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USING PLANETSCOPE SATELLITE IMAGERY TO QUANTIFY SHORELINE AND SANDBAR DYNAMICS OF THE GAM RIVER SECTION FLOWING XUAN VAN COMMUNE, TUYEN QUANG PROVINCE

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Abstract. Shoreline and sandbar dynamics directly reflect the morpho-sedimentary equilibrium of fluvial systems. This study employs 3-m resolution PlanetScope satellite imagery integrated with Geographic Information Systems (GIS) to analyse shoreline and sandbar changes along the Gam River section flowing through Xuan Van commune, Tuyen Quang province, during the period 2015-2024. Shoreline and sandbar boundaries were delineated through visual interpretation and manual digitization of multi-temporal PlanetScope imagery in a GIS environment, enabling quantitative assessment of erosion, deposition, and channel migration during 2015-2024. The results indicate that during this ten-year period. The results indicate that during 2015-2019, shoreline displacement was limited (ranging from 10-80 m), with relatively balanced erosion and deposition processes, reflecting a stable morphological condition. From 2019 onward, the shoreline changed significantly, with several areas shifting by more than 300 m. The eroded area markedly surpasses the deposited area, indicating a clear trend toward morphological instability. These changes are closely associated with sandbar dynamics, the meandering river planform, and increasing anthropogenic pressures in the study area. The study confirms that PlanetScope imagery is an effective data source for detecting rapid, reach-scale riverine geomorphic changes and provides quantitative evidence to support river management and erosion mitigation strategies.

Keywords: shoreline, sandbar, planetScope, remote sensing, geomorphic change.

1. Introduction

River shorelines and sandbars are highly dynamic geomorphic components that are governed by flow regimes, sediment transport, and human activities. Their morphological changes not only affect channel stability but also directly influence riparian land resources, ecosystems, and socio-economic development. In recent decades, under the combined impacts of climate change and intensified resource extraction and construction activities, many rivers in Vietnam have exhibited increasing erosion and morphological instability [1], [2].

Numerous global studies have utilized aerial photographs and medium-resolution satellite imagery (such as Landsat andSentinel-2) to analyze the dynamics of river shorelines and sandbars. The primary advantage of these medium-resolution datasets lies in their wide spatial coverage and accessibility, providing long-term, freely accessible historical time series free of charge, which facilitates the comprehensive assessment of erosion-accretion trends over time [3]. However, a core disadvantage is that the 10–30 m spatial resolution of such data often induces significant positioning errors, failing to accurately delineate small sandbars or complex, fine-scale shoreline variations [4]. Meanwhile, practical observations indicate that the historical aerial photographs currently archived in Vietnam are highly outdated and lack temporal continuity.

Traditional field-based survey methods provide high accuracy but are limited in spatial coverage and long-term monitoring capability. In contrast, integrating remote sensing and GIS enables continuous, synoptic observation over large areas, making it particularly effective for studying riverine geomorphic dynamics [5], [6]. Among currently available datasets, high-resolution PlanetScope imagery has been increasingly applied due to its sub-daily revisit frequency and meter-level spatial resolution (3 m) [7], [8].

The Gam River is a major tributary of the Lo River, originating in Guangxi province, China, where it is known as the Bainam River. Flowing into northern Vietnam, the river is designated as the Gam River from the border area of Co Ba commune, Cao Bang Province. The river meanders through Tuyen Quang province and joins the Lo River at the boundary of Tan Long, Xuan Van, and Yen Son communes, approximately 10 km north of Minh Xuan Ward [9]. Since 2019, to meet the increasing demand for construction materials, several sand and gravel mining sites have been licensed along the Gam River and its tributaries [10]. Correspondingly, signs of intensified shoreline and sandbar changes have been observed along the river reach passing through Xuan Van commune. However, quantitative studies assessing the magnitude and trends of these changes remain limited.

This study aims to analyze the shoreline dynamics of the Gam River before and after 2019, evaluate variations in sandbar surface area and spatial distribution, and discuss the mechanisms governing dominant erosion-deposition trends, thereby supporting the sustainable management of riparian resources.

2. Materials, methodology, and results

2.1. Study Area

The study area covers an approximately 25-km river reach of the Gam River flowing through Xuan Van commune, Tuyen Quang province (Figure 1). The channel width varies from 100 to 250 m, exhibiting a clearly meandering planform and strong seasonal hydrological variability. Significant water-level fluctuations between the dry and wet seasons promote active erosion and deposition processes. This river reach is of considerable importance for local livelihoods, transportation, and production activities, while being highly sensitive to morphological changes.

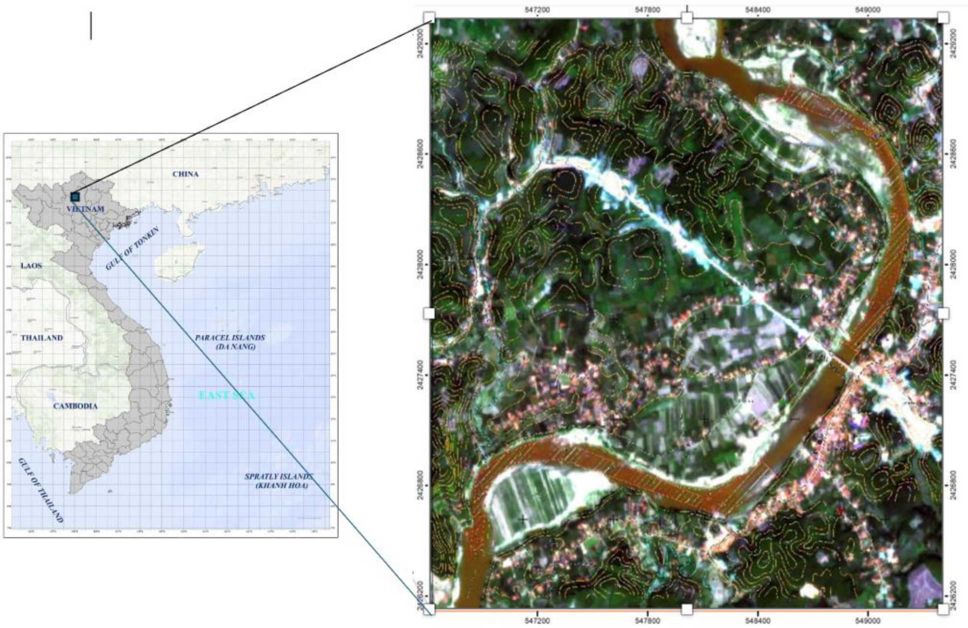

Figure 1. Location map of the study area along the Gam River flowing through Xuan Van commune, Tuyen Quang province

2.2. Data

Typically, change detection studies require at least two images for comparison. However, identifying trends in morphological variability, such as linear versus nonlinear behavior or continuous versus discontinuous patterns, requires multi-temporal datasets consisting of three or more observation dates [11]. In this study, we employed three PlanetScope satellite images featuring a 3-m spatial resolution, with the following scene IDs: 20150215_101530_0c12 (captured on Feb 15, 2015), 20190115_032512_1036 (captured on Jan 15, 2019), and 20240212_033250_242a (captured on Feb 12, 2024). The selection criteria prioritized high image quality, minimal cloud cover, and acquisition during the dry season. This approach aimed to minimize uncertainties arising from water-level fluctuations and seasonal variations in land cover.

Additionally, standardized topographic and base maps at a scale of 1:5,000, along with field survey data from 2015 and 2019, were collected to support monitoring activities and GIS analysis. These map products were sourced from the national-level R&D project: 'Research and calculation of carbon emission content using remote sensing data for greenhouse gas inventory: An experiment on VNREDSat-1 and existing imagery sources in Vietnam' (code: VT-UD.06/17-20), which belonged to the National Science and Technology Program on Space Technology (2016–2020, Code: CNVT/16-20). According to national regulations, for a 1:5,000 scale map, the allowable error for geographical features with indistinct boundaries, such as sandbars, dynamic floodplains, and vegetation limits, is 5 m on the ground (equivalent to 1.0 mm on the map) [12].

Shoreline and sandbar extraction was performed at a consistent display scale of 1:5,000 for all datasets. Each shoreline was digitized independently and cross-verified to guarantee geometric consistency.

2.3. Methodology

PlanetScope satellite imagery was preprocessed using Planet's standard orthorectified and atmospherically corrected product (the PlanetScope Analytic Ortho Scene). All images were reprojected to the national coordinate system (VN-2000 / TM-3° central meridian of 105°E) using ArcGIS Pro 3.2. The study area was consistently clipped to a uniform 25-km reach for all time periods to ensure spatial comparability. Strict image selection criteria were applied to minimize errors associated with hydrological and atmospheric variability, including cloud cover less than 5% and acquisition within the same hydrological season (specifically the late dry season, from February to March) to ensure comparable river water levels.

Shoreline and sandbar delineation were conducted manually in ArcGIS Pro at a fixed display scale of 1:5,000 to reduce operator bias. The shoreline was defined as the wet/dry interface at the riverbank toe or at the edge of visible vegetation. For sandbars, boundaries were digitized at the water–sand interface of emergent bars at the time of image acquisition. Mixed pixels along boundaries were consistently assigned to the land/sand class based on visual interpretation combined with spectral reflectance checks (specifically identifying higher reflectance in the red and near-infrared {NIR} bands). To ensure consistency and reliability, each shoreline and sandbar was independently digitized by two operators, followed by cross-validation. Discrepancies greater than 6 m (two pixels) were re-evaluated and reconciled. A 3-m buffer (one pixel) was applied to account for the inherent positional uncertainty of PlanetScope imagery with a 3 m resolution [13].

Change detection was performed using GIS overlay analysis. Shoreline displacement was quantified as the perpendicular distance between successive shorelines along transects spaced at 50-m intervals, oriented perpendicular to the 2015 baseline shoreline. Erosion and accretion areas were calculated from polygon overlays of shoreline positions. Sandbar dynamics were quantified based on changes in surface area (expressed in hectares) and the displacement distance of sandbar centroids between periods.

The classification accuracy was determined from the processing results of PlanetScope remote sensing imagery. Evaluating the reliability of these results is a critical step, achieved using the Kappa error matrix [14], [15]. This method involves comparing the classification results with known reference data to quantify the degree of agreement or discrepancy between the classified features and actual ground truth. The initial step required identifying high-resolution imagery zones on Google Earth for the years 2015, 2019, and 2024. Validation points were randomly generated within ArcGIS and subsequently populated into 2-ha buffer zones. These zones were converted into KML format and uploaded to Google Earth. Through visual image interpretation, surface cover attributes were assigned to the random validation points. The total number of these points was then verified and concurrently cross-referenced with topographic map data. The validation process was executed based on the specific sample size allocated for each respective year.

2.4. Results of accuracy and reliability assessment for image classification

Table 1. Results of the accuracy and reliability assessment for image classification

No.	Content	Year 2015	Year 2019	Year 2024
1	Training Overall Accuracy	98.82%	95.52%	95.08%
2	Validation Kappa	0.89	0.84	0.84

Statistical analysis (Table 1) indicated that the classification results achieved an overall accuracy of 98.82% for 2015, 95.52% for 2019, and 95.08% for 2024, proving that the method obtained high accuracy in object classification. However, the accuracy assessment showed that errors during the processing phase were scattered throughout most land cover layers. The underlying cause of this misclassification is the high spectral homogeneity among the subcategories that make up these target classes. Therefore, changes in land cover objects within this region need continuous monitoring for timely suitability adjustments. Additionally, the robustness of the results was verified by Kappa coefficients of 0.89 for 2015, 0.84 for 2019, and 0.84 for 2024**.**

2.5. Shoreline changes during 2015 - 2019

Between 2015 and 2019, shoreline changes along the Gam River were modest, with displacements primarily ranging from 10 to 80 m. These changes were localized to the upstream and downstream sections of the study area (Figure 2a–c). Overall, the extent of erosion and deposition was nearly balanced, and no persistent erosion hotspots were detected. This pattern reflects the natural dynamics of a meandering river, where erosion commonly occurs on outer (concave) banks and deposition on inner (convex) banks or downstream of bends.

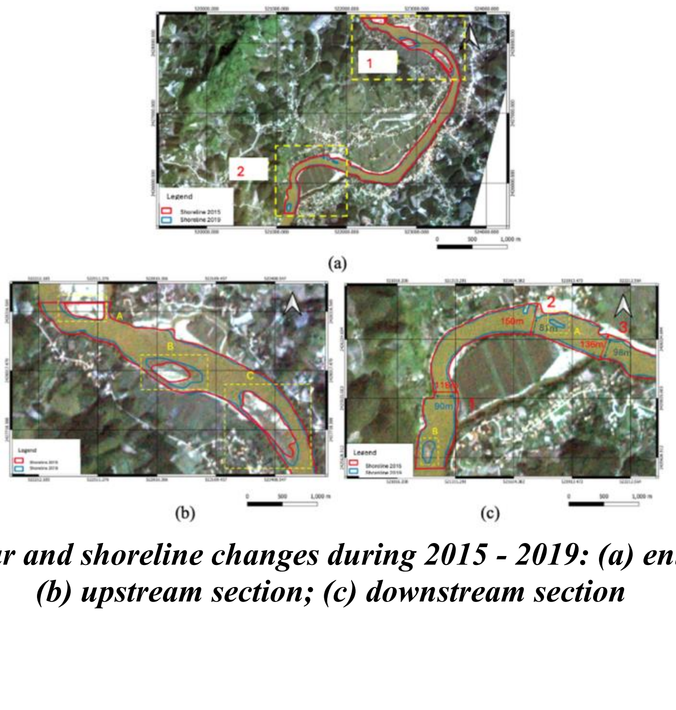

Figure 2. Sandbar and shoreline changes during 2015 - 2019: (a) entire study reach; (b) upstream section; (c) downstream section

2.6. Shoreline Changes during 2019 - 2024

From 2019 to 2024, shoreline changes along the river became more pronounced in both spatial extent and magnitude. In many areas, shoreline displacement ranged from several dozen meters to over 300 m, with erosion clearly outpacing deposition. Large meander bends composed of unconsolidated bank-forming materials experienced the highest erosion rates, while sections with exposed bedrock remained relatively stable. Image analysis and field observations consistently indicate a significant escalation in erosion processes during this five-year period.

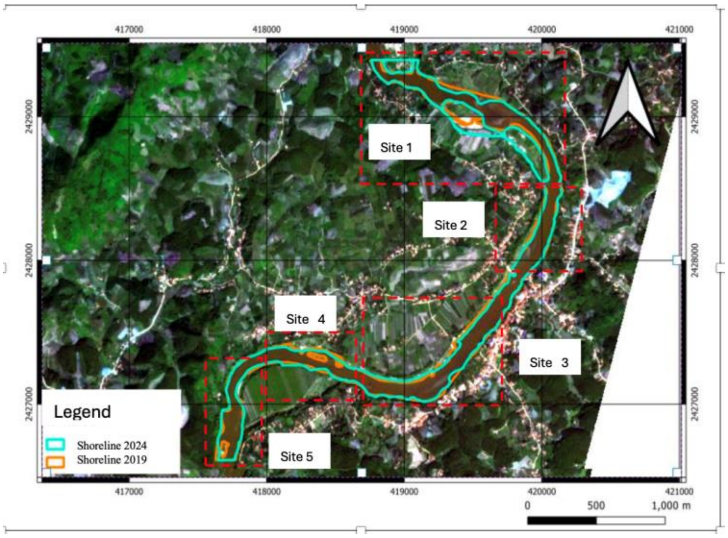

Figure 3. Shoreline changes during 2019–2024 along the Gam River flowing through Xuan Van commune, Tuyen Quang province

Table 2 provides a quantitative summary of shoreline changes and sandbar dynamics, while Table 3 presents the corresponding displacement statistics across key river reaches within the study area for the period 2015 - 2024.

Table 2. Quantitative summary of shoreline changes and sandbar dynamics along the Gam River flowing through Xuan Van commune, Tuyen Quang province (2015 - 2024)

Period	Shoreline displacement (m)	Erosion-accretion relationship	Sandbar area change	The number of sandbars changed
2015–2019	10–80	Approximately balanced	Minor changes; slight downstream migration	Limited changes
2019–2024	10–>300	Erosion clearly dominates over accretion	Many sandbars contracted or disappeared; new bars formed at different locations.	Significant reduction in existing sandbars

Table 3. Statistics of shoreline displacement at key river reaches of the Gam River flowing through Xuan Van commune, Tuyen Quang province (2015 - 2024)

River reach	**Displacement 2015 - 2019 (m)**	**Displacement 2019 - 2024 (m)**	**Dominant process**	**Notes**
Upstream meander bend	10 - 80	> 300 (at some locations)	Severe erosion	Non-cohesive bank materials
Mid-reach	10 - 80	100-300	Erosion-dominated	Strong sandbar dynamics
Downstream meander bend	10 - 80	> 200	Severe erosion	Strongly influenced by flow regime changes
Bedrock-controlled reaches	Very small (< 20)	Stable	Stable	Exposed rocky banks

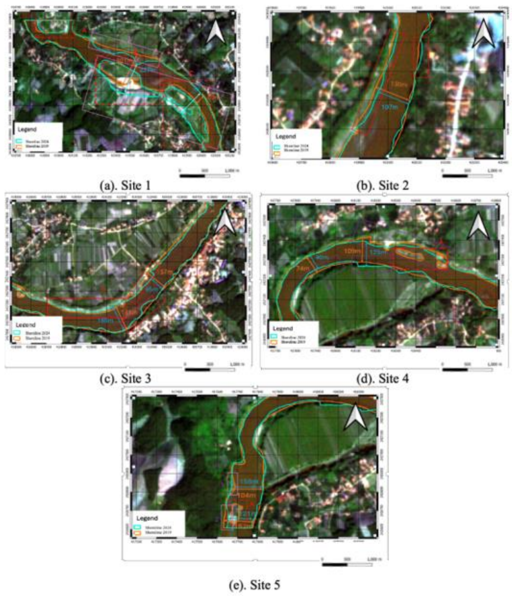

Figure 4. Shoreline changes during 2019 - 2024 in individual sections of the Gam River

2.6. Sandbar dynamics and their relationship with channel morphology

Sandbars and point bars in the Gam River play a key role in regulating flow direction and velocity. During 2015 - 2019, sandbar surface area variations were minor, accompanied by a slight downstream migration along the channel axis. In contrast, after 2019, several sandbars diminished or disappeared, while new depositional features formed at different locations. Furthermore, analytical results indicate that shoreline erosion during the 2019-2024 period was closely correlated with the intensification of construction material extraction activities in the region. Compared to the 2015-2019 period, when the riverbed remained relatively stable, the post-2019 phase recorded a surge in demand for sand and gravel for infrastructure development, leading to the licensing and expansion of multiple extraction sites in Xuan Van commune. According to comparative data from mineral reserve approvals, the volume of sand and gravel identified within the floodplains and the Gam River bed in this area increased significantly, facilitating large-scale mining operations. This intensified extraction has altered the floodplain structure, caused a sediment deficit, and directly led to severe shoreline erosion, with bank retreat distances exceeding 300 m in certain locations. These findings align with the established geomorphic principle that excessive sediment extraction causes channel instability, thereby altering flow distribution and enhancing localized bank erosion on opposing riverbanks.

2.7. Discussion

The quantitative results clearly demonstrate a substantial shift in the shoreline and sandbar dynamics of the Gam River after 2019. During the 2015-2019 period, measured shoreline displacements were restricted to approximately 10-80 m, and the total surface areas of erosion and deposition were nearly balanced. This magnitude of change is consistent with the expected behavior of a naturally meandering river under quasi-equilibrium conditions, where lateral migration occurs gradually through erosion on outer (concave) banks and deposition on inner (convex) banks or point bars. Similar displacement ranges have been reported for relatively stable river reaches analyzed using medium- to high-resolution satellite imagery across Asia and Southeast Asia [16], [17]

In contrast, the post-2019 period exhibits a marked escalation in geomorphic activity, with several riverbank sections showing a shoreline retreat exceeding 300 m over a relatively short time span. Such magnitudes are significantly higher than those observed in the earlier period and exceed the range typically attributed to natural channel migration alone. Studies using multi-temporal satellite datasets have shown that when shoreline displacement surpasses 200–300 m within a few years, external disturbances - particularly anthropogenic interventions - are often involved [2], [5]. In the case of the Gam River case, this temporal breakpoint coincides with the expansion of licensed sand and gravel mining activities after 2019, suggesting a strong linkage between human activities and accelerated bank erosion.

The marked imbalance between erosion and deposition areas after 2019 further supports the interpretation of morphological disequilibrium. While the 2015-2019 period displayed near symmetry between eroded and accreted zones, the 2019-2024 analysis shows erosion dominating most of the study reach. Comparable trends have been documented along the Mekong River, where remote-sensing-based assessments revealed that intensive sediment extraction leads to net channel incision, bank destabilization, and the downstream redistribution of sandbars [18]. This mechanism is consistent with observations in the present study, where the reduction or disappearance of several sandbars coincides spatially with zones of intensified bank retreat.

Sandbar dynamics provide an additional explanatory layer for the observed shoreline changes. Quantitative mapping indicates that sandbar surface areas were relatively stable during the 2015–2019 period, exhibiting only minor downstream migration. After 2019, however, multiple sandbars either significantly shrank or vanished, while new depositional features formed at different locations. Such reorganization alters local flow paths, increasing flow concentration toward opposing banks and enhancing near-bank shear stress on unconsolidated materials. Previous studies have demonstrated that even modest reductions in sandbar area can result in disproportionately large increases in local erosion rates, especially in meandering reaches with loose alluvial banks [17], [18]

From a methodological perspective, the ability to detect shoreline displacements ranging from tens to several hundreds of meters confirms the suitability of 3-m PlanetScope imagery for riverine geomorphic analysis at the reach scale. While uncertainties related to manual digitization and seasonal water-level variability remain, the consistent use of similar acquisition periods and uniform mapping scales minimizes systematic bias. Comparable accuracy levels have been reported in Vietnamese river studies applying remote sensing and GIS techniques, particularly when multi-year trends rather than short-term fluctuations are emphasized [19].

Overall, the Gam River reach flowing through Xuan Van commune has shifted from a relatively stable morphological state to a more unstable, erosion-dominated condition after 2019. This transition is reflected in increased shoreline displacement and pronounced sandbar reorganization. These findings highlight the value of high-resolution satellite datasets for detecting rapid, reach-scale geomorphic changes and emphasize the need for improved management of sand mining activities to mitigate ongoing riverbank degradation.

The research workflow presented here, including hydrological-season-based image selection, manual delineation at a fixed scale, cross-validation, and GIS overlay analysis, can be readily applied to other dynamic river reaches where high-resolution monitoring is required but field surveys are challenging. Future studies may automate shoreline extraction using spectral indices, such as the Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI), or machine learning algorithms to improve efficiency while maintaining the level of accuracy achieved by the manual approach adopted in this study.

The accelerated bank erosion observed after 2019 highlights the need for stricter regulation of the volume and spatial distribution of sand and gravel extraction. Continuous monitoring using PlanetScope or similar high-resolution satellite constellations, combined with the quantitative metrics developed in this study (specifically erosion area, maximum retreat distance, and sandbar area change), could function as an early warning system to support adaptive river management.

Limitations of this study include the relatively low temporal frequency (confined to three image epochs) and uncertainties associated with water-level variability between images. Future work should incorporate a larger number of PlanetScope images and, where possible, integrate water-level corrections or digital elevation models derived from LiDAR datasets.

3. Conclusions

This study demonstrates the effectiveness of integrating PlanetScope satellite imagery with GIS overlay analysis for quantifying shoreline and sandbar dynamics of the Gam River. The results indicate that during the 2015–2019 period, the river system remained relatively stable, whereas the 2019–2024 phase exhibited accelerated erosion and pronounced morphological instability. From a management perspective, the observed acceleration of bank erosion after 2019 suggests that existing sand and gravel extraction practices may exceed the geomorphic resilience of the river channel. Continuous monitoring using high-resolution satellite datasets could therefore serve as an early-warning system to support the adaptive regulation of riverbed mining activities. The proposed approach is highly feasible and can be extended to other dynamic river reaches to support sustainable resource management and mitigate riverbank degradation risks.

Note for contributor:

- Short bio: Vu Thi Phuong Thao is a lecturer at the Faculty of Environment, Hanoi University of Mining and Geology, and Nguyen Phi Hung is a lecturer at the Faculty of Mining, Hanoi University of Mining and Geology.

- Author's contributions: Vu Thi Phuong Thao: conceptualization, methodology, software, formal analysis, investigation, data curation, writing, review & editing; Nguyen Phi Hung: formal analysis, investigation, data curation, supervision, validation.

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