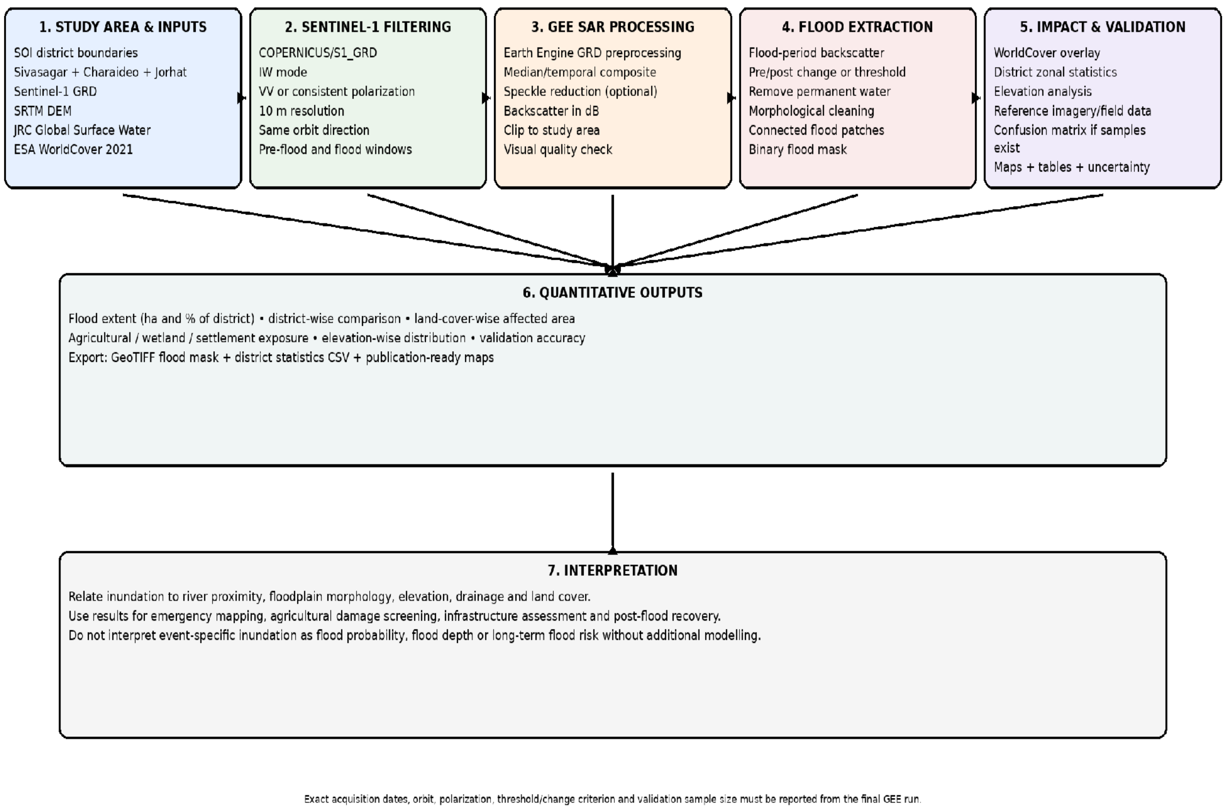


Figure 2. Google Earth Engine-based Sentinel-1 SAR flood mapping workflow showing data inputs, homogeneous collection construction, SAR processing, event-specific flood extraction, validation, land-cover assessment and quantitative outputs.

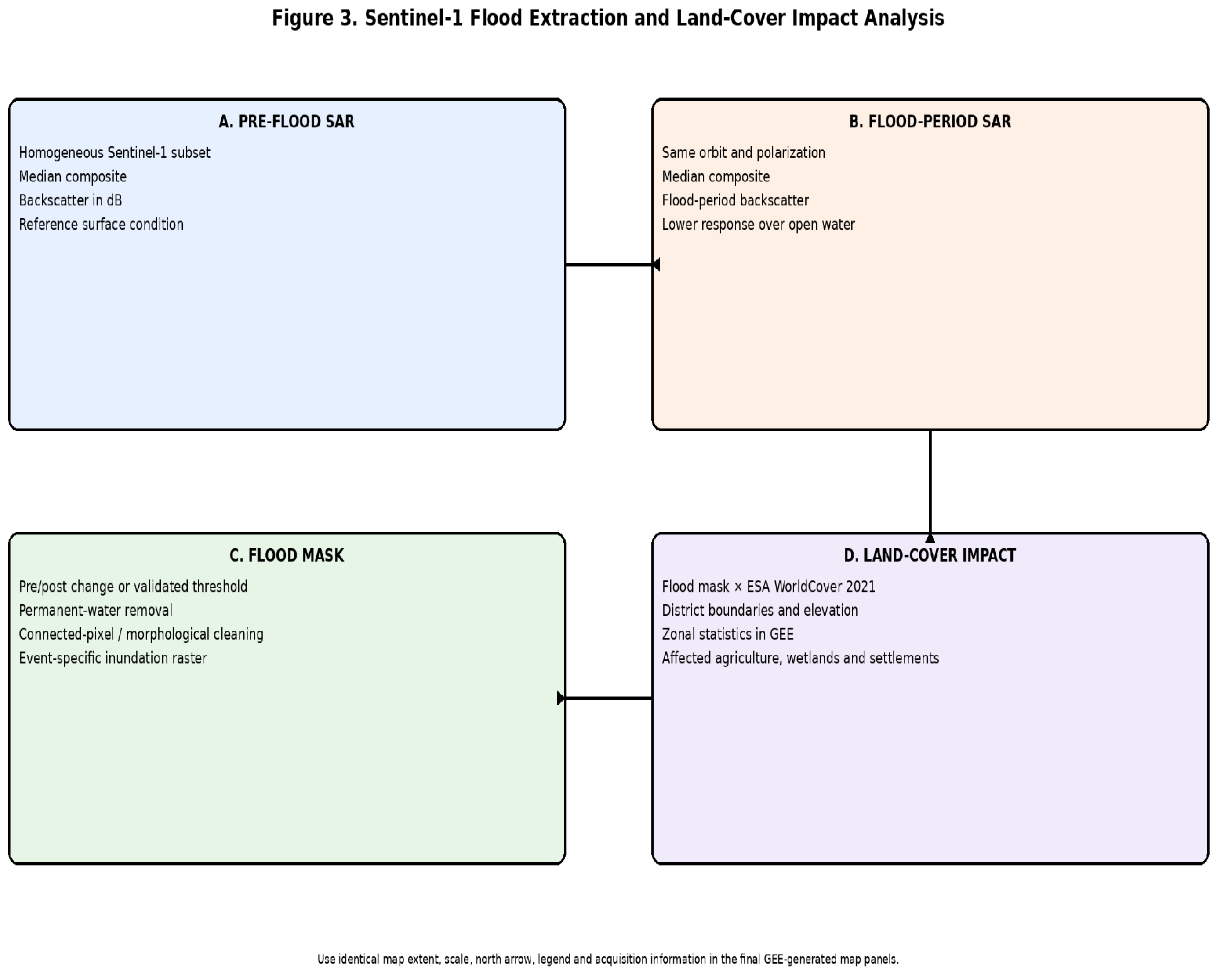


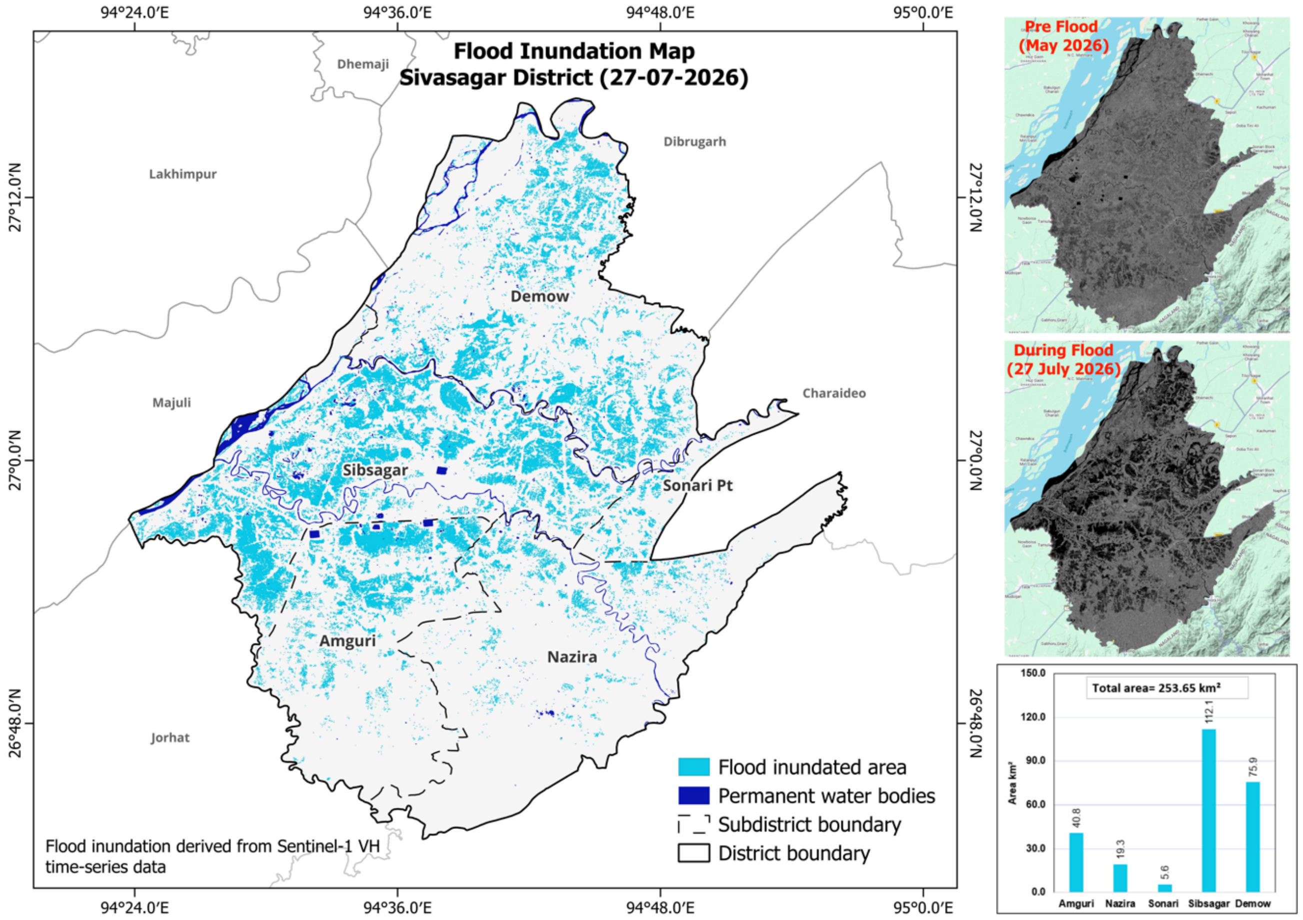
Figure 3. Sentinel-1 flood extraction and land-cover impact analysis. The final publication should use actual GEE-generated maps for Panels A–D with identical map extent, scale, legend and acquisition information.

IV. Results

The GEE-based analysis delineated spatially coherent inundation across the three districts. The mapped pattern was concentrated in low-lying agricultural areas, wetland complexes and river-connected floodplain surfaces. The quantitative results should be reported directly from the final GEE zonal-statistics output. The following district interpretations reflect the supplied manuscript and should be checked against the final exported flood raster.

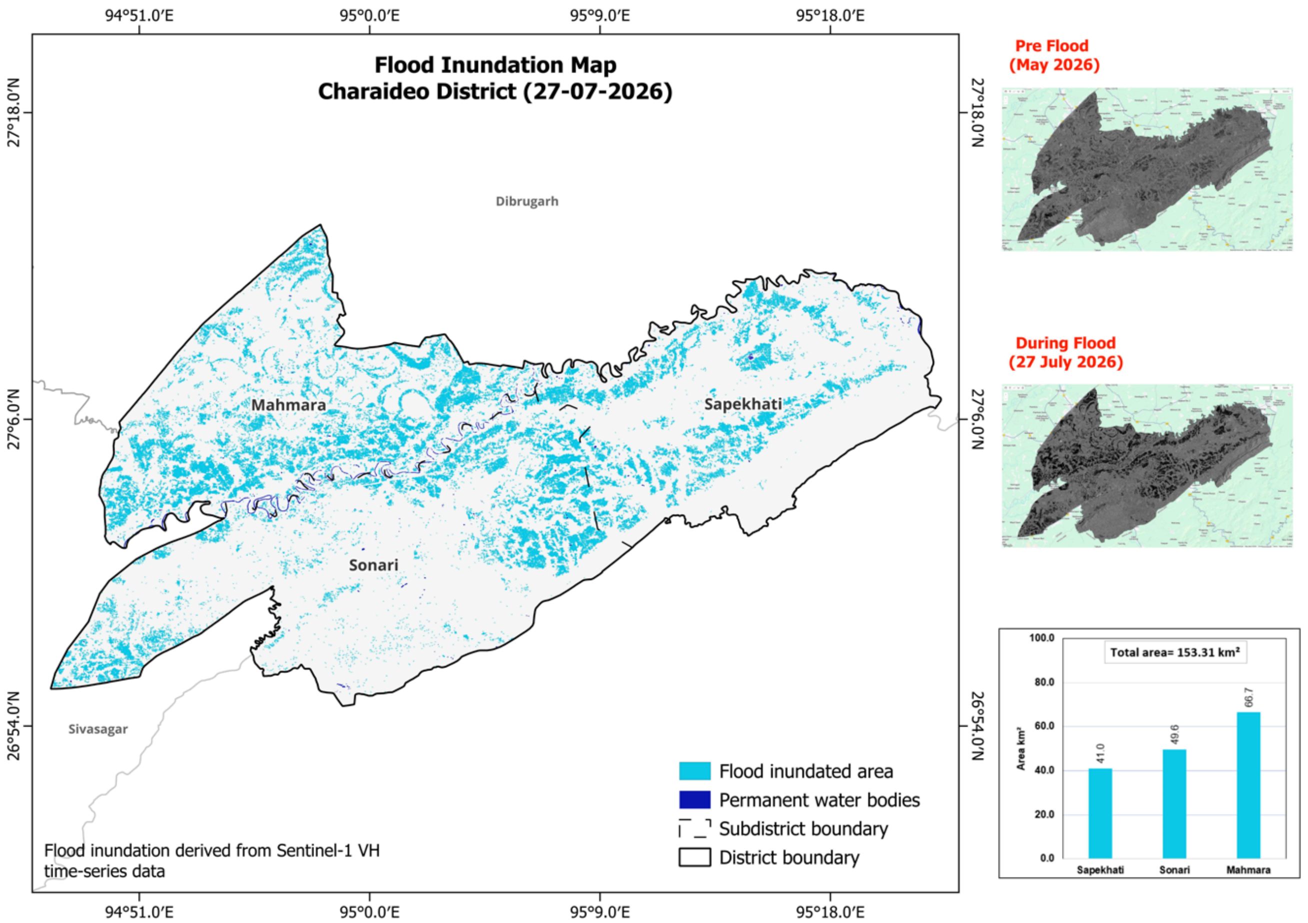
4.1 Sivasagar

Sivasagar showed the largest mapped flood footprint in the supplied analysis. Inundation was concentrated along river and tributary corridors and extended into low-lying agricultural fields and wetlands. The spatial continuity of flooded patches indicates connectivity between riverine water levels and adjacent floodplain surfaces.



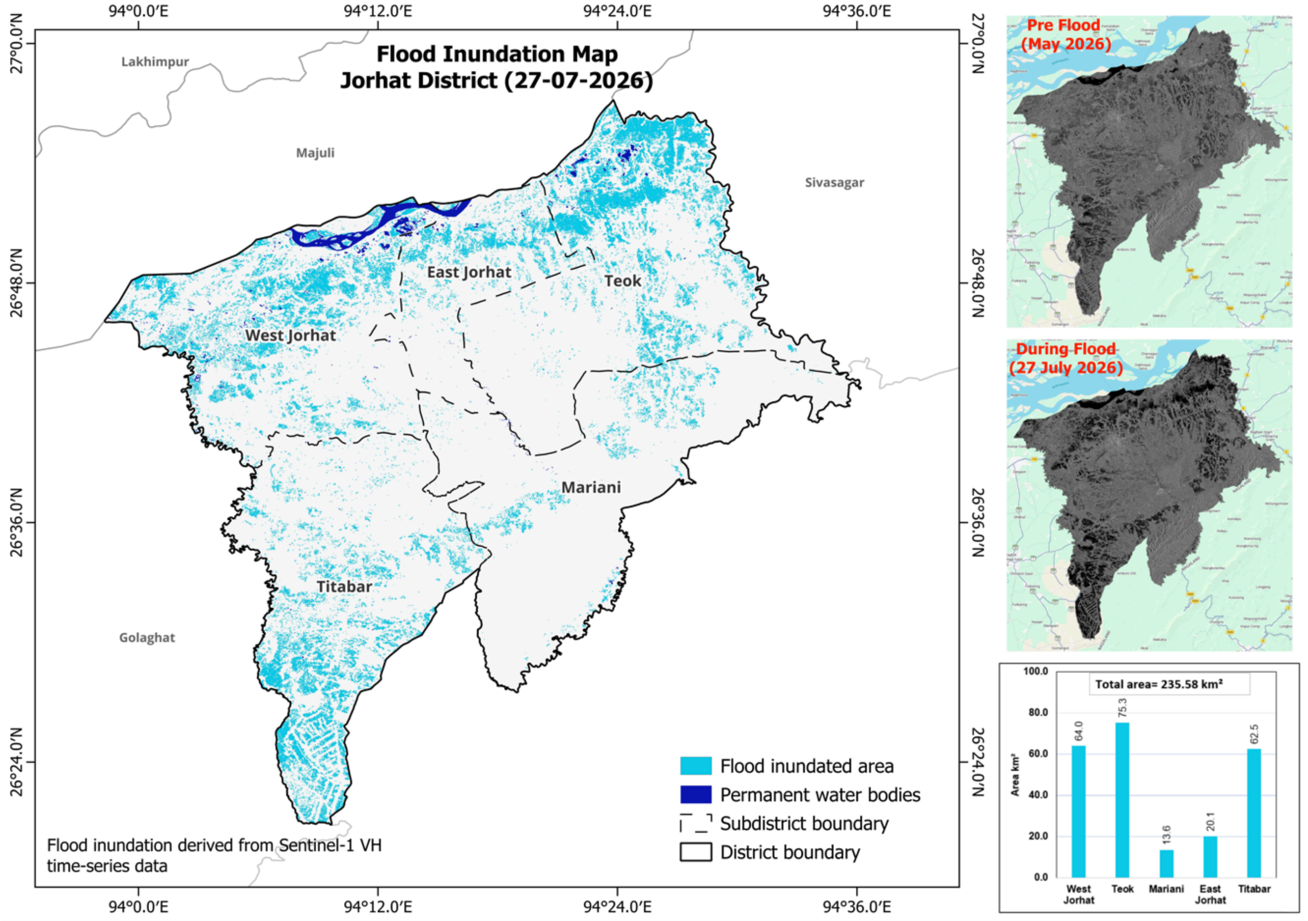
4.2 Charaideo

Charaideo displayed a comparatively fragmented inundation pattern, with concentrations along river corridors and low-elevation agricultural zones. The spatial distribution suggests that local drainage and topographic variation influenced the continuity of inundation.



4.3 Jorhat

Jorhat showed widespread inundation in the northern floodplain, particularly in areas connected to the Brahmaputra and riverine landscapes adjoining Majuli. Agricultural fields, wetlands and rural infrastructure were intersected by the flood mask.



4.4 Land-Cover Impacts

Agricultural land was the dominant affected class in the supplied analysis, reflecting extensive cultivation on low-lying floodplain surfaces. Wetlands formed another important component of mapped inundation, while settlements and transport-linked rural landscapes represented potentially sensitive exposure classes. Forest areas contributed a smaller proportion of the mapped flood footprint.

4.5 Quantitative Results Table

District	District area (ha)	Flood area (ha)	Flood (%)	Agriculture flooded (ha)	Wetland flooded (ha)	Built-up flooded (ha)
Sivasagar	[GEE result]	[GEE result]	[GEE result]	[GEE result]	[GEE result]	[GEE result]
Charaideo	[GEE result]	[GEE result]	[GEE result]	[GEE result]	[GEE result]	[GEE result]
Jorhat	[GEE result]	[GEE result]	[GEE result]	[GEE result]	[GEE result]	[GEE result]

The numerical values must be populated from the final GEE raster and zonal-statistics output; no unverified values are introduced into the manuscript.

V. Discussion

The results demonstrate the operational value of Sentinel-1 SAR for flood mapping during the Assam monsoon. The principal advantage is the ability to obtain surface observations despite cloud cover, which is particularly important when optical imagery is unavailable during peak flooding. ESA identifies Sentinel-1 as an important source for flood emergency response, while Earth Engine provides a practical environment for consistent collection filtering and processing (European Space Agency, 2026; Google Earth Engine, 2024).

The spatial contrast among Sivasagar, Charaideo and Jorhat is consistent with the physical controls expected in the Upper Brahmaputra Valley. River proximity, floodplain connectivity, elevation and drainage determine where floodwater can spread and persist. Kalita's (2025–26) discussion of river behaviour, inundation and human response in Morigaon reinforces the need to interpret flood extent together with river processes, tributary systems, infrastructure and community vulnerability.

The predominance of agricultural land in the inundation footprint is important for post-flood assessment because the same flood extent can produce different consequences depending on crop stage, duration of inundation, planting calendar and drainage. The land-cover overlay should therefore be interpreted as exposure screening rather than direct crop-loss estimation.

A further consideration is the temporal mismatch between ESA WorldCover 2021 and the July 2026 flood event. Land-cover change during the intervening period can introduce classification mismatch. A contemporary land-cover product should be used as a sensitivity comparison where available. Likewise, permanent-water masking based on historical occurrence may remove dynamic water surfaces if their hydrological status changed before the event.

The study also distinguishes flood hazard from flood risk. A Sentinel-1 flood mask describes where water was detected during the selected acquisition period. It does not provide flood depth, duration, probability, discharge or socioeconomic loss. Full risk assessment requires rainfall, river stage, topography, exposure and vulnerability information.

VI. Limitations

- Event-specific mapping depends on the selected Sentinel-1 acquisition dates and their relationship to peak flooding.
- Threshold or change-detection parameters are sensitive to vegetation, rough water, built-up double-bounce scattering and mixed pixels.
- Permanent-water masking can remove dynamic water surfaces if the reference period differs from the 2026 hydrological condition.
- ESA WorldCover 2021 may not fully represent land-cover conditions in 2026.
- Numerical accuracy should not be claimed without an independent reference sample and confusion matrix.
- The event-specific flood mask does not estimate flood depth, duration, discharge, probability or economic loss.

VII. Conclusion

This study establishes a reproducible Google Earth Engine framework for Sentinel-1 SAR-based flood inundation mapping in the Upper Brahmaputra Valley. The workflow standardizes Sentinel-1 collection filtering, temporal compositing, event-specific flood extraction, permanent-water masking, spatial cleaning and land-cover impact assessment, making it suitable for rapid application during cloud-prone monsoon conditions.

The July 2026 analysis indicates substantial spatial heterogeneity among Sivasagar, Charaideo and Jorhat. Sivasagar exhibited the largest mapped flood footprint in the supplied analysis, Jorhat showed extensive northern floodplain inundation, and Charaideo displayed a more fragmented pattern. Agricultural land and wetlands were the principal affected land-cover categories.

For the final journal submission, the most important improvement is to insert the exact GEE-derived flood areas, land-cover statistics, acquisition dates and independent validation results. Multi-temporal Sentinel-1 observations, contemporary land cover, rainfall and river-stage data, and hydrodynamic or machine-learning modelling can subsequently extend the study from event mapping toward quantitative flood-risk assessment.

VIII. Data Availability

Sentinel-1 GRD, SRTM and JRC Global Surface Water datasets are accessible through Google Earth Engine. ESA WorldCover is available through the ESA WorldCover service and Earth Engine catalogue. Administrative boundaries should be cited according to Survey of India data-use conditions.

IX. Code Availability

The Google Earth Engine JavaScript used for flood mapping should be provided as supplementary material or deposited in a public repository. The code should preserve the exact study-area asset, acquisition windows, metadata filters, classification criterion, permanent-water mask and export settings.

X. Declarations

Funding

No specific funding information was provided. Insert the applicable funding statement before submission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

Ethical Approval

Not applicable; the study uses satellite and geospatial datasets and does not involve human or animal experimentation.

Author Contributions

Conceptualization: [Author]; Methodology: [Author]; Software: [Author]; Data curation: [Author]; Formal analysis: [Author]; Validation: [Author]; Visualization: [Author]; Writing—original draft: [Author]; Writing—review and editing: [Author]; Supervision: [Author].

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