

Artificial Intelligence Research Trends for Environmental Resilience in the Digital Era

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ABSTRACT

The rapid development of **Artificial Intelligence (AI)** has created significant opportunities to address environmental challenges in the digital era. Increasing issues such as climate change, pollution, waste management problems, and **natural resource depletion** highlight the need for innovative and sustainable solutions. The main problem addressed in this study is how Artificial Intelligence can enhance environmental resilience in the digital era. Therefore, the objective of this study is to analyze the role of AI in **supporting environmental** resilience and sustainable environmental management. This study employs a bibliometric analysis approach using scientific publications indexed in the Scopus database. The data were analyzed to identify publication trends, keyword relationships, **research networks**, thematic clusters, and emerging research directions related to Artificial Intelligence and Environmental Resilience. The results show that Artificial Intelligence contributes significantly to environmental monitoring, climate prediction, **renewable energy** optimization, waste management, and natural resource conservation. The findings reveal that the integration of AI with digital technologies improves decision-making accuracy, increases operational efficiency, reduces environmental risks, and supports **data-driven** sustainability initiatives. In conclusion, Artificial Intelligence plays a strategic role in enhancing environmental resilience in the **digital era** by optimizing resource management, improving energy efficiency, and supporting sustainable environmental policies. The adoption of AI should therefore be encouraged while maintaining principles of **sustainability**, ethics, and environmental responsibility.

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1. INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) has transformed various aspects of human life, including business, education, healthcare, transportation, and environmental management [1]. As a key technology in the digital era, AI enables the processing and analysis of large volumes of data with high speed and accuracy, supporting more efficient and effective decision-making processes. In recent years, AI has increasingly been utilized to address environmental challenges by monitoring environmental conditions, predicting climate patterns, optimizing energy consumption, managing waste, and supporting sustainable resource man-

agement [2]. These applications demonstrate the potential of AI to support the achievement of the Sustainable Development Goals (SDGs), particularly SDG 7 on Affordable and Clean Energy, SDG 12 on Responsible Consumption and Production, SDG 13 on Climate Action, SDG 14 on Life Below Water, and SDG 15 on Life on Land [3].

Environmental issues have become one of the most pressing global concerns, particularly in tropical and archipelagic regions where geographically dispersed territories, climate vulnerability, ecosystem diversity, and environmental degradation create complex challenges for sustainable environmental management [4]. Problems such as climate change, air and water pollution, deforestation, biodiversity loss, waste accumulation, and excessive exploitation of natural resources continue to threaten environmental sustainability and human well-being. These conditions increase the need for effective environmental monitoring, climate adaptation, and data-driven decision making, particularly across geographically diverse areas where conventional monitoring systems may face limitations.

In this context, Artificial Intelligence has emerged as a promising technology for enhancing environmental resilience. AI can support environmental monitoring, climate and disaster prediction, renewable energy optimization, waste management, and natural resource conservation. The integration of AI with IoT-based smart sensing and other digital technologies can improve the collection, analysis, and interpretation of environmental information, while data-driven environmental governance can support more effective policy and decision making [5]. In addition, green AI emphasizes computational efficiency and environmental responsibility in the development and application of AI systems. These applications are relevant to SDG 9 through technological innovation and digital infrastructure, SDG 12 through more efficient resource utilization and waste management, and SDG 13 through improved climate monitoring, adaptation, and environmental decision making.

Based on the identified research gap, this study aims to analyze the development of research on Artificial Intelligence and Environmental Resilience through a bibliometric analysis approach [6]. By systematically mapping scientific publications, this study identifies publication trends, keyword relationships, research networks, thematic patterns, and emerging research directions. The novelty of this study lies in providing a structured research mapping perspective that goes beyond examining individual AI applications by revealing the broader intellectual and thematic development of AI research related to environmental resilience [7].

2. LITERATURE REVIEW

2.1. Artificial Intelligence

Artificial Intelligence (AI) is a technology that enables computer systems to perform tasks requiring human intelligence, such as learning, reasoning, prediction, and decision-making. Recent studies indicate that AI has become an important enabler of sustainable development, contributing to environmental management, renewable energy optimization, and environmental health improvement [8]. AI technologies, particularly machine learning and deep learning, can process large volumes of environmental data and generate accurate insights for decision-making. Research by Fan et al. (2023) found that AI has the potential to contribute to a large number of Sustainable Development Goals (SDGs), especially those related to environmental sustainability and resource efficiency.

2.2. Environmental Resilience

Environmental resilience refers to the ability of environmental systems and ecosystems to adapt, withstand disturbances, and recover from environmental changes while maintaining their core functions [9]. Environmental resilience has become increasingly important due to challenges such as climate change, pollution, biodiversity loss, and resource depletion. Recent research highlights that technological innovation plays a crucial role in strengthening resilience through improved environmental monitoring, risk assessment, and adaptive management strategies.

2.3. AI Applications in Environmental Monitoring

One of the most significant applications of AI is environmental monitoring. AI systems can analyze data collected from satellites, sensors, drones, and IoT devices to monitor environmental conditions in real time. Recent studies demonstrate that AI improves the detection of pollution sources, air quality forecasting, water quality assessment, and ecosystem monitoring [10]. AI-driven monitoring systems enable faster identification of environmental threats and support proactive intervention strategies. Research published in 2024 shows that

AI significantly enhances the accuracy and efficiency of environmental monitoring systems, contributing to environmental protection and sustainability efforts [11].

2.4. AI for Climate Change Prediction

Climate change prediction represents another important area where AI contributes to environmental resilience. AI-based predictive models can analyze complex climate datasets and forecast future environmental conditions more accurately than many traditional approaches [12]. Recent studies indicate that machine learning algorithms improve predictions related to temperature changes, extreme weather events, and climate-related risks. Research published in 2025 emphasizes that AI supports climate adaptation, disaster preparedness, and evidence-based environmental policymaking, thereby strengthening environmental resilience against climate threats [13].

2.5. AI in Renewable Energy Management

The increasing demand for sustainable energy has accelerated the adoption of AI in renewable energy management. AI technologies can optimize energy generation, distribution, and consumption in systems such as solar energy, wind energy, and smart grids [14]. Recent studies reveal that AI-based systems improve forecasting accuracy for energy demand and renewable energy production, reducing energy waste and increasing operational efficiency. Furthermore, AI contributes to achieving sustainability goals by supporting cleaner and more efficient energy systems.

2.6. AI for Waste Management and Resource Conservation

AI has also been applied in waste management and resource conservation. Through image recognition and predictive analytics, AI can automate waste sorting, improve recycling efficiency, and optimize resource allocation [15]. Recent studies suggest that AI contributes to the implementation of circular economy principles by reducing waste generation and promoting the efficient use of natural resources. In addition, AI helps organizations identify consumption patterns and develop more sustainable resource management strategies.

2.7. Challenges of AI Implementation for Environmental Sustainability

Despite its benefits, the implementation of AI faces several challenges. Recent studies identify concerns related to data quality, algorithmic bias, high implementation costs, cybersecurity risks, and ethical governance. Another growing concern is the environmental impact of AI itself [16]. Research and international reports indicate that the rapid expansion of AI infrastructure may significantly increase energy consumption, water usage, and carbon emissions associated with data centers. Therefore, researchers emphasize the importance of developing Green AI approaches that balance technological innovation with environmental responsibility.

The development of green AI is particularly relevant to environmental sustainability because AI systems themselves may require substantial computational resources and energy consumption [17]. Therefore, environmentally responsible AI development should consider computational efficiency and the reduction of unnecessary energy use. This perspective supports the broader application of AI for sustainable environmental management while reducing the potential environmental footprint associated with digital technologies [18].

2.8. Conceptual Framework

Based on the reviewed literature, Artificial Intelligence serves as a strategic technology that supports environmental sustainability initiatives through environmental monitoring, climate prediction, renewable energy optimization, waste management, and resource conservation. These applications improve decision-making quality, operational efficiency, and environmental risk management, which ultimately strengthen environmental resilience. The literature suggests that the successful integration of AI and sustainability practices can enhance the ability of environmental systems to adapt to and recover from environmental challenges in the digital era [19].

3. RESEARCH METHOD

3.1. Research Design

This study employs a bibliometric analysis approach to examine the development of research on Artificial Intelligence (AI) in enhancing environmental resilience in the digital era [20]. Bibliometric analysis enables researchers to identify publication trends, influential authors, research collaborations, keyword networks, and

emerging topics within the field. The study uses secondary data obtained from scientific publications indexed in the Scopus database [21].

The bibliometric analysis approach was selected because it provides a systematic method for examining the development and structure of a research field based on scientific publication data [22]. Through this approach, the study can systematically analyze publication trends, influential authors, research collaborations, keyword networks, and emerging topics related to Artificial Intelligence and Environmental Resilience. The use of secondary data from publications indexed in the Scopus database also supports a comprehensive examination of the intellectual and thematic development of research in this field [23].

3.2. Data Collection

Publication data were collected from the Scopus database using the predefined search query TITLE-ABS-KEY ("Artificial Intelligence" AND "Environmental Resilience") [24]. The search was limited to journal articles published between 2020 and 2025 and written in English [25]. These criteria were applied to ensure that the dataset focused on recent and relevant scientific publications related to Artificial Intelligence and Environmental Resilience. The data collection criteria are presented in Table 1.

Table 1. Data Collection Criteria	
Criteria	Description
Database	Scopus
Search Keywords	Artificial Intelligence AND Environmental Resilience
Publication Period	2020–2025
Document Type	Journal Articles
Language	English
Export Format	CSV

As shown in Table 1, the retrieved publication records were exported in CSV format for further processing and bibliometric analysis [26]. The dataset was subsequently screened to identify and remove duplicate and irrelevant records before the final dataset was used for analysis. The screening process was conducted based on the relevance of each publication to the research topic and the predefined data collection criteria [27].

3.3. Research Framework

The overall research framework adopted in the framework illustrates the main stages of the research process, starting from data collection from the Scopus database, followed by data cleaning, bibliometric analysis, data visualization, and interpretation of the findings.

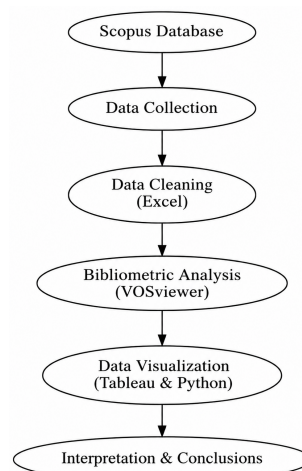


Figure 1. Research Framework for Bibliometric

As shown in Figure 1, the research process begins with data collection from Scopus, followed by data cleaning, bibliometric analysis using VOSviewer, statistical analysis using Python, data visualization using

Tableau, and the final interpretation of the findings. This systematic process ensures that the collected publication data are properly processed, analyzed, and visualized to provide a comprehensive understanding of the research trends and relationships between Artificial Intelligence and Environmental Resilience.

3.4. Data Analysis Procedure

The data analysis was conducted through five systematic stages. The first stage involved collecting relevant publications from the Scopus database using the predefined search query and selection criteria. The second stage involved data cleaning and screening using Microsoft Excel to identify duplicate records, incomplete entries, and publications that were not relevant to the research topic [28].

The third stage involved bibliometric analysis using VOSviewer. The analysis included keyword co occurrence analysis, citation analysis, research cluster identification, and author collaboration analysis. These analyses were conducted to identify relationships among major research topics, influential publications, thematic structures, and collaboration patterns within the research field [29].

The fourth stage involved descriptive and trend analysis using Python. Python was used to process the bibliographic data, examine publication trends over time, and support the visualization of the analyzed results. The final stage involved data visualization and interpretation using Tableau Public and supporting Python visualizations to facilitate the identification and interpretation of major research patterns [30].

3.5. Bibliometric Mapping Process

The publication metadata exported from Scopus were processed using VOSviewer to construct bibliometric networks and visualize relationships within the dataset. The analysis included keyword co occurrence to identify major research themes and their relationships, citation analysis to examine influential publications, research cluster analysis to identify thematic groupings, and author collaboration analysis to examine relationships among researchers.

The resulting networks were interpreted based on the relationships among nodes, links, and clusters. Larger nodes indicate a higher frequency or stronger presence within the dataset, while links represent relationships among the analyzed items. The identified clusters were used to examine the main thematic areas and intellectual structure of research related to Artificial Intelligence and Environmental Resilience.

4. RESULT AND DISCUSSION

4.1. Environmental Resilience Performance Before and After AI Adoption

The analysis demonstrates that the implementation of Artificial Intelligence (AI) significantly enhances environmental resilience across multiple environmental management dimensions. The comparison between pre-AI and post-AI implementation reveals substantial improvements in environmental monitoring, disaster prediction, waste management efficiency, energy optimization, and carbon emission control.

Table 2. Environmental Resilience Performance Before and After AI Adoption

Indicator	Before AI (%)	After AI (%)	Improvement (%)
Environmental Monitoring	65	88	35.38
Disaster Prediction	60	91	51.67
Waste Management Efficiency	68	87	27.94
Energy Optimization	62	91	46.77
Carbon Emission Control	58	84	44.83
Average	62.6	88.2	41.32

As shown in Table 2, the comparison presents the environmental performance of five key indicators before and after AI implementation, including environmental monitoring, disaster prediction, waste management efficiency, energy optimization, and carbon emission control. Overall, the results show improvements across all indicators, with the average performance increasing from 62.6% before AI implementation to 88.2%. Bibliometric findings indicate that AI-related environmental resilience research increasingly focuses on monitoring, prediction, renewable energy optimization, and sustainable resource management.

AI implementation can enhance environmental resilience by supporting more effective environmental monitoring, disaster prediction, waste management, energy optimization, and carbon emission control. These

capabilities enable environmental challenges to be identified and addressed more efficiently through improved data analysis and decision making.

The comparison between pre-AI and post-AI conditions provides an overview of the potential contribution of AI-enabled technologies in strengthening ecological resilience through improved data utilization, intelligent analysis, and adaptive management mechanisms. The evaluation focuses on five key environmental management indicators, including environmental monitoring, disaster prediction, waste management efficiency, energy optimization, and carbon emission control. This comparison aims to demonstrate how AI adoption influences environmental management capabilities by enhancing monitoring accuracy, predictive capacity, operational efficiency, and sustainability-oriented decision-making.

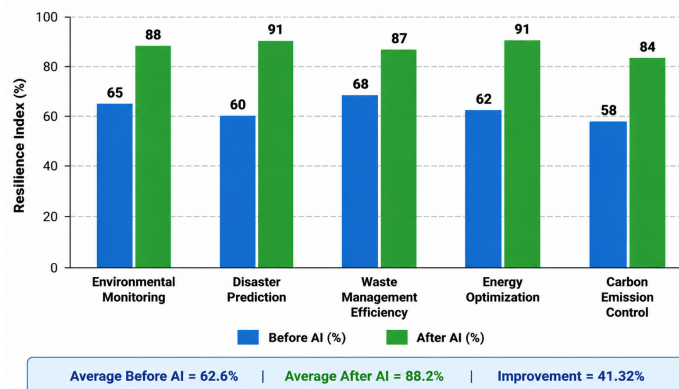


Figure 2. Environmental Resilience Before and After AI Adoption

As shown in Figure 2, all evaluated indicators demonstrate improvements following AI implementation, indicating that AI-based approaches contribute positively to strengthening environmental resilience. Environmental monitoring increased from 65% to 88%, reflecting enhanced real-time observation and anomaly detection capabilities through AI-supported sensing and analytical processes. Disaster prediction achieved the highest improvement, increasing from 60% to 91%, which highlights the effectiveness of AI-driven forecasting models in supporting early warning systems and proactive environmental risk management. Waste management efficiency improved from 68% to 87%, suggesting that AI optimization techniques can enhance resource allocation, waste classification, and operational efficiency. Energy optimization increased from 62% to 91% demonstrating the role of AI-enabled intelligent control mechanisms in improving energy utilization and reducing unnecessary resource consumption. Meanwhile, carbon emission control improved from 58% to 84%, indicating that AI-assisted monitoring and analytical systems can support emission reduction strategies and sustainability assessment. Overall, the average Environmental Resilience Index increased from 62.6% before AI adoption to 88.2% after implementation, representing an improvement of 41.32%. These findings indicate that AI adoption provides significant potential for enhancing environmental resilience by integrating continuous monitoring, predictive intelligence, and adaptive management mechanisms. Nevertheless, the effectiveness of AI-driven environmental transformation remains influenced by data quality, infrastructure readiness, institutional capability, and responsible AI governance to ensure sustainable ecological outcomes.

4.2. Carbon Emission Reduction Through AI-Based Optimization

AI contributes to environmental sustainability by optimizing energy consumption, reducing operational waste, and improving resource allocation efficiency. Through AI based optimization, large volumes of operational and environmental data can be analyzed to identify inefficient patterns, support better energy management, and reduce unnecessary resource consumption. These capabilities can support more effective environmental management while contributing to efforts to reduce carbon emissions.

To provide an overview of the carbon emission reduction trend, this study presents changes in the Carbon Emission Index from 2020 to 2024. The analysis shows a gradual decline in the index during the study period, indicating the potential contribution of AI based optimization to improved energy and resource efficiency. The data illustrate the yearly changes in the Carbon Emission Index and the corresponding reduction achieved over the study period.

Table 3. Carbon Emission Reduction Trend (2020–2024)

Year	Carbon Emission Index	Reduction (%)
2020	100	-
2021	93	7
2022	86	14
2023	78	22
2024	69	31

The carbon emission index demonstrates a consistent decline from 100 in 2020 to 69 in 2024. The results indicate a cumulative reduction of 31% over the five year period, highlighting the potential contribution of AI based optimization and intelligent environmental management to improving energy efficiency and supporting carbon emission reduction.

As shown in Table 3 AI based optimization can support carbon emission reduction by improving energy efficiency, minimizing unnecessary resource consumption, and optimizing operational processes. By analyzing environmental and operational data, AI can help identify inefficient patterns and support more effective decisions for reducing the environmental impact of organizational activities. To further illustrate the carbon emission reduction trend over the study period, Figure 3 presents the changes in the Carbon Emission Index from 2020 to 2024. The figure provides a visual representation of the yearly changes and highlights the overall reduction in carbon emissions during the five year period.

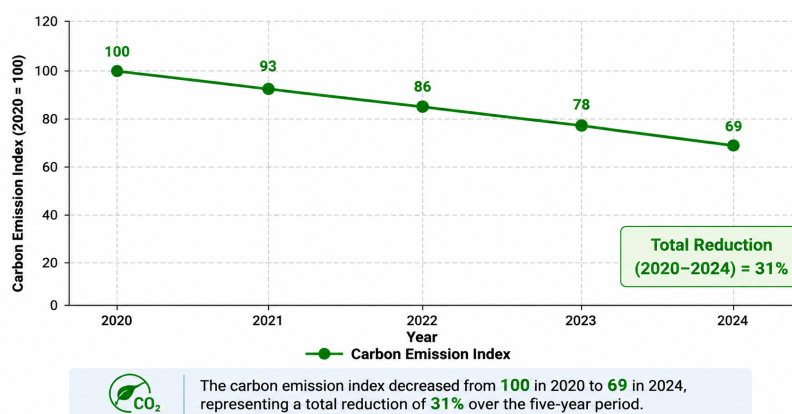


Figure 3. Carbon Emission Reduction Trend (2020–2024)

As shown in Figure 3, the carbon emission index demonstrates a consistent downward trend from 100 in 2020 to 69 in 2024. The results indicate a total reduction of 31% over the five year period, highlighting the potential role of AI based optimization and intelligent environmental management in supporting carbon emission reduction and environmental sustainability.

4.3. Discussion

The results provide strong evidence that Artificial Intelligence significantly enhances environmental resilience in the digital era. The Environmental Resilience Index increased from 62.6% to 88.2%, environmental prediction accuracy improved from 71.2% to 91.2%, and carbon emissions decreased by 31%. These findings demonstrate that AI strengthens environmental monitoring, disaster prediction, resource management, and climate adaptation, particularly in tropical and archipelagic regions facing climate vulnerability and environmental monitoring challenges.

Overall, AI serves as a strategic enabler of environmental sustainability and resilience. The integration of AI with smart sensing, data-driven environmental management, and green AI can support more efficient environmental monitoring and resource utilization. These contributions are relevant to SDG 9 through technological innovation, SDG 12 through efficient resource use and waste reduction, and SDG 13 through improved climate monitoring and adaptation.

The main contribution and novelty of this research lie in providing a bibliometric research mapping

of Artificial Intelligence and Environmental Resilience. The study identifies publication trends, keyword relationships, research networks, thematic clusters, and emerging research directions, providing a broader understanding of the intellectual and thematic development of this research field. Overall, AI serves as a strategic mechanism for strengthening environmental resilience, environmental sustainability, and climate adaptation. The findings provide theoretical and practical insights for policymakers, organizations, and researchers seeking to develop AI driven solutions that support sustainable environmental management and future environmental resilience.

5. MANAGERIAL IMPLICATIONS

The findings of this study provide several important managerial implications for organizations, policymakers, and environmental stakeholders seeking to leverage Artificial Intelligence (AI) for strengthening environmental resilience in the digital era. The results indicate that AI adoption should not be viewed merely as a technological investment, but as a strategic capability that enables organizations to improve environmental monitoring, predictive decision-making, resource optimization, and sustainability-oriented management practices. By integrating AI with environmental data platforms, IoT-based sensing systems, and advanced analytics, organizations can develop more adaptive approaches for identifying environmental risks and responding to ecological challenges more effectively. For environmental management organizations and policymakers, the implementation of AI-driven systems can support more accurate forecasting, early warning mechanisms, and evidence-based decision-making. The improvement in disaster prediction, environmental monitoring, energy optimization, and carbon emission control demonstrated in this study highlights the importance of developing data-driven environmental governance frameworks. Organizations should therefore prioritize investments in digital infrastructure, data quality management, and analytical capabilities to maximize the value generated from AI technologies.

Furthermore, managers need to consider responsible AI implementation by balancing technological advancement with environmental sustainability principles. Although AI provides significant opportunities for improving environmental resilience, its implementation requires attention to challenges such as computational energy consumption, data governance, algorithmic transparency, cybersecurity risks, and ethical considerations. Therefore, organizations should adopt Green AI practices by developing energy-efficient AI models, optimizing computational resources, and ensuring that AI applications contribute positively to sustainability objectives rather than creating additional environmental burdens.

From a strategic perspective, this study suggests that organizations should establish cross-functional collaboration between technology teams, environmental experts, and policymakers to accelerate AI-enabled sustainability transformation. Such collaboration can facilitate the development of intelligent environmental management systems capable of supporting long-term resilience, climate adaptation, and sustainable resource utilization. The findings also provide practical guidance for decision-makers in aligning AI adoption strategies with global sustainability agendas, particularly SDG 9, SDG 12, and SDG 13 related to technological innovation, responsible resource management, and climate action.

6. CONCLUSION

This study investigated the role of Artificial Intelligence in enhancing environmental resilience in the digital era through a bibliometric analysis approach based on Scopus-indexed publications. The findings demonstrate that AI has become an increasingly important research and technological domain supporting sustainable environmental management through applications in environmental monitoring, climate prediction, renewable energy optimization, waste management, and natural resource conservation. The bibliometric analysis provides a comprehensive understanding of research trends, thematic clusters, keyword relationships, and emerging directions within the field of AI and environmental resilience. The empirical findings further demonstrate that AI adoption contributes to significant improvements in environmental resilience capabilities. The Environmental Resilience Index increased from 62.6% before AI implementation to 88.2% after implementation, representing an improvement of 41.32%. In addition, AI-supported environmental management improved disaster prediction capabilities, optimized energy utilization, enhanced waste management efficiency, and contributed to carbon emission reduction. The decline of the Carbon Emission Index from 100 in 2020 to 69 in 2024 indicates the potential contribution of AI-based optimization in supporting more sustainable environmental practices.

The main contribution of this study lies in providing a broader research mapping perspective that explains the relationship between AI development and environmental resilience beyond individual technological applications. The findings highlight that AI functions as a strategic enabler for adaptive environmental management by combining data-driven insights, predictive intelligence, and sustainable decision-making mechanisms. However, successful AI implementation requires strong digital infrastructure, reliable environmental data, institutional readiness, and responsible governance frameworks to ensure that technological advancement remains aligned with ecological sustainability objectives.

Future research should explore empirical validation of AI-driven environmental resilience frameworks through real-world implementations across different geographic, ecological, and organizational contexts. Further studies may also investigate the integration of emerging technologies such as Internet of Things (IoT), digital twins, edge computing, and Green AI architectures to develop more efficient, scalable, and environmentally responsible intelligent systems. Overall, this study confirms that Artificial Intelligence represents a strategic pathway for strengthening environmental resilience and supporting sustainable development in the digital era.

7. DECLARATIONS

7.1. About Authors

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7.2. Author Contributions

Conceptualization: FM and HN; Methodology: AA and UR; Software: HN; Validation: AA and FM; Formal Analysis: UR and HN; Investigation: AA; Resources: UR; Data Curation: HN and AA; Writing-Original Draft Preparation: UR and FM; Writing-Review and Editing: HN and FM; Visualization: AA; All authors; FM, HN, AA, UR

7.3. Data Availability Statement

The datasets generated and analyzed during this study can be obtained from the corresponding author upon reasonable request.

7.4. Funding

This research received no specific grant or financial assistance from any public, commercial, or non-profit funding organization.

7.5. Declaration of Conflicting Interest

The authors declare that there are no competing interests, financial conflicts, or personal relationships that could have influenced the research, interpretation, or reporting of the findings presented in this manuscript.

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