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ARTIFICIAL INTELLIGENCE IN MANGROVE MANAGEMENT POLICY IN INDONESIA: A SYSTEMATIC LITERATURE REVIEW

Kecerdasan Buatan dalam Kebijakan Pengelolaan Mangrove di Indonesia: Tinjauan Pustaka Sistematis

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ABSTRACT

Mangroves play a crucial role in climate change mitigation and coastal protection, yet they face pressures from environmental degradation and limited policy implementation. This study employs a *systematic literature review* to examine the role of *artificial intelligence* (AI) in mangrove management and its policy implications in Indonesia. Findings indicate that AI, through *machine learning*, *deep learning*, and integration with *remote sensing* data, is effective in monitoring, mapping, restoration assessment, and predicting ecosystem changes. These technologies have the potential to support evidence-based policymaking, including prioritizing restoration areas, optimizing resource allocation, and enhancing decision-making systems. However, AI adoption faces challenges related to data quality and availability, institutional capacity, and ethical and governance concerns. The study highlights opportunities for developing inclusive and interdisciplinary AI governance frameworks, which could strengthen policy effectiveness and promote sustainable mangrove management in Indonesia.
Key words: Artificial Intelligence, Coastal Ecosystem, Evidence-based Policy, Machine Learning, Mangrove Management, Remote Sensing, Sustainable Management

ABSTRAK

Mangroves play a crucial role in climate change mitigation and coastal protection, yet they face pressures from environmental degradation and limited policy implementation. This study employs a *systematic literature review* to examine the role of *artificial intelligence* (AI) in mangrove management and its policy implications in Indonesia. Findings indicate that AI, through *machine learning*, *deep learning*, and integration with *remote sensing* data, is effective in monitoring, mapping, restoration assessment, and predicting ecosystem changes. These technologies have the potential to support evidence-based policymaking, including prioritizing restoration areas, optimizing resource allocation, and enhancing decision-making systems. However, AI adoption faces challenges related to data quality and availability, institutional capacity, and ethical and governance concerns. The study highlights opportunities for developing inclusive and interdisciplinary AI governance frameworks, which could strengthen policy effectiveness and promote sustainable mangrove management in Indonesia.
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INTRODUCTION

Mangroves play a crucial role in mitigating and adapting to global environmental and climate change, including in Indonesia. Extensive mangrove ecosystems can absorb and store three times more blue carbon than terrestrial forests. Furthermore, mangroves act as a buffer against abrasion, dampening ocean waves and storms, and inhibiting seawater intrusion into the land. However, mangrove ecosystems face pressure from climate change and human activities (Lestari et al., 2025). Sea level rise, high rainfall variations, increasing sea and air temperatures, and increased storms and extreme winds pose threats to mangrove growth and sustainability. Furthermore, mangrove degradation due to land conversion, pollution, and physical damage further weakens their ecological function. Furthermore, the restoration and protection policies recently enacted in Government Regulation of the Republic of Indonesia Number 27 of 2025 (PP RI No. 27.2025) have not been fully implemented in remote areas of Indonesia.

The Indonesian government has initiated various mangrove restoration and protection policies. However, their implementation still faces challenges such as cross-sectoral coordination, limited up-to-date spatial data, and weak evidence-based monitoring and evaluation mechanisms (Setiawan et al., 2022). Reactive and unintegrated policy approaches often lead to ineffective mangrove management programs at the local and national levels (Ilman et al., 2021). Recent research by Huqail et al. (2025) suggests that monitoring mangrove development, management, and policies on the coast can be driven by artificial intelligence (AI).

In the last decade, Artificial Intelligence (AI) has rapidly developed as an analytical tool in the environmental sector, particularly for land cover change monitoring, ecosystem mapping, and big data-based predictive modeling (Li et al., 2022). Technologies such as machine learning, deep learning, and satellite imagery integration have been shown to significantly improve the accuracy of detecting ecosystem degradation compared to conventional methods (Zhu et al., 2023). Although the use of AI in environmental studies is expanding, its application in the context of mangrove management policy, particularly in Indonesia, remains limited and fragmented (Rahman et al., 2023). Most research focuses on the technical aspects of mangrove mapping and classification, without explicitly linking them to implications for public policy and natural resource governance (Friess & Webb, 2021).

Conventional approaches to mangrove policy formulation generally rely on field surveys and static data, which are time-consuming and expensive, making them less responsive to the dynamics of coastal ecosystem change (Setyawan et al., 2020). Furthermore, to date there has been no literature synthesis that systematically examines how AI can support the mangrove policy decision-making process in Indonesia, indicating a significant research gap (Rahman et al., 2023).

Based on these gaps, this study aims to identify the role and forms of AI application in mangrove management, analyze its implications for mangrove management policies in Indonesia, and classify trends, methods, and challenges in AI use based on previous research findings through a systematic literature review approach (Kitchenham et al., 2009). To achieve these objectives, this study focuses on three main questions, namely: (1) how artificial intelligence has been applied in mangrove management studies, (2) what policy implications arise from the application of AI in mangrove management in Indonesia, and (3) what future challenges and opportunities are identified in the literature related to the integration of AI and mangrove policies (Petticrew & Roberts, 2006).

Theoretical Framework And Conceptual Background

Artificial Intelligence in Environmental Management

Artificial intelligence (AI) is a branch of computer science that focuses on the ability of systems to mimic human cognitive processes such as big data processing, decision-making, and automated learning (Russell & Norvig, 2021). In the context of environmental management, AI encompasses a range of computational techniques such as machine learning, deep learning, and data integration from spatial technologies like remote sensing and Geographic Information Systems (GIS), which are capable of processing complex data quickly and accurately (Goodfellow et al., 2020; Zhang et al., 2022). Machine learning utilizes algorithms trained on historical data to identify patterns and predict ecosystem changes, while deep learning utilizes artificial neural networks for image classification, making it highly effective in detecting vegetation cover and land degradation (Kumar et al., 2021). Remote sensing and GIS enhance the application of AI by providing rich temporal-spatial data, enabling real-time monitoring of environmental dynamics (Li et al., 2022). Overall, the use of AI in natural resource management has shown positive impacts in terms of efficiency and analytical accuracy, which are essential for evidence-based decision-making (Smith et al., 2023).

Mangrove Management Policy in Indonesia

Artificial intelligence (AI) is a branch of computer science that focuses on the ability of systems to mimic human cognitive processes such as big data processing, decision-making, and automated learning (Russell & Norvig, 2021). In the context of environmental management, AI encompasses a range of computational techniques such as machine learning, deep learning, and data integration from spatial technologies like remote sensing and Geographic Information Systems (GIS), which are capable of processing complex data quickly and accurately (Goodfellow et al., 2020; Zhang et al., 2022). Machine learning utilizes algorithms trained on historical data to identify patterns and predict ecosystem changes, while deep learning utilizes artificial neural networks for image classification, making it highly effective in detecting vegetation cover and land degradation (Kumar et al., 2021). Remote sensing and GIS enhance the application of AI by providing rich temporal-spatial data, enabling real-time monitoring of environmental dynamics (Li et al., 2022). Overall, the use of AI in natural resource management has shown positive impacts in terms of efficiency and analytical accuracy, which are essential for evidence-based decision-making (Smith et al., 2023).

AI and Policy-Making Processes

Within the public policy framework, evidence-based policy emphasizes the importance of using data and empirical evidence to enhance the legitimacy and effectiveness of public decisions (Nutley et al., 2018). AI systems have the potential to be strategic tools in supporting the policy formulation process through big data processing and predictive models that can enrich the evidence base, particularly in the context of monitoring complex environments such as mangroves (Rahman et al., 2023). AI-based decision support systems (DSS) can provide simulations of various policy scenarios, allowing policymakers to evaluate the potential impacts of each policy option before implementation (Power, 2020). The integration of AI into DSS systems also enables more dynamic and responsive policy evaluations to changing field conditions, thereby strengthening the policy feedback mechanisms essential for continuous policy reform (Bardach & Patashnik, 2020). Thus, the application of AI serves not only as a technical analysis tool but also as a component that can strengthen the value chain in the formulation and evaluation of public policies, including mangrove management policies.

METHODS

Research Design

This study uses a Systematic Literature Review (SLR) approach to systematically identify, evaluate, and synthesize scientific findings related to the application of artificial intelligence (AI) in mangrove management and its implications for policy in Indonesia. The SLR approach is particularly relevant for cross-disciplinary studies such as AI and environmental policy, which have diverse methodologies and research contexts. A systematic literature search strategy was conducted using several reputable scientific databases, namely Scopus, Web of Science, and Google Scholar, to ensure broad and high-quality coverage of the literature (Gusenbauer & Haddaway, 2020). The search was conducted using a combination of keywords structured around the main research concepts, such as "artificial intelligence," "machine learning," "mangrove management," and "coastal policy," combined using Boolean operators (AND, OR). The publication year range was limited to 2010–2024 to capture the latest developments in AI in environmental management and public policy, along with the rapid advancement of computing technology in the last decade (Li et al., 2022).

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established to ensure the relevance and quality of the articles analyzed. Included articles were scientific publications in the form of peer-reviewed journal articles, international conference proceedings, and research reports discussing the application of AI in mangrove management or coastal ecosystems with policy relevance. The primary geographic focus was Indonesia, but global studies were also included if they had relevant implications for the Indonesian mangrove policy context (Friess & Webb, 2021). Articles were excluded if they did not explicitly discuss AI, were irrelevant to mangrove management or policy, or were non-scientific opinion pieces or popular publications.

Screening, Selection Process, and Analysis

The article screening and selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and repeatability of the research process (Page et al., 2021). The selection process included initial identification of articles from databases, removal of duplications, screening of titles and abstracts, and assessment of full-text eligibility. In the final stage, only articles meeting all inclusion criteria were further analyzed. The number of articles at each selection stage is presented in a PRISMA flowchart to provide a clear overview of the literature selection process. Data analysis was conducted using a descriptive analysis approach to map publication trends and research characteristics, and thematic analysis to identify key themes related to the role of AI in mangrove management and public policy (Braun & Clarke, 2006). Furthermore, a simple bibliometric analysis was used to identify collaboration patterns and research focus, strengthening the quantitative and qualitative synthesis of findings (Donthu et al., 2021).

RESULT

Publication Trends

A systematic literature review shows that publications related to the application of artificial intelligence (AI) in mangrove management and environmental policy have increased significantly over the past decade. The publication trend began to increase in 2018 and showed a sharper spike after 2020 (Figure 1), in line with the development of machine learning technology and the availability of high-resolution satellite imagery for coastal ecosystem monitoring. This increase reflects the growing global focus on the integration of intelligent technologies in environmental management and data-driven policy (Li et al., 2022; Rahman et al., 2023).

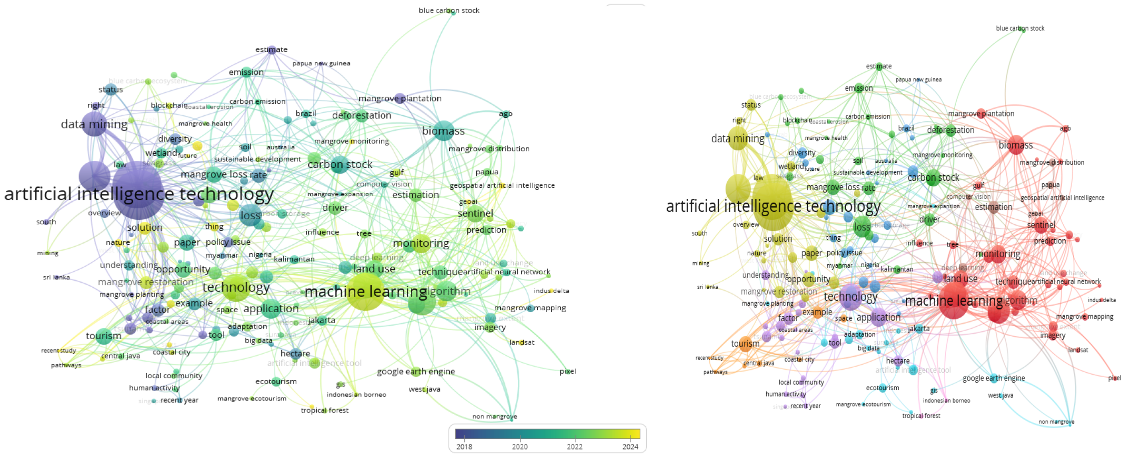
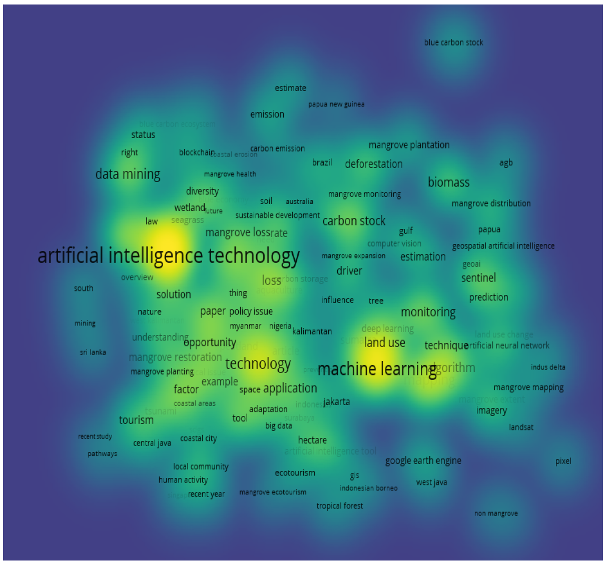


Figure 1. Overlay and Network visualization

Publication distribution shows that most articles are published in multidisciplinary journals focusing on environmental science, remote sensing, and sustainability (Figure 1). Journals such as Remote Sensing, Ocean & Coastal Management, and Sustainability are the primary publication channels for research related to AI and mangroves, while contributions from public policy journals remain relatively limited (Friess & Webb, 2021). This indicates that AI studies in mangroves are still dominated by technical and ecological perspectives, with suboptimal involvement of policy analysis.

Types of Artificial Intelligence Used

Based on the Vosviewer classification, machine learning is the most widely used AI approach in mangrove management research (Figure 2). Algorithms such as Random Forest, Support Vector Machine, and Neural Networks are commonly applied for mangrove cover classification and coastal land change analysis due to their ability to handle non-linear and multivariate data (Kumar et al., 2021). The use of machine learning has been shown to improve the accuracy of mangrove mapping compared to conventional statistical methods (Zhu et al., 2023).



Gambar 2. Density Visualisation

Furthermore, the integration of remote sensing and deep learning-based image classification is becoming an increasingly dominant trend, particularly in studies using Landsat, Sentinel, and UAV imagery (Figure 2). This approach enables the detection of changes in mangrove cover at high temporal and spatial resolution, thus supporting long-term monitoring of coastal ecosystems (Li et al., 2022). Several studies have also developed AI-based decision support systems (DSS) and predictive modeling to simulate management scenarios and predict the impact of policies on future mangrove conditions (Power, 2020).

Applications of AI in Mangrove Management

A literature synthesis shows that the primary application of AI in mangrove management focuses on monitoring and mapping activities. AI is used to identify mangrove distribution, monitor land cover changes, and detect habitat fragmentation with high accuracy and greater time efficiency than traditional field surveys (Giri et al., 2021). The use of AI in mapping also allows for faster data updates, which is crucial for adaptive policy planning.

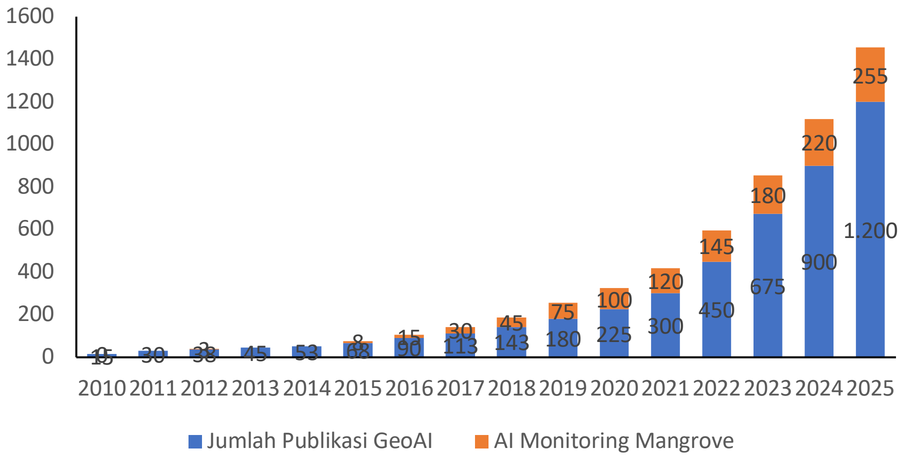


Figure 4. AI publication (modified Wang et al., 2024)

In addition to monitoring, AI is also used to detect degradation and evaluate the success of mangrove restoration. Several studies have shown that deep learning algorithms can distinguish degraded and successfully restored mangrove areas based on the spectral and temporal characteristics of satellite imagery (Friess et al., 2020). Furthermore, AI-based predictive modeling is being used to project changes in mangrove ecosystems due to anthropogenic pressures and climate change, providing a picture of long-term risks to coastal areas (Alongi, 2020).

Policy-Relevant Findings

From a policy perspective, literature findings indicate that AI provides strong empirical evidence to support data-driven mangrove management policies. The spatial and predictive information generated by AI can be used to determine restoration priority locations, optimize budget allocations, and increase transparency in environmental policy monitoring (Setiawan et al., 2022). This evidence strengthens the evidence-based policy approach to mangrove ecosystem management.

Table 1. History of the development of the AI period in policy and institutions

Period	AI in Policy & Institutions
2010–2015	Monitoring of policies & legislative texts (e.g., Gnowit)
2016–2020	Internal AI for admin & data analytics in bureaucracy
2021–2024	Generative AI & public service automation; federal use inventory
2025–Now	Increasingly formal AI: AI minister (Diella), public consultation analysis, and descriptive AI (Chat) tailored to the needs of government agencies

Sources: modifikasi OECD (2025)

Furthermore, several studies highlight the role of AI in supporting policy planning and evaluation processes through decision support systems capable of simulating various mangrove management scenarios. Although the direct application of AI in policy processes in Indonesia remains limited, its integration has significant potential to improve the effectiveness of cross-sectoral policies and strengthen sustainable mangrove governance (Rahman et al., 2023).

DISCUSSION

Implications for Mangrove Management Policy in Indonesia

The findings of this study indicate that the application of artificial intelligence (AI) has significant potential to strengthen evidence-based mangrove management policies. AI systems enable large-scale integration of spatial and temporal data, enabling policymakers to obtain more accurate and up-to-date information on mangrove conditions, levels of degradation, and the effectiveness of restoration programs (Rahman et al., 2023). With the support of machine learning algorithms and remote sensing, policies no longer rely solely on static data or periodic reports, but rather on continuous monitoring systems that respond to ecosystem changes (Li et al., 2022).

In the Indonesian context, these implications are particularly relevant given the vast coastal area and the complexity of mangrove governance, which involves multiple levels of government. AI integration can support the determination of priority locations for national mangrove restoration, as outlined in large-scale mangrove rehabilitation programs, by simultaneously considering ecological, social, and economic factors (Setiawan et al., 2022). Thus, AI plays a strategic role as a tool to bridge the gap between national policies and implementation at the local level, particularly in adaptive and evidence-based mangrove management (Friess & Webb, 2021).

Challenges and Limitations

The findings of this study indicate that the application of artificial intelligence (AI) has significant potential to strengthen evidence-based mangrove management policies. AI systems enable large-scale integration of spatial and temporal data, enabling policymakers to obtain more accurate and up-to-date information on mangrove conditions, levels of degradation, and the effectiveness of restoration programs (Rahman et al., 2023). With the support of machine learning algorithms and remote sensing, policies no longer rely solely on static data or periodic reports, but rather on continuous monitoring systems that respond to ecosystem changes (Li et al., 2022).

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Opportunities and Future Directions

Furthermore, this study also identifies strategic opportunities for developing AI-based mangrove policies in the future. Integrating AI into national mangrove management policies can be achieved through the development of decision support systems connected to national databases and used across ministries and agencies (Power, 2020). This approach aligns with the government's digital transformation agenda and can enhance cross-sectoral policy coordination more effectively.

Furthermore, cross-sector collaboration between government, academia, the private sector, and local communities is key to the successful implementation of AI in mangrove management. These partnerships not only strengthen technical capacity but also ensure that AI technology is used inclusively and appropriately to the local socio-ecological context (Nurhidayah et al., 2023). From an academic perspective, future research agendas should focus on strengthening the link between AI analysis results and actual policy impacts, including long-term policy evaluation and the development of a sustainable AI governance framework for mangrove ecosystem management (Donthu et al., 2021).

CONCLUSION

This research shows that Artificial Intelligence (AI) has emerged as an increasingly important tool in mangrove ecosystem management, particularly through the application of machine learning, remote sensing, and predictive modeling for monitoring, mapping, and analyzing coastal ecosystem change. AI integration can be utilized as a policy support tool to determine restoration priorities, monitor rehabilitation, evaluate policies, provide empirical evidence, and ensure transparency and accountability, as proposed by Setiawan et al. (2022). The challenge of using AI is the limited scope of the literature, which can potentially lead to bias. However, the opportunity to develop a contextual and inclusive AI governance framework, as well as interdisciplinary research that integrates technological, policy, and socio-ecological aspects, is an important agenda to support sustainable mangrove management in the future (Friess & Webb, 2021).

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