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Article

Towards Responsible GeoAI Frameworks for Ethical Governance and Global Sustainability

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ABSTRACT

Geospatial Artificial Intelligence (GeoAI) is transforming research and industry by integrating artificial intelligence with geospatial sciences to enhance analysis, prediction, and decision-making across environmental and societal domains. Despite its potential, the global adoption of GeoAI is hindered by challenges such as the absence of standardized protocols, insufficient transparency, algorithmic bias, weak accountability, and limited ethical and privacy safeguards. This study introduces a comprehensive and scalable framework that embeds ethical principles and governance mechanisms into GeoAI development and implementation. The framework integrates geospatial science, Artificial Intelligence (AI) methodologies, and domain expertise through a structured, multi-stage process that includes benchmarking, expert consultation, framework design, and iterative validation. Ethical guidelines and competency standards are incorporated to ensure fairness, transparency, inclusivity, and alignment with international directives, particularly those of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM). The results highlight how responsible GeoAI practices can strengthen interoperability, reproducibility, and collaboration across academia, industry, and policy sectors. By aligning GeoAI innovation with the United Nations Sustainable Development Goals (SDGs), this study contributes to building a transparent, fair, and trustworthy GeoAI ecosystem that advances scientific innovation, sustainable governance, and global equity.

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Research Highlights

- Proposes a comprehensive GeoAI framework integrating ethics, skills, and governance.
- Addresses gaps in standardization, transparency, privacy, bias, and accountability.
- Emphasizes collaboration among academia, industry, and policymakers to align with the SDGs.
- Promotes a scalable, responsible, and ethically grounded GeoAI ecosystem for sustainability.

1. Introduction

The integration of Artificial Intelligence (AI) into geospatial technologies, commonly referred to as Geospatial Artificial Intelligence (GeoAI), has become a transformative force across academia, government, and industry. By combining the spatial analytical power of Geographic Information Systems (GIS) with the learning and predictive capabilities of AI, GeoAI offers new possibilities for addressing complex global challenges such as disaster management, sustainable urban planning, and environmental monitoring. However, this rapid advancement brings ethical and governance challenges related to transparency, bias, accountability, and data security, which, if unaddressed, may compromise trust and societal acceptance [1, 2]. As the world increasingly relies on AI-assisted geospatial decision-making, the need for standardized, transparent, and ethically grounded frameworks has become urgent.

Despite its potential, the global GeoAI landscape remains fragmented, lacking shared ethical standards, inclusive governance mechanisms, and consistent data-handling practices. Key concerns include algorithmic bias in spatial datasets, privacy risks from large-scale data collection, and the lack of mechanisms to ensure fairness and accountability in AI-driven spatial analytics. These challenges extend beyond technical limitations; they affect policymaking, education, and equity in global geospatial data access. As highlighted in the United Nations Global Geospatial Information Management (UN-GGIM) report (https://ggim.un.org/meetings/GGIM-committee/13th-Session/side_event/31%20July_CR-A_GeoAI_PrivateSector.pdf) (accessed on 30 September 2023), building ethical and collaborative GeoAI systems is essential to achieving the UN Sustainable Development Goals (SDGs). Therefore, integrating ethical principles into GeoAI practices is not only a technical priority but also a moral and societal necessity (http://ggim.un.org) (accessed on 30 August 2017).

To address these gaps, this study aims to establish comprehensive ethical and GeoAI solution frameworks that promote responsible innovation and sustainability in geospatial intelligence. The following key questions guide the research. (a) How can ethical, standardized, and collaborative frameworks be developed to guide responsible GeoAI applications? (b) What principles and governance mechanisms are necessary to ensure fairness, transparency, and accountability in GeoAI-driven systems? (c) How can GeoAI frameworks align with international standards, such as those proposed by the UN-GGIM, and support the implementation of SDGs? To answer these questions, the study builds on a structured, multi-stage methodology that includes benchmarking, expert consultation, framework design, and iterative validation. The developed frameworks integrate geospatial science, AI, and domain knowledge while embedding ethical principles, including inclusivity, transparency, explainability, and privacy protection [2–5]. By incorporating Explainable AI (XAI) techniques, the proposed approach ensures that AI-based geospatial decisions remain interpretable and justifiable, particularly in sensitive domains like land administration, disaster risk assessment, and environmental governance [1, 2]. Moreover, the study emphasizes the role of data governance, cybersecurity, and capacity building in fostering a resilient and equitable GeoAI ecosystem. In addition, the results reveal that effective GeoAI governance requires a balance between technological innovation and ethical oversight. Findings highlight the importance of continuous updating of geospatial methods, skill competencies, and ethical awareness across academia, industry, and government sectors. The proposed frameworks also demonstrate how GeoAI initiatives can support the SDGs by strengthening institutional capacity, promoting data transparency, and fostering international collaboration. Furthermore, the research underscores the need to foster partnerships among academia, the private sector, and UN-GGIM member states to establish a shared understanding of ethical GeoAI practices and their societal implications [1, 6–8].

From a technological perspective, the study identifies key innovations, such as the development of generative AI-driven geospatial tools (e.g., Geospatial Generative Pre-trained Transformer (GeoGPT) and Geospatial Infrastructure Management Ecosystem (GeoIME)-Generative Pre-trained Transformer (GPT)) [9, 10], demonstrating how AI can enhance spatial analytics while adhering to ethical governance principles. However, to prevent bias, misinformation, and unequal control over data, these models must be regulated by global ethical guidelines [11, 12]. Hence, the proposed frameworks advance the dual goals of scientific excellence and social responsibility by ensuring that GeoAI contributes to equitable, sustainable, and trustworthy outcomes [13–26].

The remainder of this paper is organized as follows: Section 2 presents an overview of related work and theoretical background on GeoAI and ethical frameworks. Section 3 details the methodology and framework development process. Section 4 presents the results and discussion, highlighting the ethical and operational implications of the proposed GeoAI frameworks. It also provides an integrated discussion on policy, collaboration, and educational perspectives. Finally, Section 5 concludes with recommendations for future research, emphasizing pathways for global collaboration and responsible GeoAI innovation.

2. Literature Review

GeoAI has emerged at the intersection of geospatial sciences and artificial intelligence, combining GIS, remote sensing, and machine learning to provide intelligent spatial analysis, predictive modeling, and decision support [27, 28]. By leveraging algorithms such as deep neural networks, graph neural networks, and recurrent models, GeoAI enables the extraction of patterns and insights from complex spatial datasets, enhancing applications in urban planning, disaster management, environmental monitoring, and land administration [29–32]. While early GeoAI studies emphasized technical capabilities, such as classification accuracy or feature extraction [28, 33], recent studies highlight the growing need to integrate ethical, transparent, and interpretable AI into geospatial applications. XAI methods have become particularly important, as stakeholders require a clear understanding of AI-driven spatial decisions to ensure trust and accountability [34–36]. This evolution indicates that the potential of GeoAI extends beyond technical innovation to socially responsible and ethically guided geospatial intelligence.

Despite its potential, GeoAI raises significant ethical concerns that can affect data reliability, public trust, and decision-making outcomes. Key issues include algorithmic bias, fairness, privacy, accountability, and transparency [27, 37]. Biases can arise from unevenly distributed datasets, leading to inequitable outcomes in applications such as flood risk assessment or urban resource allocation. Privacy concerns are amplified in geospatial contexts because GeoAI often relies on sensitive location-based data collected from satellites, drones, and mobile devices [38, 39]. Transparency and interpretability are also pressing challenges. Many AI models remain "black boxes," making it difficult for decision-makers to understand, verify, or challenge their outputs [34]. To address these issues, ethical frameworks are being developed to ensure human-centred AI, enforceable accountability mechanisms, and adherence to privacy and data governance standards [40]. Integrating these considerations into GeoAI is critical to avoid unintended social or environmental consequences and to foster stakeholder trust.

Besides, global initiatives, including the OECD AI Principles [41], UNESCO's *Recommendation on the Ethics of AI* [42], and the UN-GGIM framework (http://ggim.un.org) [43] have emphasized the importance of responsible AI through fairness, transparency, inclusivity, and accountability. These frameworks provide a foundation for establishing ethical practices but often lack the granularity required for geospatial applications. GeoAI requires domain-specific adaptations that address spatial data characteristics such as temporal variability, scale, and locational uncertainty [44]. Moreover, responsible AI and trustworthy AI frameworks underscore value alignment, participatory governance, and continuous monitoring throughout the AI lifecycle [27, 37]. Participatory governance models are particularly effective because they involve academia, industry, and policymakers in co-designing AI applications, thereby promoting accountability and ethical compliance [45]. These models are crucial for GeoAI, where decisions directly impact societal, environmental, and economic outcomes.

In addition, standardization is fundamental for responsible GeoAI development. International bodies like the International Organization for Standardization (ISO) and the Open Geospatial Consortium (OGC) have developed guidelines to ensure data quality, interoperability, and reliability in geospatial systems. Extending these standards to encompass AI-specific considerations, including ethics, fairness, and transparency, remains an emerging research priority [30, 31, 40, 43]. Standardized metadata, model documentation, and validation protocols can improve reproducibility and trust in GeoAI outputs. Initiatives such as the UN-GGIM Integrated Geospatial Information Framework (IGIF) (http://ggim.un.org) facilitate harmonized governance, helping countries adopt ethical AI standards while enabling cross-border collaboration. Nonetheless, disparities in technical capacity and policy maturity across countries present challenges for global standardization.

Furthermore, GeoAI can significantly contribute to the SDGs by enabling evidence-based decision-making and enhancing environmental, social, and economic monitoring [30]. Applications include disaster resilience assessment, land use optimization, and resource management, underscoring GeoAI's transformative potential for sustainable governance. To realize this potential, fostering collaboration among stakeholders, academic institutions, industry, and member states is essential [27, 43, 46]. Networks such as the UN-GGIM Academic Network and Private Sector Network provide platforms for interdisciplinary research, policy dialogue, and capacity building. Case studies such as GeoIME and GeoGPT demonstrate that integrating ethical principles, transparency, and human-centred design into GeoAI tools can enhance accountability and trust.

Finally, despite advances, several research gaps remain. First, there is no comprehensive GeoAI framework that integrates ethical, technical, and governance dimensions. Second, interoperability and standardization across countries and sectors remain limited, hindering collaborative efforts. Third, structured curricula and skill development programs in GeoAI ethics and technology are lacking, slowing the adoption of responsible practices. Thus, this study addresses these gaps by proposing an integrated GeoAI and ethical solution framework that combines geospatial science, AI, and governance principles. By embedding fairness, transparency, accountability, and sustainability into GeoAI design and implementation, the study aims to advance responsible innovation and ensure alignment with global standards and SDGs.

3. Methodology

3.1. Proposed GeoAI Framework

GeoAI represents the convergence of geospatial sciences, AI, and domain-specific expertise, collectively enabling transformative advancements across environmental, academic, and industrial sectors. The proposed framework (Figure 1) establishes an integrative pathway for applying GeoAI technologies through a cohesive and synergistic structure. We benchmark the framework against United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) reports (http://ggim.un.org) to ensure alignment with global standards and sustainable development objectives.

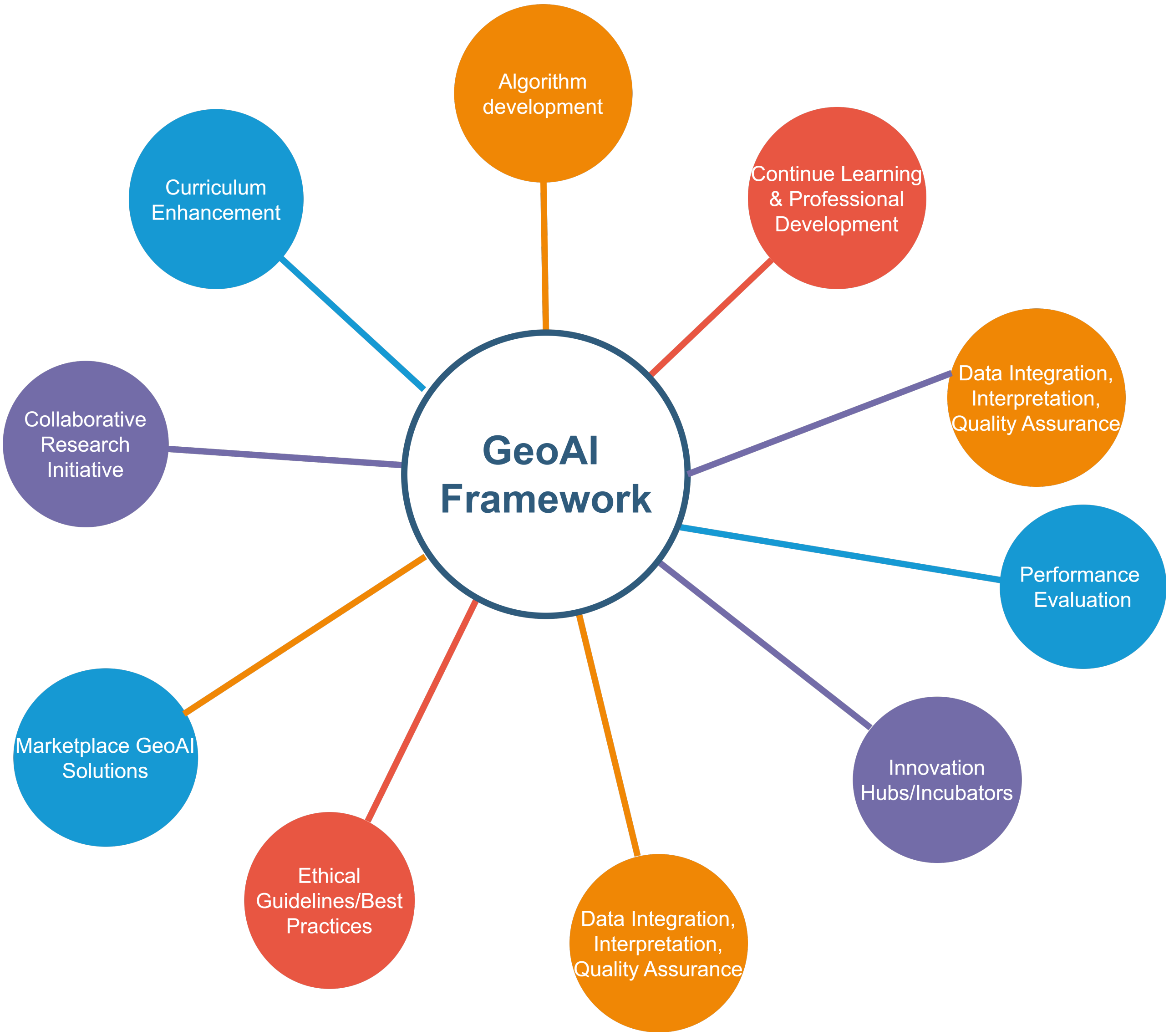

Figure 1. GeoAI framework.

The methodological process for framework development comprised four key stages, including (a) benchmarking and review—a comprehensive analysis of existing GeoAI frameworks, ethical standards, and international guidelines (e.g., UN-GGIM, Sandai Framework, ISO) to identify conceptual and technical gaps. (b) Expert knowledge interpretation—consultation with domain experts from academia, government, and the private sector to synthesize insights and define priority areas. (c) Framework structuring—integration of technological, ethical, and governance components into interconnected elements, emphasizing interoperability, transparency, and inclusivity, and (d) validation and refinement—iterative review and alignment with case studies and peer-reviewed evidence to ensure applicability to Member States, academia, and private-sector applications. This proposed framework provides a structured and scalable approach to harness the transformative capabilities of GeoAI, promoting innovation and collaboration across diverse domains.

3.2. Ethical Guidelines and Best Practices Framework

To ensure the responsible use of GeoAI technologies, a comprehensive ethical framework was developed that emphasizes privacy, transparency, and accountability. These guidelines were formulated based on established standards and literature [16, 18, 21, 25], focusing on the governance of GeoAI applications at local, national, and international levels. The development process involved (a) defining ethical dimensions [27], identification of key domains, including fairness, inclusivity, explainability, and accountability in GeoAI. (b) Integration of regulatory standards, aligning with global frameworks such as the UN-GGIM, Sandai Framework, and AI ethics recommendations. (c) Governance and policy architecture—establishment of multi-level governance mechanisms ensuring ethical compliance and equitable access to geospatial data and AI systems, and (d) monitoring and compliance—design of a continuous auditing mechanism for evaluating ethical adherence and minimizing algorithmic bias. This holistic structure supports responsible innovation, enabling societies to benefit from GeoAI while fully mitigating ethical and societal risks.

3.3. The Proposed Skills and Required Competencies of the GeoAI Framework

Building upon the conceptual foundation of the proposed framework, a complementary GeoAI Skills and Competencies Framework (Figure 1) was developed to identify the essential knowledge, technical expertise, and professional attributes required within the GeoAI ecosystem. We establish this framework through (a) competency mapping—identification of interdisciplinary skill domains, encompassing geospatial sciences, AI, data analytics, and programming. (b) Integration of technical and cognitive skills—a combination of spatial modeling, machine learning, and programming proficiency with adaptability, critical thinking, and collaboration. (c) Framework alignment—establishing connections between competencies in Figure 1 (e.g., foundational geospatial knowledge, XAI, programming) and the operational components in Figure 2 (e.g., curriculum enhancement, algorithm optimization), and (d) lifelong learning emphasis—incorporation of continuous upskilling mechanisms to ensure professionals remain proficient with emerging technologies, cloud computing, and GeoAI standards. This framework provides a roadmap for academia, industries, and public institutions to build human capacity and promote a skilled workforce for GeoAI-driven sustainable development.

In addition, another crucial facet is the development of cross-disciplinary ecosystems centred around GeoAI. The authors propose recognizing the potential of AI-driven geospatial analysis to permeate diverse domains and industries, leading to innovative solutions and approaches. This integration promises to revolutionize decision-making processes and generate insights across diverse fields. However, a conceptual diagram is designed to visually represent this evolving landscape (Figure 3). This proposed diagram serves as a visual guide, encapsulating the essence of the discussed trends in a comprehensive and accessible manner.

The initial phase involves clearly defining the scope and objectives of the GeoAI ecosystem. This includes identifying the specific domains and industries where AI-driven geospatial analysis can be applied effectively. Our goals focus on enhancing decision-making processes and generating actionable insights across these diverse fields. At this stage, it is crucial to establish a vision that aligns with broader trends in technology and societal needs. Next, central to the GeoAI ecosystem is the creation of a Knowledge on Demand Hub, which acts as a central repository and processing unit for geospatial data and AI algorithms. This hub facilitates real-time data integration, enabling seamless access to up-to-date information.

Figure 2. Skills and required competencies GeoAI framework.

Figure 3. Future GeoAI interactive model.

Additionally, it supports collaborative, interactive interfaces, enabling stakeholders from different disciplines to engage with the data and contribute to the analysis. The hub also incorporates XAI techniques to ensure transparency and trust in the decision-making processes derived from the data. Then, to foster participation and incentivize contributions within the GeoAI ecosystem, a tokenized economy should be established. This involves creating digital tokens that can be used to represent assets, facilitate blockchain-based transactions, and reward participants for their contributions. The tokenized economy is designed to enhance privacy and security through decentralized trust mechanisms, ensuring that all interactions are transparent and secure. This economic framework will encourage active engagement and collaboration among stakeholders.

In the next step, a robust system of digital identities is crucial for managing access and permissions within the GeoAI ecosystem. This system streamlines identity management, making it easier for users to securely access the resources they need. Built-in artificial intelligence can further enhance the security and efficiency of these identity management systems, ensuring that only authorized individuals have access to sensitive data and tools. After that, content creation platforms play a vital role in the GeoAI ecosystem by providing spaces for users to generate, share, and monetize content. These platforms offer monetization options for creators, encouraging them to produce high-quality geospatial data and analyses. Additionally, they support community building and interaction, fostering a collaborative environment where knowledge can be exchanged and built upon. Built-in AI can help curate and organize content, making it more accessible and useful for all users.

Decentralized applications (DApps) are essential for enabling autonomous operation within the GeoAI ecosystem. These applications are developed using open-source methodologies, allowing for continuous improvement and innovation. DApps are also designed with cross-platform compatibility in mind, ensuring that they can be accessed and used across different devices and operating systems. This will promote scalability, generalization, and localization of the GeoAI solutions, making them applicable in a wide range of contexts. Then, Peer-to-peer (P2P) transactions are a key component of the GeoAI ecosystem, enabling direct user-to-user exchanges without the need for intermediaries. These transactions should be facilitated through decentralized trust mechanisms, ensuring that all parties involved can trust the integrity of the transactions. Enhanced privacy and security measures should be implemented to protect users' personal and financial information. P2P transactions promote a more democratic and equitable distribution of resources within the ecosystem. Finally, the GeoAI ecosystem is designed to integrate future interactive models that can adapt to emerging technologies and changing user needs. These models are scalable, allowing the ecosystem to grow and evolve over time. They should also be generalized, ensuring that the solutions developed within the ecosystem can be applied to a wide range of problems and industries. Model localization will enable tailored solutions that address specific regional challenges and opportunities. By following these steps, a comprehensive and dynamic GeoAI ecosystem is developed, driving innovation and transformation across various domains and industries. The integration of AI-driven geospatial analysis into this ecosystem promises to revolutionize decision-making processes and generate valuable insights, ultimately leading to more informed and effective actions.

3.4. Ethics, Privacy, and Legal Considerations

Navigating the ethical and legal landscape of geospatial data and AI algorithms requires a balanced approach to innovation and responsibility. The proposed framework integrates (a) ethical auditing—regular assessment of algorithmic processes to ensure fairness, interpretability, and non-discrimination. (b) Privacy and consent management—implementation of anonymization, data encryption, and informed consent procedures to protect sensitive information. (c) Legal compliance—adherence to national and international regulations concerning data sharing, intellectual property, and cybersecurity, and (d) equity and inclusion—promotion of accessibility and diversity to prevent digital divides and algorithmic bias across societies. Collectively, these measures establish a trustworthy GeoAI environment that safeguards human rights while enabling innovative geospatial applications.

3.5. Communication and Visualization

Effective communication and visualization of GeoAI-derived insights are critical for bridging technical innovation with decision-making. This study emphasizes (a) stakeholder-centred design, simplifying complex spatial-AI concepts for policymakers, researchers, and communities. (b) Advanced large language models and visualization tools—employing Geographical Information System (GIS) dashboards, GeoIME-GPT, Geospatial GPT (GeoGPT), 3D modeling, and virtual/augmented reality for immersive data interaction. (c) Collaborative communication platforms—promoting transparency and open data sharing across interdisciplinary networks, and (d) capacity building—training professionals in data storytelling, visual analytics, and participatory mapping to enhance interpretability. Such approaches ensure that GeoAI outputs are comprehensible, actionable, and aligned with real-world decision-making processes in environmental and societal contexts [24, 47].

3.6. Integrative Perspective: Cross-Disciplinary Ecosystem

Beyond its technical dimensions, the proposed framework envisions the establishment of cross-disciplinary GeoAI ecosystems (Figure 3) that connect scientific, technological, and societal domains. The methodological steps include (a) ecosystem mapping, which involves identifying intersections between GeoAI and other fields, such as environmental monitoring, public health, and urban planning. (b) Innovation hubs and incubators—establishment of collaborative research and development platforms to accelerate GeoAI-driven innovations. (c) Policy and advocacy integration—aligning national and regional GeoAI strategies with the UN SDGs and the Sendai Framework for Disaster Risk Reduction, and (d) feedback and evolution—implementation of iterative evaluation and stakeholder feedback loops to ensure the framework's adaptability and long-term relevance. This integrative model encapsulates the evolving landscape of GeoAI, fostering a future of ethical, data-driven, and resilient planetary systems.

4. Results and Discussion

4.1. Ethical and GeoAI Solution Frameworks

The results of this study underscore the transformative potential of GeoAI across geospatial education, governance, and industry. However, a significant gap remains in the systematic integration of ethical considerations and the structured implementation of GeoAI technologies. To address this, the study developed a comprehensive ethical and solution framework, detailed in Table 1 and Figure 2, which provides guidance for stakeholders at local, national, and international levels. This framework highlights the importance of ethical governance, data security, standardization, and collaboration to ensure GeoAI deployments are responsible, transparent, and socially beneficial. Table 1 organizes the key components of the framework across three primary stakeholder levels: local and national governments, national and international organizations, and industry or private sector alliances. At the governmental level, policy formulation and revision involve establishing dynamic regulatory bodies to oversee GeoAI deployment, enabling policies to remain adaptive to technological advancements. Ethics and privacy standards are enforced through clear guidelines that ensure transparency, fairness, and accountability in the use of GeoAI systems. Governments also standardize geospatial data formats, enforce cybersecurity protocols, and implement data sharing practices that balance openness with privacy, while conducting societal impact assessments to guide informed decision-making. Inclusive stakeholder engagement and public consultation are central to ensuring that policies reflect the needs of communities and uphold human rights. National and international organizations complement these efforts by developing proactive frameworks aligned with global standards such as UN-GGIM and OECD guidelines. They foster innovation ecosystems by funding research initiatives, supporting capacity building and education programs, and promoting interdisciplinary collaboration between academia and industry. These organizations ensure that ethical considerations, human rights, and equitable access to GeoAI technologies are prioritized, while also enabling international collaboration to harmonize practices across regions.

Table 1. The proposed ethical guidelines and best practices framework.

Components					
At Local and National Levels, Governments		**National and International Organizations**		**Industry or Private Sector and Alliances**	
	Description		**Description**		**Description**
Policy formulation and revision	Establish bodies to govern dynamic policies for GeoAI deployment.	**Proactive framework development**	Local and national governments lead AI frameworks, aligned globally and tailored to regions.	**Strategic collaboration in AI and GeoAI**	Industry alliances unite sectors to drive progress in ethical AI and GeoAI.
Ethics and privacy standards	Ethics and privacy are paramount; policies ensure transparency, fairness, and accountability in the use of GeoAI, with robust privacy standards.	**Alignment with the UN framework**	UN framework guides global AI harmony and collaboration.	**Knowledge sharing and expertise integration**	Partnerships exchange best practices, driving AI and GeoAI for the benefit of society.
Establishing data standards	Standardizing geospatial data formats, structures, and quality is crucial for reliable GeoAI insights.	**OECD guidelines integration**	OECD guides inform global, inclusive governance.	**Ethics-centric technology development**	Alliances prioritize ethics in AI and GeoAI, ensuring the development of ethical solutions.
Cybersecurity, data security protocols	Enforce cybersecurity to ensure data integrity and the GeoAI system.	**Ethical considerations and human rights**	Frameworks must prioritize ethics, safeguard rights, impacts and consequences, ensure respectful AI and GeoAI.	**Local empowerment through global collaboration**	Global alliances empower local governments with AI for growth.
Data sharing and accessibility guidelines	Balance data sharing with privacy and guide responsible practices.	**Accessibility and inclusivity**	Ensure equitable AI, Open GeoAI access, bridging digital divides.	**Innovation hubs and incubators**	Alliances create hubs for AI, GeoAI R&D, and nurturing startups.
Identification of challenges and opportunities	Policy formulation: assess challenges, anticipate roadblocks, and identify innovation avenues.	**Innovation ecosystems**	Governments foster innovation by funding research, startup incubators, and academia-industry collaboration.	**Policy advocacy and framework development**	Alliances advocate for ethical AI, and GeoAI policies.
Societal impact assessment	Mandate rigorous societal impact assessments for informed decisions	**Capacity building and education**	Invest in education for effective AI and GeoAI engagement.	**Capacity building and training programs**	Alliances are empowered by AI and GeoAI skills for broader engagement.
Stakeholder engagement and public consultation	Inclusive stakeholder engagement ensures comprehensive policies.	**Regulatory oversight and compliance**	Establish bodies for AI and GeoAI oversight to ensure legal compliance.	**Sustainable socioeconomic impact**	Alliances drive sustainable development: jobs, innovation, and a better life.
------	-------	**International collaboration**	Global collaboration is crucial for the governance of AI and GeoAI.	**Diversity and inclusive initiatives**	Alliances foster diverse and inclusive AI and GeoAI for unbiased solutions.

Table 1. *Cont.*

Components					
Monitoring and Regulatory Agencies and Bodies		**Academics and Research Institutes**		**Public, Communities, Civil Society, and NGOs**	
	Description		**Description**		**Description**
User and consumer protections	Regulatory agencies safeguard user rights and ensure fair practices.	**Societal impact assessment**	Institutions assess the impact of AI and GeoAI on ethics, the economy, and society.	**Human rights-centric approach**	Advocate for human-centric AI and GeoAI that respects rights.
Competency standards and training	Agencies set and enforce industry standards for ethical competence.	**Advocacy for ethical practices**	Promote ethical AI and GeoAI through open dialogue, rigorous research, and collaborative efforts.	**Fairness and equity advocacy**	Advocate for fair and equitable AI and GeoAI deployment.
Data management and sharing regulations	Bodies set data handling and sharing rules for accuracy and privacy.	**Development of innovative courses**	Institutions offer advanced AI, GeoAI, trust, ethical, and social applications courses for job readiness.	**Ethical considerations in policy formulation**	Advocate for ethical policies in AI, GeoAI.
Data privacy and transparency measures	Agencies establish strict privacy standards and ensure the ethical handling of data.	**Curriculum enhancement for relevance**	Institutions update curricula to reflect industry trends.	**Day-to-day relevance and impact**	Advocacy aims for practical, positive impacts and consequences of AI and GeoAI.
Accessibility and reliability standards	Agencies mandate tech accessibility and set reliability standards.	**Upskilling and continuous learning**	Institutions offer upskilling opportunities for professionals to stay current.	**Community engagement and empowerment**	Empower communities with AI and GeoAI knowledge.
Societal well-being and ethical practices	Agencies ensure ethics, well-being, and the greater good of society.	**Promotion of interdisciplinary learning**	Institutions promote interdisciplinary learning for holistic understanding.	**Advocacy for inclusivity**	Advocate for inclusive AI and GeoAI development.
Enforcement and compliance oversight	Bodies ensure compliance and enforce penalties for violations.	**Collaboration with industry and policymakers**	Engage with industry and policymakers to inform and develop practical policies.	**Monitoring policy implementation**	Monitor and regulatory AI and GeoAI policies and advocate adjustments.
Continuous monitoring and adaptation	Agencies adapt to tech changes for effective regulation.	**Research and innovation hubs**	Institutions create hubs for AI, GeoAI research, and innovation.	**Partnerships for collective impact**	Collaborate for human-centric AI and GeoAI policies effectively.
Consumer education and advocacy	Agencies educate consumers and advocate for their interests.	**Publication of impactful research**	Institutions shape AI, GeoAI knowledge, trends, and policies.	**Advocacy for transparent governance**	Advocate for transparent, accountable AI and GeoAI governance.
Collaboration with industry stakeholders	Regulation requires collaboration with diverse industry stakeholders.	**Community engagement and outreach**	Institutions participate in community events to share insights on AI and GeoAI.	-------	

Industry and private sector alliances play a pivotal role in translating ethical principles into operational practices. By fostering strategic collaborations, innovation hubs, and Research and Development (R&D) incubators, these alliances drive the development of ethics-centric technologies, facilitate knowledge sharing, and empower stakeholders with advanced AI and GeoAI skills. They also ensure sustainable socioeconomic impact by creating jobs, supporting inclusive initiatives, and advocating for policies that promote responsible use of geospatial technologies. Overall, the framework demonstrates that ethical governance, technical innovation, and societal responsibility are interconnected and mutually reinforcing. By integrating policy formulation, ethics, privacy, standardization, cybersecurity, accessibility, capacity building, and international collaboration, this structured approach enables a scalable, responsible, and sustainable GeoAI ecosystem. The framework provides a roadmap for stakeholders to navigate ethical challenges while harnessing the full potential of GeoAI for societal and environmental benefit.

4.2. Ethical Considerations in GeoAI

The integration of GeoAI into geospatial applications raises concerns regarding data privacy, surveillance, consent, and the adequacy of existing legal frameworks. The study identified a lack of structured education in legal and ethical aspects, despite their pivotal role in ensuring the responsible deployment of AI. Ethical challenges include: (a) Data privacy and security, (b) transparency and accountability, (c) bias and fairness, (d) regulatory frameworks, and (e) interdisciplinary collaboration. However, given these ethical concerns, the study calls for integrating dedicated courses on GeoAI ethics into university curricula and professional training programs. This approach will cultivate responsible AI practitioners who can implement GeoAI solutions while mitigating risks.

To bridge existing gaps in digital infrastructure and transformation, this framework emphasizes integrating cloud computing, machine learning, and conversational data interaction to enable seamless geospatial analysis. Moreover, the study emphasizes that harnessing GeoAI's full potential requires strategic investments in education, infrastructure, and policy. Therefore, the key recommendations include: (a) further development of global and regional policies that standardize ethical AI practices in geospatial domains, (b) encouraging cross-disciplinary research collaborations to address ethical, technical, and regulatory challenges, (c) establishing open-access datasets and Application Programming Interface (APIs) to improve transparency and reduce biases in GeoAI models, and (d) strengthening institutional support for GeoAI-driven governance and decision-making. Thus, by addressing these gaps through ethical considerations and a structured solution framework, GeoAI can serve as a transformative force in achieving the UN-GGIM's ambitious geospatial goals by 2030. Implementing these recommendations will pave the way for responsible, efficient, and impactful GeoAI applications in academia, industry, and governance.

4.3. Discussion and Implications

The findings of this study underscore the transformative potential of GeoAI across academia, industry, and governance, while also highlighting critical gaps in ethical oversight, standardization, and stakeholder engagement. By systematically analyzing ethical considerations and developing a structured solution framework, this study demonstrates that responsible GeoAI deployment requires a multi-layered approach that integrates technical, social, and policy dimensions. In particular, the results show that successful implementation depends not only on advanced AI capabilities but also on well-defined governance structures, robust data standards, privacy safeguards, and continuous capacity building. From a policy perspective, GeoAI frameworks must be designed to align with global standards while being adaptable to local and regional contexts. At the governmental level, proactive policy formulation, regulatory oversight, and societal impact assessments are crucial to ensure transparency, fairness, and accountability. National and international organizations play a vital role in promoting cross-border collaboration, harmonizing ethical guidelines, and integrating best practices, such as the OECD and UN-GGIM frameworks. Industry and private sector alliances are equally important, as they foster innovation hubs, facilitate knowledge exchange, and develop ethics-centric technologies that mitigate the risks associated with bias, misinformation, and inequitable access.

The study emphasizes the importance of capacity-building and education for achieving sustainable and ethical GeoAI applications. Universities and professional training programs should integrate interdisciplinary curricula that combine geospatial science, AI methodologies, and ethical governance. Upskilling initiatives, workshops, and collaborative research foster the development of competent practitioners capable of implementing AI solutions that respect legal, social, and ethical standards. Furthermore, fostering multi-stakeholder collaboration among academia, industry, governments, and civil society strengthens shared understanding, drives innovation, and ensures that GeoAI solutions contribute positively to societal well-being. The policy implications of these findings are substantial. Governments and organizations should adopt adaptive governance models that can respond to rapid technological advances, establish clear guidelines for data privacy and cybersecurity, and support open-access datasets and APIs to promote transparency. Strategic investments in innovation ecosystems and research hubs can accelerate the development of ethically grounded GeoAI solutions. Additionally, policies that encourage international collaboration and inclusive participation are essential to prevent digital divides and ensure equitable benefits across communities. Table 2 summarizes the critical policy areas, recommended actions, and expected societal impacts, providing a concise reference for stakeholders seeking to operationalize these insights.

Table 2. Key policy areas, recommended actions, and societal impacts for responsible geoai implementation.

Policy Area	Key Recommendations	Expected Impact
Data governance	Implement strict data standards, privacy regulations, and responsible data-sharing protocols.	Ensures data integrity, security, and ethical handling of geospatial information.
Ethical oversight	Establish ethics review boards and adopt UN-GGIM and OECD guidelines for AI governance.	Promotes transparency, fairness, accountability, and the protection of human rights.
Collaboration and stakeholder engagement	Encourage partnerships between academia, industry, government, and civil society; create innovation hubs.	Fosters knowledge sharing, capacity building, and equitable access to GeoAI technologies.
Capacity building and education	Develop structured curricula and professional training in AI ethics, XAI, and GeoAI applications.	Prepares skilled practitioners capable of deploying responsible and effective GeoAI solutions.
Monitoring and adaptive governance	Conduct societal impact assessments and continuously update policies based on feedback and technological developments.	Ensures dynamic, context-sensitive governance that evolves with GeoAI advancements.
Sustainable development alignment	Integrate SDG objectives into GeoAI policy and application guidelines.	Enhances social, economic, and environmental outcomes while supporting global sustainability goals.

Finally, the discussion indicates that responsible GeoAI deployment is not solely a technological challenge but a socio-technical endeavour that requires integrated solutions. By addressing ethical, educational, and policy dimensions concurrently, the proposed framework can guide decision-makers toward sustainable, accountable, and impactful applications of GeoAI that align with the UN SDGs. This approach positions GeoAI as a transformative tool that advances innovation while ensuring fairness, inclusivity, and long-term societal benefit.

5. Conclusion

The emergence of GeoAI marks a pivotal moment in the evolution of geospatial sciences, offering an unprecedented opportunity to unite technology, ethics, and governance for global sustainability. This study presented an integrative GeoAI framework that bridges the gap between innovation and responsibility, one that is adaptable, transparent, and aligned with the UN SDGs. By proposing structured frameworks for ethical governance, competency development, and cross-sector collaboration, this work lays the foundation for a future in which AI-driven geospatial intelligence operates with fairness, inclusivity, and societal benefit at its core. GeoAI's transformative capacity lies not only in its analytical precision but also in its potential to reshape humanity's perception and management of spatial challenges. From disaster resilience and land administration to environmental monitoring, the responsible implementation of GeoAI can deliver actionable insights to build a more equitable and sustainable planet. Yet, achieving this vision demands a deliberate balance between technological progress and ethical stewardship. Transparent decision-making, explainable models, and robust data governance are essential to preserving trust while mitigating biases and inequities that may arise from automated geospatial analyses.

A key outcome of this research is the introduction of a comprehensive skills and competencies framework that emphasizes lifelong learning and interdisciplinary collaboration. It empowers future professionals to combine geospatial expertise with machine learning, cloud computing, and ethical reasoning. Similarly, the inclusion of ethical auditing, privacy protection, and policy integration underscores that GeoAI innovation must remain accountable to human values. Despite the framework's strengths, several limitations must be acknowledged. First, the framework is conceptual and requires empirical validation across diverse geospatial applications and geographic regions. Second, the rapid evolution of AI and GeoAI technologies may introduce unforeseen ethical and technical challenges that are not fully addressed in this study. Third, the proposed guidelines depend on effective stakeholder engagement, which may vary in implementation due to institutional, cultural, or resource constraints.

Future research should focus on testing and refining the GeoAI framework in real-world case studies, evaluating its effectiveness in enhancing ethical decision-making, fairness, and inclusivity. Additionally, developing quantitative metrics to assess GeoAI's societal impact and the effectiveness of bias mitigation strategies would strengthen practical adoption. Further work could also explore integrating emerging AI paradigms, such as federated learning and generative models, while ensuring adherence to ethical and policy standards. Cross-disciplinary studies combining social sciences, ethics, and geospatial AI are recommended to foster a holistic understanding and governance of GeoAI systems globally. In essence, this paper envisions GeoAI as more than a technological tool; it is a catalyst for global cooperation and a driver of informed, ethical, and sustainable decision-making. By embedding ethics and inclusivity at the heart of geospatial intelligence, GeoAI can transform not just how we analyze the Earth, but how we care for it, advancing a shared vision of a resilient, equitable, and habitable planet.

Author contributions

S.P.: Conceptualization; Methodology; Investigations; Writing—original draft; Formal analysis; Writing–review & editing; Validation; Visualization; Project administration. Z.S.M.-G.: Conceptualization; Methodology; Formal analysis; Data curation; Writing—review & editing; Validation; Visualization; Project administration. L.C.: Conceptualization; Methodology; Investigations; Formal analysis; Data curation; Writing—review & editing; Validation; Visualization; Project administration. G.G.: Conceptualization; Methodology; Investigations; Writing—review & editing; Supervision; Validation; Visualization; Project administration. M.S.: Validation; Visualization; Writing—review & editing. N.K.: Validation; Writing—review & editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data is available upon request.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Use of AI and AI-Assisted Technologies

The authors used AI tools to improve the English writing. After using these tools, the authors carefully reviewed and edited the content as needed and take full responsibility for the content of the published article.

List of acronyms and abbreviations

Acronym	Full term
AI	Artificial Intelligence
GeoAI	Geospatial Artificial Intelligence
GIS	Geographic Information System
ML	Machine Learning
DL	Deep Learning
UN-GGIM	United Nations Committee of Experts on Global Geospatial Information Management
SDGs	Sustainable Development Goals
EO	Earth Observation
GPS	Global Positioning System
API	Application Programming Interface
SDI	Spatial Data Infrastructure
QC	Quality Control
AN	Academic Network
PSN	Private Sector Network
GeoGPT	Generative Pre-trained Transformer
GeoIME	Geospatial Infrastructure Management Ecosystem
R&D	Research and Development
ISO	International Organization for Standardization
XAI	Explainable AI
ANN	Artificial Neural Network
R-CNN	Region-based Convolutional Neural Network
SVM	Support Vector Machine
GNN	Graph Neural Network
LiDAR	Light Detection and Ranging
DApps	Decentralized applications
P2P	Peer-to-peer
UN	United Nations
OGC	Open Geospatial Consortium
IGIF	Integrated Geospatial Information Framework
OECD	Organisation for Economic Cooperation and Development

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