Applications of Artificial Intelligence in Environmental Management in Vietnam: A Mini Review

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ABSTRACT: Vietnam faced serious environmental challenges, including air pollution, waste management issues, natural disasters, climate change, and biodiversity loss. This paper provided a mini-review of artificial intelligence (AI) applications in the environmental sector in Vietnam, based on studies published between 2020 and 2025. AI was effectively applied in various domains, such as high-accuracy air quality forecasting using models such as LightGBM and CatBoost; optimization of solid waste management through Random Forest and integrated IoT systems; flood and landslide prediction using XGBoost and LSTM; climate change impact assessment based on stacked LSTM architectures; and natural resource monitoring employing convolutional neural networks combined with geographic information systems. These studies demonstrated that AI outperformed traditional methods in terms of accuracy and efficiency, thereby supporting data-driven decision-making. However, major challenges remained, including limitations in data availability, human resources, and technical infrastructure. The paper further proposed development directions such as establishing open databases, strengthening human capacity building, and promoting international collaboration to accelerate AI adoption in alignment with Vietnam's National AI Strategy toward 2030. Overall, AI was expected to become a key enabling tool for sustainable environmental management in Vietnam.

KEYWORDS: Artificial intelligence; environmental management; Vietnam.

1. Introduction

Artificial intelligence (AI) increasingly established itself as a foundational technology in modern science and engineering. AI aimed to enable machines to emulate human cognitive functions such as learning, reasoning, and prediction [1]. Globally, AI was widely and effectively applied to address a range of pressing environmental challenges. For instance, in air quality management, machine learning algorithms demonstrated high predictive accuracy in forecasting pollutant concentrations, thereby supporting early warning systems in regions

lacking sufficient monitoring stations [2,3]. In addition, AI was extensively applied in flood and disaster forecasting. Recent studies indicated that deep learning models integrated with hydrological models improved large-scale flood prediction accuracy by four to six times compared with conventional modeling approaches [4]. In the field of water resources management, intelligent algorithms enabled rapid detection of contaminants and early warning of water pollution incidents, significantly enhancing the efficiency of water quality management and emergency response [5]. Moreover, the application of deep learning to remote sensing data opened new opportunities for forest monitoring, substantially improving accuracy and operational efficiency in detecting deforestation and large-scale vegetation degradation [6].

Vietnam was a rapidly developing economy; however, accelerated urbanization and industrialization imposed substantial pressure on waste management systems and water resources. Water quality in many river basins deteriorated due to insufficient treatment of industrial and domestic wastewater, leading to adverse consequences for public health and aquatic ecosystems [7]. Statistical data showed that 87% of domestic wastewater in Vietnam was not treated. Limited regulatory enforcement capacity and high treatment costs remained critical barriers that contributed to widespread environmental pollution across many provinces. Although numerous studies proposed cost-effective technological solutions for pollution control and wastewater treatment [8], effective monitoring of implementation and comprehensive environmental assessment remained challenging. In parallel, municipal solid waste generation in Vietnam increased rapidly and was projected to double within the next 15 years, exerting significant pressure on existing waste treatment infrastructure. According to the Ministry of Natural Resources and Environment (2023), the total amount of municipal solid waste was 25 million tons per year. Furthermore, Vietnam was ranked among the countries most severely affected by air pollution globally [9]. Air pollution in major urban centers reached alarming levels, with fine particulate matter ($PM_{2.5} = 28.7$ μg/m³) and other pollutants frequently exceeding national and international air quality standards. Another critical challenge facing Vietnam was climate change. The country was consistently classified as one of the most climate-vulnerable nations worldwide and was frequently exposed to extreme weather events such as tropical storms, floods, droughts, and widespread landslides, which posed increasing risks to socio-economic stability and environmental sustainability [10].

These challenges necessitated more effective environmental management solutions, in which AI was expected to play a pivotal role as a data-driven decision-support tool to mitigate pollution and enhance climate change adaptation in Vietnam. Numerous scientific studies published in reputable journals demonstrated that AI applications significantly improved the accuracy of environmental prediction and monitoring, thereby enabling policymakers and managers to propose timely and evidence-based interventions. Despite its substantial potential, the deployment of AI in environmental management in Vietnam remained limited, and many application domains had yet to be fully explored. Therefore, this paper provided an updated review of recent research on AI applications in the environmental sector in Vietnam. Specifically, peer-reviewed publications from credible sources during the period 2020–2025 were systematically synthesized to present a comprehensive overview of current research trends, technological advances, application domains, and remaining gaps, thereby providing a scientific basis for future research directions and policy-oriented solutions.

2. Applications of Artificial Intelligence in Environmental Management

2.1. Air quality monitoring.

Air pollution has become a critical issue in major Vietnamese cities such as Hanoi and Ho Chi Minh City, necessitating effective monitoring and forecasting tools. In recent years, machine learning and deep learning techniques have been increasingly applied to predict fine particulate matter and gaseous pollutants with substantially improved accuracy [11, 12]. Among the most commonly used approaches are ensemble models (e.g., RF, XGBoost, LightGBM, and CatBoost) and deep learning architectures such as LSTM and CNN for capturing nonlinear and spatiotemporal patterns in air quality data. Rajnish Rakholia et al. (2023) developed a multi-output machine learning model to simultaneously forecast multiple air pollutants (NO_2, SO_2, O_3, and CO) on an hourly basis in Ho Chi Minh City. The study utilized datasets collected from six monitoring stations during 2021–2022 and integrated meteorological, traffic, and industrial activity variables. The results demonstrated that the global multivariate machine learning model achieved higher predictive accuracy than pollutant-specific single-output models, with significantly lower root mean square error (RMSE) and mean absolute percentage error (MAPE) [12]. Similarly, Minh et al. (2021) integrated the Weather Research and Forecasting (WRF) model with machine learning using an Extra Trees regression approach to predict $PM_{2.5}$ concentrations in Ho Chi Minh City up to 48 hours in advance. The Extra Trees model achieved a coefficient of determination (R^2) of 0.68 and an overall prediction accuracy of approximately 74% for short-term $PM_{2.5}$ forecasting, representing a substantial improvement over conventional statistical methods [11].

Beyond real-time forecasting, AI has also been applied to large-scale spatial mapping of air pollution. Ngo et al. (2023) employed the Light Gradient Boosting Machine (LightGBM) algorithm in combination with satellite observations (OMI and TROPOMI) to generate daily ground-level NO_2 concentration maps across Vietnam. The LightGBM model achieved a Pearson correlation coefficient of $r = 0.77$ and a root mean square error (RMSE) of approximately 7.93 $\mu g\ m^{-3}$ when validated against ground-based monitoring data, outperforming conventional modeling approaches. Notably, the annual mean NO_2 maps for the period 2019–2021 exhibited a very high agreement with in situ observations ($r = 0.95$), effectively compensating for the current limitations associated with the sparse national monitoring network [13]. A major constraint for AI-based air quality modeling in Vietnam is the limited availability of high-quality input data, as many localities lack automated air monitoring stations or sufficient financial resources for continuous measurements. Consequently, the development of models capable of achieving reliable performance under data-scarce conditions has emerged as a practical and necessary solution. Nguyen P. D. M. et al. (2024) evaluated a wide range of machine learning models (RF, XGBoost, CatBoost, and SVM) and deep learning architectures (LSTM, CNN, and ConvLSTM) to enhance the spatial resolution of $PM_{2.5}$ maps from 3 km to city scale. The best performance was obtained using a CatBoost model incorporating a two-day temporal lag, which increased the correlation coefficient by 57% and reduced prediction errors (RMSE, MRE, and MAE) by 42–75% relative to existing $PM_{2.5}$ products [14]. These findings indicate that boosted decision tree models may outperform complex deep neural networks in short-term and data-limited scenarios. Overall, AI-based air quality applications in Vietnam have contributed to the development of early

warning systems for pollution episodes and have strengthened the capacity of environmental authorities to proactively and accurately manage urban air quality.

2.2. Waste management and treatment.

Municipal solid waste management in Vietnam is facing increasing challenges due to rapid urbanization and the continuous growth of waste generation [15]. AI-based studies have contributed significantly to waste generation forecasting and optimization of collection and treatment systems. Frequently used approaches include ensemble learning algorithms (e.g., RF, SVR, and KNN) as well as deep learning models for classification and operational optimization tasks. Nguyen Xuan Cuong et al. (2021) compared six machine learning models to predict household solid waste generation in Vietnam. Using eight input variables, including population, household expenditure, and retail activity, the study identified Random Forest (RF) and K-Nearest Neighbors as the most effective algorithms. The RF model provided reliable predictions, demonstrating strong potential to support integrated planning of waste collection and treatment systems nationwide [15]. In a related direction, Tran Anh Khoa et al. developed a smart waste management system integrating Internet of Things (IoT) sensors and machine learning at Ton Duc Thang University. The system deployed smart bin sensors and route optimization algorithms, enabling collection vehicles to dynamically select the shortest routes, thereby reducing operational costs and ensuring timely collection before bins reached capacity. Experimental results indicated that this AIoT-based system significantly reduced collection time compared with fixed scheduling strategies [16]. In addition, AI models have been increasingly applied to waste classification and recycling processes. A representative study proposed an intelligent plastic waste sorting system based on deep learning and Delta robotics, achieving a classification accuracy of approximately 96% across different plastic types and demonstrating strong potential for automation in recycling operations [17]. However, current AI applications in waste collection and processing remain highly dependent on mechanical equipment, highlighting the need for more innovative solutions in material recovery, recycling, and circular resource utilization [18]. Overall, AI is playing an increasingly important role in Vietnam's waste management sector, ranging from waste generation forecasting and collection route optimization to enhanced waste sorting and recycling efficiency, thereby reducing environmental burdens and operational costs.

2.3. Disaster forecasting and risk management.

Vietnam is frequently exposed to a wide range of natural hazards, including floods, tropical storms, landslides, and droughts. Early warning systems and hazard risk mapping therefore play a critical role in mitigating socio-economic losses and enhancing disaster preparedness. Recent studies have consistently demonstrated the superiority of AI-based approaches over conventional methods in disaster simulation, forecasting, and early warning applications. Commonly applied techniques include ensemble learning algorithms (e.g., RF, XGBoost, LightGBM, and CatBoost) and deep learning architectures such as LSTM, CNN, and Transformer-based models for spatiotemporal prediction tasks. Nguyen Hao Quang et al. (2025) integrated GIS and remote sensing data with eight machine learning algorithms to generate flood susceptibility maps for Hoa Vang District, Da Nang. The evaluated models included boosting-based algorithms and conventional classifiers. All individual models

achieved strong predictive performance with area under the curve (AUC) values exceeding 0.95, while the boosting models reached AUC values above 0.97. Notably, a hybrid ensemble model combining boosting and RF achieved an outstanding AUC of 0.998. The resulting high-resolution flood risk maps enabled precise identification of flood-prone areas, thereby supporting prioritized mitigation and land-use planning strategies [19]. Similarly, Nguyen Phuoc Sinh et al. (2024) developed a hybrid hydrological model integrating the physically based HEC-HMS rainfall–runoff model with a LSTM encoder–decoder network to enable real-time flood forecasting for the Krong H'nang Reservoir in the Central Highlands of Vietnam. The hybrid framework was calibrated using 33 flood events recorded between 2016 and 2021. The results demonstrated substantial improvements in water level prediction accuracy, particularly for six-hour lead-time forecasts, where the Kling–Gupta efficiency (KGE) increased by up to 69% compared with the standalone HEC-HMS model. The system has been operationally implemented to support reservoir management, thereby enhancing flood control performance and operational safety [20].

Additional studies have focused on landslide susceptibility assessment using machine learning approaches. Tran V. A. et al. (2024) developed RF, Gradient Boosting Machine (GBM), and Support Vector Machine (SVM) models to evaluate landslide susceptibility in Van Yen District, Yen Bai Province. Thirteen topographic, geological, and climatic variables were incorporated, including slope, rainfall, land cover, distance to rivers, roads, and fault lines. The RF model achieved the best predictive performance with an AUC of 0.883, outperforming both SVM and GBM. The resulting landslide susceptibility maps were classified into five hazard levels (very low to very high), enabling local authorities to delineate high-risk zones for proactive evacuation planning and slope stabilization measures [21]. Similarly, Das et al. (2024) applied RF models to analyze the spatial variability of landslide risk following major storm events in Central Vietnam. The RF model achieved a high predictive accuracy with AUC values exceeding 0.95 and sensitivity greater than 90%, demonstrating strong reliability for large-scale landslide risk assessment [22].

Several experimental studies have also explored the use of deep learning architectures, such as LSTM and Transformer-based models, for flood and storm prediction in Vietnam. For instance, Pham et al. (2025) proposed LSTM and Temporal Convolutional Network (TCN) models to forecast flood-inducing rainfall and typhoon frequency, achieving prediction accuracies of 96% for storms and 97% for flood events [23]. Meanwhile, Ha Duong Hai et al. (2023) applied CNN and LSTM models to predict the Standardized Precipitation–Evapotranspiration Index (SPEI) for the Mekong Delta, demonstrating promising performance for three- and six-month drought forecasting. Although AI-based studies on drought and typhoon prediction in Vietnam remain relatively limited, this research direction is expected to expand rapidly, driven by the increasing availability of climate datasets and the strong capability of deep learning models to capture nonlinear spatiotemporal patterns [24]. Overall, AI has demonstrated substantial potential in enhancing the accuracy and reliability of disaster forecasting in Vietnam, enabling early warning systems and supporting evidence-based disaster preparedness and risk reduction strategies to minimize human and economic losses.

2.4. Climate change adaptation and mitigation.

Climate change poses severe challenges to Vietnam, including sea-level rise, saline intrusion, altered rainfall patterns, and increasing risks to food security and public health. AI has emerged

as an effective analytical tool for climate scenario assessment and for supporting the development of adaptation and mitigation strategies. Commonly applied approaches include deep learning models such as LSTM for time-series forecasting and ensemble learning algorithms (e.g., XGBoost and GPR) for spatial vulnerability and environmental risk assessment. One major research direction focuses on greenhouse gas emission forecasting and policy-oriented mitigation planning. Nguyen Ha Thi Thu (2025) applied a stacked long short-term memory (Stacked LSTM) deep learning model to forecast Vietnam's CO_2 emissions up to 2030 based on international economic indicators, including tourism activity, foreign direct investment, and export performance. The model achieved high predictive accuracy (RMSE = 0.1201; R^2 = 0.8657), outperforming conventional ARIMA and regression-based approaches. These projections provide valuable evidence to support national carbon neutrality pathways and emission control strategies in tourism and industrial sectors [25]. Sea-level rise has also intensified coastal salinization, particularly in the Mekong Delta. Nguyen Tien Giang et al. (2021) developed machine learning models, including polynomial regression and Gaussian process regression (GPR), to predict salinity intrusion using limited in situ observations combined with remote sensing data. The models demonstrated low prediction errors under data-scarce conditions, enabling early warning of dry-season salinity intrusion [26]. Similarly, Nguyen Huu Duy et al. (2025) established a vulnerability assessment framework for salinity impacts in the Red River Delta by integrating optimized XGBoost models with socio-economic surveys on household adaptive capacity. The hybrid framework achieved very high predictive accuracy (R^2 = 0.964–0.968) in spatial salinity mapping, supporting targeted adaptation planning at the local scale [27]. In addition, AI-based approaches have been applied to assess the long-term impacts of climate change in the Mekong Delta, providing early warnings of land degradation and ecosystem vulnerability [28]. Overall, AI is increasingly serving as a powerful decision-support tool in climate change research in Vietnam, enabling policymakers to develop more informed, adaptive, and mitigation-oriented strategies.

2.5. Natural resource management and biodiversity monitoring.

Vietnam is endowed with abundant natural resources and high biodiversity but is increasingly under pressure from rapid economic development and climate change. The integration of AI with remote sensing technologies has significantly enhanced the capacity for timely and fine-scale monitoring of natural resources and biodiversity dynamics. Commonly applied AI approaches include ensemble learning algorithms (e.g., RF and XGBoost) and deep learning architectures such as CNN and ANN for classification, mapping, and prediction tasks.

AI has proven to be an effective tool for the conservation of freshwater and coastal ecosystems. Deep learning models have been applied to species recognition using image and acoustic data, enabling efficient monitoring of endangered wildlife. A representative study reported a classification accuracy of 95.8% in identifying endangered species in Vietnam [29]. In freshwater and coastal ecosystems, AI-based real-time environmental monitoring has also advanced substantially. The integration of deep learning with satellite imagery enabled the development of the first 10 m resolution mangrove forest map for southern Vietnam, achieving an overall accuracy exceeding 90% [30].

AI has also been widely applied in land cover classification, biomass estimation, and deforestation monitoring. Truong Van Thinh et al. (2024) employed a time-feature CNN to generate a national land use and land cover (LULC) map at 10 m spatial resolution across

Vietnam. The CNN model demonstrated strong capability in discriminating complex land cover classes, achieving an overall accuracy of 90.5%, outperforming global products such as Dynamic World [31]. his study represents the first successful application of temporal CNN architectures for national-scale LULC mapping in a cloud-prone tropical country, providing valuable support for forest management and land-use planning. In parallel, Nguyen An et al. (2025) utilized remote sensing and GIS to monitor forest cover dynamics across three provinces representing distinct climatic zones in Vietnam. Satellite data processing was conducted on the Google Earth Engine (GEE) platform, with land cover classification implemented using Random Forest algorithms. The framework demonstrated strong capability in handling complex forest monitoring tasks and supports sustainable forest management practices nationwide [32]. Collectively, these advances enable more accurate and timely tracking of forest resources, contributing directly to Vietnam's sustainable forestry and biodiversity conservation objectives.

AI models have been widely applied in water quality assessment and groundwater potential mapping in Vietnam. Dao Nguyen Khoi et al. (2022) evaluated twelve machine learning models, ranging from decision trees and boosting algorithms to neural networks, to predict the Water Quality Index (WQI) for the La Nga River in Dong Nai Province. The models used physicochemical parameters (e.g., pH, dissolved oxygen, biochemical oxygen demand, nitrogen, phosphorus) as inputs and WQI as the output variable. Comparative results indicated that most machine learning models achieved strong predictive performance ($R^2 > 0.95$), with XGBoost yielding the best accuracy ($R^2 = 0.989$; RMSE = 0.107). The superior performance of XGBoost highlights its capability to capture nonlinear relationships between water quality parameters and WQI, thereby enabling early warning of river pollution levels. The study further suggested integrating WQI prediction models into automated monitoring systems to support real-time water quality management [33]. Nguyen et al. (2020) applied an artificial neural network combined with the Real AdaBoost algorithm (RABANN) to generate groundwater potential maps for Dak Nong Province. These maps provide valuable decision support for water resource authorities in identifying priority zones for groundwater exploration and sustainable abstraction, thereby reducing the risks of overexploitation in environmentally sensitive areas [34]. Collectively, these studies contribute to a more comprehensive understanding of Vietnam's water resources under the combined pressures of anthropogenic activities and climate change, thereby supporting scientifically informed integrated water resources management.

3. Overall Assessment and Future Perspectives

Existing studies have clearly demonstrated the substantial potential and benefits of AI in addressing environmental challenges in Vietnam. Many problems that were previously difficult to solve using conventional approaches have become tractable through the application of advanced machine learning and deep learning algorithms [19]. Particularly under conditions of constrained environmental budgets, AI offers a cost-effective and scalable solution for enhancing monitoring, prediction, and decision-making efficiency. Vietnam has many advantages in researching AI models thanks to its still-untapped potential. Currently, there is a strong demand for AI applications and many "real-world problems" in both businesses and public services. In addition, the Vietnamese language and local context create a promising research "niche". The growing community and the ability to leverage global advancements

help domestic teams shorten experimentation time, allowing them to focus on model fine-tuning and deployment. At the same time, the government's interest and supportive policies serve as a major driving force for AI research to develop strongly in the coming years.

Despite these opportunities, Vietnam continues to face substantial challenges in building national AI capacity. Recent assessments indicate that the country remains at an early stage of AI development, lagging behind several regional peers in terms of investment intensity, digital infrastructure, and research output [36]. The pool of high-quality AI professionals remains limited, with most expertise concentrated in a small number of leading technical universities, and formal AI education programs are still emerging. Moreover, data and technological constraints further impede large-scale deployment: although environmental data are abundant, they remain fragmented, poorly interoperable across sectors, and insufficiently standardized, while high-performance computing infrastructure for AI remains limited [15]. From a regulatory perspective, although the national AI strategy has been issued, legal frameworks and technical standards for AI deployment are still evolving, particularly regarding data governance, data sharing mechanisms, and AI ethics.

Vietnam is pursuing an approach that leverages its strengths while addressing its limitations through a relatively clear and coherent chain of national policies and programs. The Government of Vietnam promulgated the National Strategy on Research, Development, and Application of AI toward 2030, aiming to foster a robust domestic AI ecosystem and position Vietnam as a leading regional innovation hub within ASEAN, with global competitiveness in AI solutions by 2030 [35]. The strategy identifies AI as a core enabling technology of the Fourth Industrial Revolution and prioritizes investment in sectors where Vietnam has strong demand and comparative advantages, including natural resource management and environmental protection. This policy framework provides a critical institutional foundation for accelerating AI-driven environmental applications. Data infrastructure is supported through state data-sharing mechanisms and the National Data Portal under Decree No. 47/2020/ND-CP (2020), the National Data Center Project under Resolution No. 175/NQ-CP (2023), and Directive No. 32/CT-TTg (2024). At the same time, the Data Law No. 60/2024/QH15 (2024) and its implementation plan (Decision No. 75/QD-TTg, 2025) strengthen data governance and cross-border data processing. Regarding risk governance, Vietnam has promulgated Decree No. 13/2023/ND-CP on personal data protection (including data protection impact assessments), introduced a regulatory sandbox for banking and FinTech under Decree No. 94/2025/ND-CP, and issued responsible AI guidelines by the Ministry of Science and Technology (Decision No. 1290/QD-BKHCN, 2024). In parallel, policy incentives and financial support have fostered the establishment of numerous AI research centers within enterprises, research institutes, and universities. Based on the current landscape, several strategic directions are proposed:

a) Establishing open, interoperable, and regularly updated environmental data platforms to promote cross-agency data sharing and enrich training datasets for AI models;

b) Strengthening investment in computational infrastructure and human capital development, particularly in environmental data science and AI engineering at universities and research institutes;

c) Adopting advanced AI paradigms, such as transfer learning and federated learning, to leverage pretrained models and improve performance under data-scarce conditions;

d) Enhancing international collaboration and technology transfer, drawing on best practices from advanced countries in integrating AI into environmental monitoring and management systems (e.g., AI-assisted transboundary flood forecasting frameworks of the Mekong River Commission).

With continued policy support, technological maturation, and coordinated investments, AI is expected to become a core component of environmental decision-support systems in Vietnam in the near future, substantially contributing to sustainable environmental governance and climate resilience.

4. Conclusions

The application of AI in the environmental sector in Vietnam has demonstrated substantial value, ranging from improved accuracy in air pollution and disaster forecasting to optimized waste management, enhanced climate change adaptation, and strengthened biodiversity conservation. Machine learning and deep learning models not only overcome many limitations of conventional approaches but also provide cost-effective solutions that support timely, data-driven decision-making by environmental managers and policymakers. Despite significant progress, Vietnam continues to face key challenges, including limited availability of high-quality data, shortages of skilled human resources, and insufficiently integrated computational infrastructure. The National AI Strategy toward 2030 provides a critical foundation for overcoming these barriers and accelerating both research and large-scale implementation. Looking ahead, deeper integration of AI with complementary technologies such as remote sensing, the IoT, and transfer learning is expected to unlock new opportunities for developing intelligent and resilient environmental management systems. These advances will contribute to reducing environmental risks, enhancing adaptive capacity, and promoting green and sustainable development in Vietnam.

Acknowledgments

Author Contribution

Nguyen Van Thanh: Conceptualization, Validation, Writing; Pham Thuong Giang: Investigation, Writing; Nguyen Thi Thu Thuy: Writing – review & editing.

Competing Interest

The authors declare no competing interests.

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