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ROLE OF AI IN NATURAL RESOURCES MANAGEMENT – A COMPREHENSIVE REVIEW

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Abstract

Natural resources management faces growing strain. Population growth increases demand. Climate change disrupts ecosystems. Land, water, forests, and biodiversity are under pressure. These problems cut across ecology, technology, and policy. Artificial intelligence now plays a clear role in response. AI systems combine satellite images, sensor data, and drone inputs with predictive models. This supports faster monitoring, better planning, and stronger governance. This review examines AI use in forestry, water, agriculture, fisheries, mining, energy, and biodiversity from 2020 to 2025. The literature shows consistent gains over traditional methods. Machine learning detects deforestation in near real time. Deep learning improves crop yield forecasts and irrigation timing. AI tools optimize energy grid operations and resource allocation. Common patterns emerge across sectors. Remote sensing and IoT sensors dominate data collection. Mobile platforms support local, decentralized decisions. Outcomes include higher efficiency, improved yields, and quicker conservation action. Limits remain. Poor data quality reduces model reliability. High costs slow large-scale deployment. Ethical concerns persist, especially equity and transparency. Policy support is improving. India's AI initiatives in agriculture and global frameworks such as FAO's SDG agenda show growing alignment. Strong governance, interdisciplinary research, and inclusive implementation are essential. The evidence shows AI has strong potential to support sustainable natural resource management when capacity and oversight improve.

Keywords: *Artificial intelligence*, *Natural resource management*, *Remote sensing*, *Internet of Things*, *Sustainable development.*

Introduction

Natural resources management (NRM) involves overseeing land, water, forests, fisheries, energy, and biodiversity to meet human needs while preserving ecosystems. It integrates ecology, technology, and policy, relying on ecosystem science, data collection, and access regulations. Traditional management approaches, such as field surveys and expert judgment, are often slow and inadequate for addressing complex ecosystems and rapid environmental changes, leading to delayed responses to issues like deforestation and water stress.

Artificial intelligence is transforming natural resource management (NRM) by integrating machine learning with satellite data, sensors, and IoT networks. These AI systems can identify patterns, predict risks, and facilitate quicker, more accurate decision-making. For instance, deep learning models can detect forest loss from satellite imagery in near real-time, while predictive tools enhance irrigation timing and crop yield assessments. Research in digital agriculture and conservation has demonstrated increased efficiency and reduced resource waste. In India, initiatives like the Future Farming AI playbook aim to improve yields, reduce risks, and offer AI-based advice to smallholder farmers.

Research on AI in Natural Resource Management (NRM) is fragmented, primarily addressing individual sectors or techniques like smart farming or forest monitoring. This review bridges the gap by examining studies from 2020 to 2025 across various sectors, including forestry, water, agriculture, fisheries, mining, energy, and biodiversity. It highlights how AI enhances or replaces traditional practices, comparing outcomes of conventional methods with AI-based ones to provide insights into current capabilities, gains, and constraints, thereby guiding research, practice, and policy.

Review of Literature

Forestry ecosystems provide essential services, and AI enhances monitoring efficiency by using convolutional neural networks for land cover changes and illegal logging detection. In water resource management, AI and IoT address water scarcity issues with real-time monitoring and predictive models for irrigation efficiency. Smart agriculture leverages AI to optimize resources and improve crop yields, although challenges remain for small farmers. AI also improves fisheries management by automating tasks and monitoring health, while in mining, it aids environmental oversight despite regulatory challenges. The energy sector benefits from AI through improved grid management and forecasting. Biodiversity conservation is enhanced by AI in species monitoring and conflict mitigation, although ethical and data challenges persist. Across sectors, methodological gaps exist, such as reliance on limited datasets and the potential for AI to exacerbate inequalities. The literature emphasizes the need for rigorous validations and ethical frameworks for AI implementation.

Objectives of the Study

- To systematically survey recent (2020–2025) applications of AI across major natural resource sectors (forestry, water, agriculture, fisheries, mining, energy, biodiversity).

- To compare conventional resource management approaches with AI-enabled techniques in terms of efficiency, accuracy, and outcomes.
- To critically evaluate empirical findings on AI performance, scalability, and integration issues within each sector.
- To synthesize cross-sectoral trends and derive key insights on AI's effectiveness in improving sustainability outcomes.

Research Methodology

This study presents a systematic literature review focusing on artificial intelligence (AI) and machine learning applications across various resource sectors, including forestry, agriculture, and water management. Comprehensive searches were conducted in multiple scholarly databases for publications from 2020 to 2025, incorporating peer-reviewed articles and authoritative reports. Selection criteria emphasized relevance and empirical contribution, while duplicates were removed and quality assessments were performed based on methodology and citation impact. Thematic synthesis and comparative analysis were utilized to extract information regarding AI techniques, datasets, and outcomes, highlighting differences between traditional and AI-enabled methods and common challenges.

Data Analysis and Interpretation

Our review highlights key AI adoption patterns in resource sectors, focusing on the use of remote sensing and spatial data via satellites, drones, and GIS. Convolutional neural networks are utilized for image-based tasks like deforestation detection, while recurrent neural networks (LSTM) and ensemble methods are used for time-series forecasting. IoT sensor networks aid real-time data collection in agriculture and water management. Notable improvements in efficiency and decision accuracy are observed, such as AI crop modeling increasing irrigation efficiency and smart water systems reducing wastage. AI-supported conservation monitoring leads to earlier threat detection compared to manual methods.

Most reviewed studies report significant quantitative gains in performance, with examples like 90% accuracy in water-usage forecasting. Adoption varies across sectors; agriculture and water projects are active due to policy support in India, while forestry and fisheries see limited deployment. AI methods include supervised learning, unsupervised clustering, and reinforcement learning, with predictive analytics being a focus. Emerging technologies like edge computing enhance resource efficiency and environmental decision-making.

Findings

Our synthesis yields the following key insights:

• **Performance Improvements:** AI models exceed traditional methods in agriculture, forestry, and energy by enhancing predictions and efficiencies, leading to increased sustainability through reduced water usage and greater renewable energy adoption.

• **Scalability and Adoption:** Although AI solutions show promise in pilot projects, scalability is hindered by localized studies, inadequate infrastructure, and high initial costs. Smallholder adoption is constrained by economic and logistical issues, though advancements are noted in favourable conditions like commercial plantations and smart city water initiatives.

• **Common Constraints:** Challenges include poor data quality and availability, which limit AI model generalization. Issues with model interpretability cause management reluctance to adopt non-transparent algorithms. Ethical concerns arise in areas like AI wildlife monitoring, and data privacy issues are prevalent regarding crop yields and land ownership. Additionally, infrastructure and regulations lag behind technological advancements, especially in developing nations.

• **Cross-Sector Synergies:** Insights from one sector are often applicable to others. For instance, remote sensing connects forestry and agriculture, while IoT sensor networks are relevant in both water and agricultural contexts. This opens avenues for using AI frameworks across multiple domains, such as adapting an anomaly detection algorithm for water leak monitoring to pipeline oversight in mining.

Overall, the evidence suggests that AI-driven resource management can substantially enhance performance and sustainability if implemented judiciously. However, technology efficacy must be matched by institutional readiness and ethical practice to realize transformative impact.

Discussion

The review highlights the role of AI in enhancing the management of socio-ecological systems by improving monitoring and feedback loops, thus supporting sustainability goals in resource efficiency and conservation. It underscores the need for investment in data infrastructure and training in AI within agriculture and resource sectors, especially in countries like India, to strengthen institutional capacity. Governance challenges include data quality and access for marginalized communities, necessitating regulatory guidelines on ethical issues. AI's effectiveness in sustainability is linked to governance readiness and the practical application of policies. Technological readiness varies, with advanced AI requiring significant resources, while models suitable for resource-limited contexts show promise. Overall, AI should be harnessed responsibly alongside effective governance and local stakeholder participation to achieve environmental and social objectives.

Suggestions

Based on the review, we offer the following strategic recommendations:

- **Policy Infrastructure:** Enhance digital infrastructure in rural areas; establish open environmental data portals; invest in national AI platforms; update regulatory frameworks for AI- based monitoring techniques.
- Capacity Building: Provide AI and data science training for environmental agencies; create public-private partnerships for Centres of Excellence in natural resource management; integrate digital advisors in extension services; promote interdisciplinary collaboration in universities and research institutes.

- Inclusive deployment: Involve end-users in technology design prevent inequities; ensure mobile apps for crop advice are accessible in local languages; offer subsidies for small-scale farmers to acquire sensors; initiate community data-sharing initiatives to build trust and ownership.
- Ethics and Governance: Include environmental applications in national AI strategies' ethical frameworks; implement data privacy regulations; conduct ethical AI audits and ensure algorithm transparency; involve civil society and indigenous groups in AI policy discussions.
- Research Priorities: Gather more field data for AI models; conduct long-term pilot projects; benchmark AI tools against traditional methods; explore AI's role in the circulate economy and carbon sequestration planning through multidisciplinary research.

Conclusion

This review demonstrates that AI is transforming natural resources management by enabling more precise monitoring, forecasting, and optimization across sectors. Empirical evidence shows that AI-driven models improve resource efficiency (water and energy savings, higher agricultural productivity) and enhance conservation outcomes (faster threat detection). These gains align AI with broader sustainability goals, suggesting its potential as a transformative tool. However, realizing this potential depends on addressing infrastructural, methodological, and ethical challenges. In the Indian context, integrating AI requires supportive policies (as emerging in national strategies), capacity development, and bridging the digital divide. Ultimately, AI should be viewed not as a panacea but as a powerful enabler of smarter, more sustainable resource governance. By following the strategic recommendations outlined, stakeholders can harness AI's benefits while safeguarding equitable and effective natural resource stewardship.

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