

A Systematic Review of Geographic Information Systems, Artificial Intelligence, Big Data Analytics, and Geospatial Intelligence: Toward an Integrated GeoAI–GEOINT Framework

النظامية للتطبيقات الجغرافية المكانية المعتمدة على الذكاء الاصطناعي واستخبارات المصادر المفتوحة

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Abstract:

This study presents a systematic literature review (SLR) examining the convergence of Geographic Information Systems (GIS), Artificial Intelligence (AI), Big Data Analytics, and Geospatial Intelligence (GEOINT) within the emerging GeoAI paradigm. Following PRISMA guidelines, we analyze 26 peer-reviewed studies (2019–2026) to address three critical research questions regarding technological integration, operational bottlenecks, and socio-environmental applications. Findings reveal a paradigm shift from descriptive, static mapping toward predictive, autonomous, and intelligence-driven spatial systems. While machine learning and deep learning dominate feature extraction from high-dimensional datasets, significant challenges persist regarding model interpretability, real-time data synchronization, and ethical governance. To bridge the gap between technological innovation and non-military public service delivery, this paper introduces a conceptual multi-layer GeoAI–GEOINT framework. The framework is tailored to optimize spatial decision-making, such as educational resource distribution and infrastructural planning in infrastructure-constrained environments. Consequently, this review establishes a strategic roadmap for transitioning from fragmented spatial data processing to integrated operational intelligence.

Keywords : GeoAI; Geospatial Intelligence (GEOINT); Big Data Analytics; Spatial Decision Support Systems; Public Service Delivery

تصنيف جال: R5، C55، C8

المخلص:

تقدم هذه الدراسة مراجعة منهجية للأدبيات (SLR) تتناول تقارب نظم المعلومات الجغرافية (GIS) والذكاء الاصطناعي (AI) وتحليلات البيانات الضخمة والاستخبارات الجغرافية المكانية (GEOINT) ضمن نموذج الذكاء الجغرافي المكاني الناشئ. وبتابع إرشادات PRISMA، قمنا بتحليل 26 دراسة محكمة (2019-2026) للإجابة على ثلاثة أسئلة بحثية حاسمة تتعلق بالتكامل التكنولوجي، والمعوقات التشغيلية، والتطبيقات الاجتماعية

والبيئية. تكشف النتائج عن تحول نموذجي من رسم الخرائط الوصفية الثابتة إلى أنظمة مكانية تنبؤية، ذاتية التشغيل، وقائمة على الذكاء. وبينما يهيمن التعلم الآلي والتعلم العميق على استخلاص الميزات من مجموعات البيانات عالية الأبعاد، لا تزال هناك تحديات كبيرة فيما يتعلق بتفسير النماذج، ومزامنة البيانات في الوقت الفعلي، والحوكمة الأخلاقية. ولسد الفجوة بين الابتكار التكنولوجي وتقديم الخدمات العامة غير العسكرية، تقدم هذه الورقة إطاراً مفاهيمياً متعدد الطبقات للذكاء الجغرافي المكاني والاستخبارات الجغرافية المكانية. صُمم هذا الإطار خصيصاً لتحسين عملية اتخاذ القرارات المكانية، مثل توزيع الموارد التعليمية وتخطيط البنية التحتية في البيئات ذات البنية التحتية المحدودة. وبناءً على ذلك، تُرسخ هذه المراجعة خارطة طريق استراتيجية للانتقال من معالجة البيانات المكانية المجزأة إلى الذكاء التشغيلي المتكامل.

كلمات مفتاحية: الذكاء الجغرافي الاصطناعي، الاستخبارات الجغرافية المكانية (GEOINT)، تحليلات البيانات الضخمة، أنظمة دعم القرار المكاني، تقديم الخدمات العامة.

Classification JEL : C8 ،C55 ،R5

INTRODUCTION .

In the modern world of environmental information systems, the arrival of technological advancements is inevitable. Geographic Information Systems serves as the foundational technology from which the next generation of technology known as GeoAI or Artificial Intelligence (AI) in GIS emerged. The integration of AI, machine learning and deep learning into optimal GIS technology has spawned a new name that is more recognizable in the tech world today. GeoAI integrates GIS into all predictive and prescriptive analytical models through machine learning data processing, automated pattern recognition and predictive modeling that is built on spatial analysis in cartographic science. [1]

The GeoAI disruption of traditional GIS came from the expansion of the technology into a number of intelligence-driven domains in the public and private sectors. In GeoAI, mapped data is made even more useful by the inference of insights from it to be leveraged for predictions or visualizations of future scenarios. Applications in this field include security analysis and strategic planning in conjunction with high-end development of maps for real-time situational awareness. [2]

In contrast, basic GIS applications often produce only two types of output, which are visual graphical maps and static graphs only. The real shift in the current analytical landscape of GeoAI is the execution of predictive and prescriptive spatial intelligence systems, which is basically GIS on a computer or, in fact, on the radar instead of a traditional map interface. By structuring what the authors define as a structured taxonomy, they are able to identify different levels of GeoAI patterns of like AI applications. They conduct comparative synthesis of GeoAI–GEOINT integration on design workshops and technical testbed demonstrations. [3]

The importance of spatial decision support systems in the Iraqi educational context stems from the geographically driven nature of administrative decisions. The allocation of teaching staff, the selection of sites for new school construction, and the distribution of educational resources are primarily spatial decisions. Integrating GeoAI provides a scientific framework for decision-makers in education directorates (such as Anbar's) to transition from haphazard planning to planning based on geographic data modeling, thus ensuring efficient access and reducing disparities between urban and rural areas. [4]

Despite the numerous studies addressing GeoAI in general, a clear research gap exists regarding the application of geospatial intelligence (GEOINT) to non-military service institutions in developing countries. This study contributes by offering a GeoAI-GEOINT framework tailored to the educational field, taking into account the limitations of local infrastructure through the use of cloud computing. [5]

Research Gap & Questions:

Despite the proliferation of GeoAI studies, a dual research gap remains prominent in current literature. First, existing research heavily favors theoretical models or military-centric GEOINT applications, leaving a critical conceptual and operational void regarding how integrated GeoAI can optimize civilian public services (e.g, educational planning) in developing regions. Second, the literature exhibits a socio-technical contradiction between the deployment of high-dimensional deep learning algorithms and the infrastructural constraints of local directorates. To bridge these gaps, this systematic review is guided by three core Research Questions (RQs):

- RQ1: What are the dominant algorithmic and computational architectures driving the

integration of GIS, AI, and Big Data within the contemporary GeoAI–GEOINT literature?

- RQ2: What are the primary technical and ethical contradictions that hinder the transition from static spatial analysis to real-time operational intelligence?
- RQ3: How can an integrated GeoAI–GEOINT framework be conceptually structured to support decentralized administrative planning and resource distribution in resource-constrained public sectors?

2. Methodology .

This study executes a Systematic Literature Review (SLR) strictly compliant with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. Given the conceptual nature of this review, the primary analytical mechanism is qualitative thematic synthesis and methodological triangulation, rather than empirical statistical testing. The research tracking pipeline progressed through four distinct phases: identification, screening, eligibility, and final inclusion. [6]

Data Sources:

Scopus, Web of Science, and Google Scholar.

Search Strategy:

GIS AND ("GeoAI" OR "Artificial Intelligence" OR "GEOINT" OR "Big Data" OR "Spatial Analytics")

Inclusion Criteria:

- Publications between 2019–2026
- Peer-reviewed journal articles and conference papers
- Studies focusing on GIS integration with AI or GEOINT

Screening Process:

After duplicate removal and relevance filtering, 26 studies were selected for qualitative synthesis.

The study followed PRISMA guidelines The study followed PRISMA guidelines for systematic literature selection as illustrated below

Records identified through database searching (Scopus, Web of Science, Google Scholar): 312 studies

- Additional records identified through other sources: 18 studies
- Total records: 330 studies
- Duplicates removed: 74 studies
- Records after duplicates removal: 256 studies
- Records screened (title and abstract screening): 256 studies
- Records excluded (not relevant to GIS–AI–GEOINT integration): 181 studies
- Full-text articles assessed for eligibility: 75 studies
- Full-text articles excluded with reasons: 49 studies
 - Not focused on GIS integration (21 studies)
 - Not AI/Big Data related (15 studies)
 - Conceptual papers without methodology (13 studies)
- Studies included in qualitative synthesis: 26 studies

The methodological robustness score (1–5) was assigned based on predefined criteria including:

- (1) clarity of methodology,
- (2) data quality,
- (3) analytical rigor,
- (4) validation approach,
- (5) reproducibility of results.

The quality assessment indicates that the majority of included studies are published in high-impact (Q1) journals and demonstrate strong methodological rigor (scores between 4–5).

However, a small proportion of studies rely on conceptual or preprint-based approaches, which may affect the overall robustness of the synthesis. [7]

Table 1. Quality Assessment Matrix of Included Studies (N=26)

Quality Metric	Evaluation Criteria	Distribution of Selected Papers (N=26)	Methodological Weight
Inclusion Tier 1 (High Quality)	Peer-reviewed, indexed in Scopus/WoS (Q1/Q2), explicit spatial AI methodology.	18 Studies (approx. 69%)	Score: 4.5 – 5.0
Inclusion Tier 2 (Moderate)	Established conference proceedings, validated empirical frameworks.	6 Studies (approx. 23%)	Score: 3.5 – 4.4
Inclusion Tier 3 (Conceptual)	Peer-reviewed conceptual models providing architectural frameworks.	2 Studies (approx. 8%)	Score: 3.0 – 3.4

Table 2. Methodological Mapping and Contextualization of Selected Core Studies

Contextual Application & Local Adaptation (Anbar Case)	Algorithmic Paradigm	Primary Domain	Core Methodology	Author (Year)
Structuring spatial taxonomies of educational assets across vast rural zones .	Symbolic AI & ML	Knowledge Discovery	Spatial Knowledge Graphs	Janowicz et al . (2020)
Overcoming local hardware limitations via cloud-based multi-district synchronization .	Cloud Big Data Spatial	Earth Observation	Distributed Computing	Yang et al. (2019)
Automating automated map generation for	Deep Generative Models	Smart Cartography	Generative Spatial AI	Kang et al. (2024)

Contextual Application & Local Adaptation (Anbar Case)	Algorithmic Paradigm	Primary Domain	Core Methodology	Author (Year)
demographic growth tracking .				
Predictive spatial modeling for optimizing school site locations based on proximity .	CNN / Deep Learning	Public Health GIS	Spatial Deep Learning	Sahana et al . (2022)
Automating the distribution and transfer of teaching staff based on spatial proximity to eliminate administrative bias.	Hybrid GIS–AI Models	Urban Systems	Spatiotemporal Analytics	Attah et al. (2024)

Consistently, most of the research on the use of GeoAI for GEOINT is focused on two areas, the integration of GeoAI and the use of Big Data analytics. There have been a limited number of studies on the potential of using GeoAI for the purposes of GEOINT. There is also an existing imbalance between the rate of technological development and the pace of the intelligence-level applications of the latest technological developments. [8]

3. Results The synthesis of selected studies reveals five dominant scientific trends:

(1) GIS–AI–GEOINT Convergence

The advent of GeoAI technology has opened the possibility of implementing an integrated GeoAI–GEOINT ecosystem in which the agile nature of integrated analytics and intelligence layers drive automated information discovery, delivery, and understanding. Such ecosystems are rapidly moving from concept to reality as new technologies such as cloud computing, multi-intelligence processing, and spatial data science converge with traditional human-centric GEOINT workflows. [9]

(2) Dominance of Deep Learning

In the field of spatial analytics, Convolutional Neural Networks (CNN) and Graph Neural Networks (GNN) are widely applied models. The unique structures of these neural networks provide great satisfactions to introducing the spatial relationship into these models and acquiring powerful neural network models. [10]

(3) Big Data as Enabler

The realization of the concept of real-time geospatial data analysis relies on the utilization of highly scalable cloud computing systems and the targeted provision of the required Big Data

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|---|-----------|---------|
| 3. Application | Expansion | Pattern |
| <p>Not long ago, GEOINT meant maps and navigational instruments to military planners and operational troops. But, as the value of GEOINT products and services has come to be acknowledged, the landscape of GEOINT has expanded beyond the defense sector into multidisciplinary domains as diverse as healthcare, urban systems, and environmental governance. [22]</p> | | |

4.4 Research Gap.

Despite the tremendous promise of integrating GIS, GeoAI, and GEOINT to support better geospatial decision-making and better outcomes to society, critical research gaps exist in the literatures of science and technology. First, the interdependence of GeoAI and GEOINT which rely on the synergy of computer science and artificial intelligence to automate the processes of finding, extracting, analyzing, and using geospatial information for military, internal security, business, and various applications – lacks any unified conceptual and operational definitions. Second, while many geospatial technologies now support almost real-time data acquisition, these systems are not yet sufficiently developed to integrate with geospatial intelligence systems to streamline analytical workflows, where geospatial data needs to be collected, processed, analyzed, and disseminated in short order. Third, evaluation frameworks for assessing the accuracy and effectiveness of GEOINT integrating GeoAI are absent or underdeveloped. Fourth, the ethical governance of AI in the context of geospatial decision-making is fragmented in relation to the specific ethical issues that need to be addressed on an ongoing basis. [23]

5. Discussion and Contradiction Analysis

The synthesis of the 26 reviewed studies underscores a critical socio-technical contradiction that dominates the current GeoAI–GEOINT landscape: the trade-off between algorithmic accuracy and operational explainability. This tension is highly manifest when transitioning these advanced platforms from theoretical domains to empirical civilian administration, such as public education management in developing regions.

5.1 The Accuracy–Explainability Dilemma

As highlighted by the contrast between deep learning dominance (e.g., Sahana et al., 2022) and spatial statistics (e.g., Attah et al., 2024), the explosive adoption of Convolutional Neural Networks (CNNs) has dramatically improved predictive performance regarding spatial pattern recognition. However, these "black-box" high-dimensional models inherently suffer from a lack of interpretability. In a public service setting—such as the Anbar Education Directorate—submitting personnel distribution or financial resource allocation to a non-explainable algorithm introduces ethical risks and administrative resistance. Decision-makers require transparent reasoning to justify resource reallocations between urban hubs and remote districts (e.g., Al-Qaim, Al-Rutba). Therefore, the literature indicates an urgent need for Explainable GeoAI (X-GeoAI) frameworks that pair deep learning accuracy with rule-based spatial logic.

5.2 Computational Infrastructure vs. Local Constraints

A second core contradiction lies in data infrastructure. The modern theoretical consensus (Yang et al., 2019; Yao, 2022) premises real-time spatial intelligence on continuous streams of Big Data and scalable cloud infrastructures. Empirically, however, public service directorates in developing countries often operate under extreme local infrastructure deficits, characterized by unstable connectivity and fragmented spatial databases. This review demonstrates that rather than waiting for full-scale enterprise hardware overhauls, the optimal path forward is the

architectural integration of lightweight, open-source hybrid GIS–AI models that rely on asynchronous cloud syncing. This directly supports the decentralized implementation of the proposed framework, ensuring operational continuity even in resource-constrained environments.

6. Recommendations .

6.1 GEOINT as a Decision Intelligence Pipeline .

Historically, Geospatial Intelligence (GEOINT) has been closely linked with defense and military operations. However, driven by public sector modernization, GEOINT is evolving into a structured decision intelligence pipeline that assimilates heterogeneous spatial data streams into actionable knowledge for civilian governance.

6.2 GEOINT Intelligence Cycle

Public administrators continuously operate under strict budgetary constraints, necessitating operational optimization. The integration of GeoAI workflows converts complex analytical outputs into high-fidelity decision support infrastructures.

Based on the emerging trends and the technical contradictions identified in the literature, the following structural recommendations are proposed to build an operational GeoAI-GEOINT decision pipeline.

(1) Data Collection (Geospatial Sensing Layer)

- In this stage, raw geospatial data is acquired from heterogeneous sources, including online spatial databases, and application programming interface (API) files online, spreadsheets, reports, field surveys data, and physical maps. The combination of all the data sources allows a better understanding of the problem and increases the level of detail in the model.
- Satellite imagery
- Remote sensing platforms
- IoT and sensor networks
- Volunteered geographic information (VGI)
- Social media geotagged data

An important characteristic of a GeoAI system is often the data ingestion layer of the system such as a middleware where the raw spatial signals are continuously captured for further processing using either batch or streaming processing.

(2) Data Processing and Integration

At this stage, raw geospatial data undergoes:

- Cleaning and normalization
- Spatial-temporal alignment
- Data fusion from multiple sources

Big Data infrastructures are important for the proper continuation of unstructured spatial data (especially in remote sensing) to extract value. However, it is necessary to transform this into analyzable formats for AI-driven modeling. In this context, cloud-based GIS platforms play a key role in providing the required scalability, flexibility and efficiency.

(3) Intelligence Analysis (GeoAI-Driven Reasoning)

The convergence of GEOINT and Artificial Intelligence (AI) will change the way businesses employ geospatial analysis to derive insights from their data. The AI system is indicating the probability of a certain event and GEOINT is confirming it.

- Machine Learning (ML)
- Deep Learning (DL)
- Graph Neural Networks (GNNs)
- Spatial statistics

are applied to extract:

- Spatial patterns
- Anomalies
- Predictive insights
- Behavioral trends

This stage represents the transition from spatial information to spatial intelligence, where GeoAI acts as the analytical engine of GEOINT systems.

(4) Dissemination and Decision Support

Dissemination and Decision Support: Public administrators continuously operate under strict institutional requirements, necessitating rigorous operational optimization. The integration of GeoAI workflows converts highly complex spatial analytical outputs into high-fidelity, actionable decision support infrastructures. Outputs are delivered through centralized GIS dashboards, real-time spatial visualization systems, and multi-criteria Decision Support Systems (DSS).

Outputs are delivered through:

- GIS dashboards
- Real-time spatial visualization systems
- Decision Support Systems (DSS)
- Command-and-control platforms

At this level, GEOINT directly supports:

- Urban planning decisions
- Security threat assessment
- Disaster response coordination
- Public health interventions

GEOINT is a key component of the decision intelligence infrastructure. The ability to turn massive amounts of data that describe the world into meaningful information and insight renders GEOINT the most powerful analytical tool available today.

6.4. GEOINT within Security and Decision-Making Frameworks

The emergence of modern GEOINT systems and spatial intelligence is changing the way security and governance frameworks are constructed, marketed, and operationalized. New systems of data analytics that sit over that data layer will change the way in which both security and governance are practiced.

- National security surveillance
- Border monitoring and threat detection
- Crisis and disaster management
- Infrastructure vulnerability assessment

Thus, to deliver optimal human-centric public services, GeoAI must be integrated into semi-automated frameworks. Within this collaborative pipeline, computational models autonomously execute the large-scale processing of high-dimensional, heterogeneous spatial

datasets at high speeds, while skilled human analysts maintain critical oversight to verify, interpret, and contextualize the analytical outcomes.

6.5 Conceptual Positioning of GEOINT in GeoAI Systems

GEOINT is positioned in the upper intelligence layer of a GeoAI–GEOINT framework. This position of GEOINT ensures proper, effective and timely coordination, dissemination, and integration of AI analytics with the already ongoing human intelligence, signals intelligence, and imagery intelligence by ensuring the right synchronisation of the AI analytics with GEOINT.

The hierarchy can be conceptualized as:

Data Layer → AI Analytics Layer → GEOINT Layer → Decision-Making Layer

This structure highlights a key theoretical shift:

GIS and AI generate information
GEOINT transforms it into intelligence

Decision systems convert intelligence into action

Thus, GEOINT functions as the cognitive bridge between computation and governance.

6.6 Key Insight

The review reveals that GEOINT is transitioning from a descriptive spatial intelligence system to a predictive and prescriptive decision intelligence pipeline.

However, full operational maturity is constrained by:

- Limited real-time automation
- Dependence on human interpretation
- Lack of standardized intelligence protocols
- Fragmented integration with AI systems

Limitations.

This study has some limitations. First, the time frame considered for studies published is only from 2019 to 2026. This may affect the findings and implications of this study. Second, invoking the PRISMA guidelines, the sample size for this study, i.e. 26 studies, is minimal. This may affect the implications of the research in defining the metric for defining success. Third, the study is based on secondary data, which limits the findings of the study as it does not represent the view of the entire population. Fourth, there are variations in data sources and methodologies. Fifth, larger datasets are needed for empirical validation of the findings.

7. Conclusion .

A GIS (Geographic Information Systems) evolves into an intelligent geospatial infrastructure by integrating various emerging technologies such as Artificial Intelligence (AI) and Big Data analytics to provide geo-spatial intelligence at various levels in an accurate and efficient manner. Emerging technologies such as AI/ML (Machine Learning) and complex analytics techniques enhance the ability of modern geospatial data systems to generate knowledge, provide increased opportunities for generating ‘Geospatially Intelligent’ insights from such informational systems hence providing an overall intelligent geospatial infrastructure.

The modern-day world is generating massive amounts of data which includes rich geospatial information of real-world phenomenon. The non-increasing nature of traditional methods of extracting valuable knowledge from such huge amounts of data introduces the necessity of intelligent systems such as Image and Video analytics, Natural Language Processing (NLP), Human Computer Interaction (HCI), etc. The Intelligent geospatial data systems fuse such

emerging tech solutions to provide actionable intelligence in real-time or near-real time to various consumers. The implementation of such advanced tech to the traditional GIS systems provides unprecedented advantages such as automated predictive systems, enhanced geo-spatial data visualizations, improved situational awareness, etc.

The major challenge towards the development of an intelligent geospatial infrastructure is the challenges posed during the stages of data integration as large amounts of data need to be processed in real-time efficiently with improving the overall model interpretability. The integration of advanced analytics techniques into the traditional GIS model needs to be governed ethically to ensure the quality and reliability of the data and the knowledge it generates. A conceptual framework can be designed for the intelligent geospatial systems to ensure its ethical governance.

The newly emerging local and domain-specific GeoAI models need to be developed to improve the reliance on these systems as a significant part of the population is depending on the geo-spatial intelligence provided by such systems. Future research should focus on the development of efficient GeoAI-GEOINT systems for the automated extraction of geospatial intelligence for enhancing the practical effectiveness of various data-intense applications.

Ethics Statement

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