Artificial Intelligence and Spatial Analysis in the Assessment of Water and Soil Pollution and Environmental Risk Management: A Comprehensive Literature Review

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Abstract: The current global environmental studies indicate that a change in methodology is occurring from description-oriented monitoring approaches to analytical models which have greater ability to interpret the complexity of pollutants in space and time, especially in water and soil systems where natural and anthropogenic influences co-evolve. This transition has enabled the increased adoption of AI and spatial analysis alongside other technologies to uncover pollution trends, identify risk zones, and create predictive models for environmental decision-making. In this review study, recent trends in using machine learning algorithms, Geographic Information System (GIS), and remote sensing in water and soil pollution and environmental risk management are discussed, and related to the context of geographic studies in environmental fields related to water, soil, and waste pollution and environmental factors along with the issue in Iraq. Based on these findings, the study concludes that the use of artificial intelligence and spatial analysis is a new epistemological approach that brings a new way to understand the relationship between pollutant sources, spatial features, pollutant flow and environmental exposures. The study also highlights that the usefulness of these techniques is dependent on the quality of the data, the efficiency of the model and the discoverability of reliable environmental monitoring databases in space, highlighting the usefulness of these tools for the development of sustainable environmental management and early risk detection.

Keywords: Artificial Intelligence; Spatial Analysis; Water Pollution, Soil Pollution, Geographic Information Systems; Remote Sensing; Environmental Risks, Machine Learning, Sustainable Environmental Management.

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1. Introduction

The global world experienced an acceleration of the scale of environmental pressures in recent decades due to population growth, population density, urbanization, industrial development, and agricultural expansion. This has directly affected natural resources, increased levels of contamination in water, soil and air. These challenges have grown to be some of the most pressing issues in contemporary societies, given their longer-term health impacts, economic and environmental consequences, and their direct connections with food security, sustainability of natural resources and the quality of human life (UNEP, 2024).

Water and soils are among the components of the environment most exposed to stress due to human activities such as wastewater release, solid waste disposal and discharge of industrial effluents and intensive use of agricultural fertilisers and pesticides, which cause increasing concentrations of chemical and biological contaminants in the different ecosystems. In addition, environmental monitoring and analysis is already a complex process due to the spatial and temporal variability of pollutants, as well as the diverse sensory characteristics of natural and urban environments, which makes the use of more advanced tools that go beyond the traditional approach based on reduced field measurements necessary (WHO, 2024).

Recent years have seen the rapid expansion of computer science and artificial intelligence, leading to the adoption of new ways of environmental data analysis. Now, using machine learning and deep learning algorithms, or creating artificial neural networks, researchers can analyze enormous amounts of environmental data and identify intricate connections between variables, as well as to develop accurate predictions that can warn of environmental risks as early as possible and reveal trends in pollutant levels (Russell & Norvig, 2021; Zhang et al., 2023).

Along the same lines, geospatial based technologies, among them the geographic information system (GIS) and remote sensing, have also progressed over this period with respect to the potentialities of collection, analysis and representation of spatial information. Meanwhile, geospatial technologies, especially geographic information systems (GIS) and remote sensing, have advanced considerably in this field with regard to the potentialities of spatial information collection, analysis and visual representation. Advanced combinations of these technologies with artificial intelligence have resulted in the smart development of spatial analysis tools to analyse geographic pollutant distribution, to calculate environmental vulnerability areas and to generate new predictive maps and spatial information for supporting environmental plan making and environmental decision-making (Goodchild et al., 2025).

The combination of artificial intelligence and spatial analysis has emerged as one of the most rapidly expanding research fields in environmental science, thanks to its transformative ability to raise the precision of environmental monitoring, lower its cost of acquisition, boost the effectiveness of environmental risk prediction, and guide sustainable management of natural resources (Li et al., 2024). Additionally, several studies, conducted in Iraq, showed the critical role of spatial analysis for the understanding of pollution patterns of water, soil, solid waste, and many environmental factors, which makes it a proper scientific basis for using the following techniques of artificial intelligence in the future studies of these environmental pollutants (Almudhafar & Alattabi, 2019; Almudhafar, 2020; Almudhafar et al., 2024).

Based on these scientific and technical advances, this review study intends to analyse and discuss recent trends in the use of artificial intelligence and spatial analysis in water and soils pollution assessment and environmental risk management in the integrated context of sustainable development and smart environmental management, from scientific aspects, including current uses, challenges and possibilities for use of the techniques for sustainable development and smart environmental management.

Research Problem

In recent years, the application of artificial intelligence and spatial analysis techniques has been greatly expanded in multiple environmental sciences areas, mainly water and soil pollution monitoring and environmental risk assessment. Notwithstanding the growing volume of publications on the subject, many reports yield conflicting results, depending on the applied technique and its effectiveness, and on geographical areas and data used by the reports. Additionally, the strides in machine learning and deep learning technologies and methodologies and geospatial technologies have produced a significant amount of research that needs a systematic scientific review and analysis to reveal existing trends, gaps of knowledge, and potential development opportunities.

Guided by this, the following major investigation question is formulated:

How have artificial intelligence and spatial analysis applications contributed to the development of methods for assessing water and soil pollution and managing environmental risks in recent years?

This question gives rise to a number of sub-questions:

1. What are the most prominent applications of artificial intelligence used in monitoring water and soil pollution?
2. What is the role of geographic information systems (GIS) and remote sensing in supporting the spatial analysis of environmental pollutants?
3. How effective are intelligent models in predicting environmental risks compared to traditional methods?
4. What are the main challenges and obstacles to the use of artificial intelligence in environmental studies?

5. What are the expected future trends for the integration of artificial intelligence with geospatial technologies in natural resource management and the achievement of sustainable development?

Objectives of the Study

This study aims to achieve the following objectives:

1. An overview of the fundamental concepts of artificial intelligence, spatial analysis and geospatial technologies used in environmental science.
2. Analysis of recent trends in the application of artificial intelligence in the assessment of water and soil pollution.
3. To clarify the role of Geographic Information Systems (GIS) and remote sensing in supporting environmental monitoring and spatial analysis of pollutants.
4. To evaluate the effectiveness of intelligent models used in predicting environmental risks and the early detection of pollution sources.
5. Identifying the main challenges and obstacles associated with the use of artificial intelligence in environmental studies.
6. To anticipate future trends in the application of smart technologies in environmental management and the achievement of sustainable development.
7. To construct an integrated knowledge framework that clarifies the nature of the relationship between artificial intelligence, spatial analysis and environmental risk management.

Significance of the Study

The importance of this study stems from the growing significance of artificial intelligence as one of the most important modern technologies capable of developing environmental monitoring methods and improving the efficiency of pollution assessment and natural resource management. The rise in environmental problems including natural resource depletion, pollution and climate change has made the study important due to the increasing demand for analytical tools that can deal with the massive volume of data generated by environment, which is not only spatially and nationally distributed but also changes over time.

This study is a comprehensive scientific review on the most recent developments and trends in the application of artificial intelligence and spatial analysis, on which researchers, policy makers and environmental practitioners canLearn about the potential of these technological fields, and use them to develop more accurate, efficient and stable environmental monitoring systems.The study also serves as a scientific reference that brings together environmental science, geography, computer science and geographic information systems, in line with recent trends in interdisciplinary research, which has become one of the key drivers of contemporary scientific development.

2. Methodology of the Review Study

This study adopted an analytical scientific review methodology, which aims to collect, analyse and evaluate published scientific literature relating to the applications of artificial intelligence and spatial analysis in the assessment of water and soil pollution and environmental risk management. This methodology is one of the most widely used in modern review studies due to its ability to synthesise scientific knowledge, analyse research trends and identify future knowledge gaps.

The study was based on the general principles of the PRISMA 2020 framework used in the organisation of review studies, through the identification of scientific databases, keywords, selection and exclusion criteria, and mechanisms for analysing the selected studies (Page et al., 2021).

Sources of Study Collection

The study relied on a range of recognised global databases containing peer- reviewed research indexed in international repositories, most notably: Scopus, Web of Science, ScienceDirect, SpringerLink, Taylor & Francis Online, Wiley Online Library, MDPI, and Google Scholar. International reports published by the United Nations Environment Programme, the World Health Organisation ( ), the Food and Agriculture Organisation, and the World Bank were also utilised, given their significance in the field of environmental studies and sustainable development.

Keywords Used

A set of primary and secondary keywords related to the subject of the study were used, including:

Artificial Intelligence, Machine Learning, Deep Learning, Geographic Information Systems, GIS, Remote Sensing, Environmental Monitoring, Water Pollution, Soil Pollution, Environmental Risk Assessment, Spatial Analysis, Environmental Sustainability, Geospatial Technologies.

The logical operators AND and OR were also used to obtain as many studies as possible that are directly relevant to the research topic.

Study Selection Criteria

The study adopted a set of scientific criteria for selecting studies suitable for review, namely that the study must be published in a peer-reviewed scientific journal, indexed in internationally recognised scientific databases, addressing applications of artificial intelligence or spatial analysis in the environmental field, relating to water or soil pollution or environmental risk management, containing clear results, practical applications or analytical models, and published between 2020–2025 to ensure the information and research trends are up to date.

Exclusion Criteria for Studies

Unverified studies, duplicate studies, studies not directly related to environmental science, studies lacking a clear methodology or analyzable results, and studies focusing on purely technical aspects without clear environmental applications were excluded.

Analysis of Selected Studies

The studies were further sorted into groups by key themes after screening and scientific evaluation, such as artificial intelligence applications in water pollution monitoring, in soil pollution assessment, spatial analysis, geographic information systems, application of predictive environmental risk models, and future challenges and trends. Analysis of the results of the studies has been performed in order to create areas of agreement and disagreement between the studies as well as to identify current scientific developments and gaps in knowledge in this field.

3. The Theoretical Framework of Artificial Intelligence and Spatial Analysis

In the last 20 years, the world has experienced a digital revolution that has reshaped many branches of scientific and applied research, and Artificial Intelligence (AI) is one of the pivotal technologies that have accelerated these changes. AI has emerged from the theoretical stage and is now becoming a part of any data analysis, decision making and forecasting system of scientific fields, such as environmental science (Russell & Norvig, 2021).

AI is programmed as a branch of computer science that seeks to phrase systems that can emulate human cognitive processes, including reasoning, problem-solving, decision-making, classification, and learning. Their task-based architecture entails using sophisticated mathematical and statistical methods to learn from data and uncover patterns and subtle relationships among various variables (Goodfellow et al., 2016; Knight, 2025).

Machine learning is one of the most significant applications of AI in the field of environmental studies, as it involves the analysis of past data to develop models that can forecast future data or categorize different environmental phenomena. Deep learning is also considered one of the most advanced branches, given its ability to analyse big data, satellite imagery and complex environmental patterns with high accuracy.

In contrast, spatial analysis is a key focus in modern geographical and environmental studies, as it focuses on studying the spatial distribution of phenomena and analysing the spatial relationships between different variables. This type of analysis relies primarily on geographic information systems, remote sensing techniques and digital spatial data (Longley et al., 2021).

The parallel development of artificial intelligence and spatial analysis has led to the emergence of the concept of smart spatial analysis, which combines the capabilities of intelligent algorithms with the potential of geographic information systems and remote sensing. This integration enables the analysis of millions of environmental data points in a short time, the production of predictive maps of environmental risks, the identification of current and future pollution hotspots, and the support of environmental planning and decision-making processes with greater accuracy and efficiency (Li et al., 2024).

These technologies have become the cornerstone of many modern environmental studies, particularly those related to monitoring water and soil pollution, natural resource management, climate change, and the achievement of sustainable development goals.

Applications of Artificial Intelligence in Assessing Water Pollution

Water resources represent one of the most important elements of the ecosystem and are among those most affected by various human activities, given their direct link to public health, food security and economic development. Industrial, agricultural and urban expansion over recent decades has led to an increase in the quantities of pollutants discharged into rivers, lakes, reservoirs and groundwater, making water quality monitoring and the assessment of pollution levels key priorities in modern environmental studies (UNEP, 2024).

For many years, traditional water monitoring programmes have relied on field sampling and periodic laboratory analyses to determine the physical, chemical and biological characteristics of water. Although these procedures are important for providing accurate data, they face challenges related to high time and financial costs and the difficulty of covering large geographical areas, in addition to their limited ability to predict future changes or provide early detection of potential environmental risks (WHO, 2024).

The emergence of artificial intelligence has helped address many of these challenges by developing advanced analytical models capable of handling vast amounts of environmental data and converting it into indicators that aid in understanding the behaviour of pollutants and predicting their future trends. These models rely on machine learning algorithms that learn from past data and use it to build accurate predictions of various environmental variables (Russell & Norvig, 2021).

Artificial Intelligence and Water Quality Indicators

Artificial intelligence algorithms are now widely used to analyse water quality indicators and assess environmental conditions. These indicators include pH, electrical conductivity, total dissolved solids, turbidity, dissolved oxygen, biochemical oxygen demand, and chemical oxygen demand, as well as concentrations of heavy metals and various organic pollutants (Li et al., 2024).

Recent studies have shown that Random Forest, Support Vector Machine, and artificial neural network models have achieved high levels of accuracy in estimating water quality indicators compared to traditional statistical methods, particularly when dealing with large and complex databases containing a large number of environmental variables (Zhang et al., 2023).

Artificial Intelligence and Water Pollution Prediction

Early prediction of pollution levels is one of the most important applications of artificial intelligence in the water sector. Machine learning algorithms enable the analysis of historical water-related data and its correlation with climatic, hydrological and anthropogenic factors to forecast future pollution levels and identify the most vulnerable locations.

Numerous studies have shown that intelligent models are highly capable of predicting seasonal changes in water quality, the spread of chemical pollutants, and increases in bacterial loads, as well as identifying the likelihood of water resource degradation before it actually occurs. This capability is a key element in supporting environmental management programmes and taking appropriate preventive measures (Jarnda et al., 2025).

Artificial Intelligence and Monitoring of Bacterial Water Pollution

Bacterial contamination is one of the most serious types of water pollution due to its direct link to human and animal health. Artificial intelligence techniques are increasingly being used to analyse water bacteriological data and assess the likelihood of microbial contaminant spread.

These applications help identify locations most vulnerable to bacterial contamination and assess the relationship between environmental characteristics and microorganism populations, as well as build predictive models to estimate the risk of bacterial contamination within various water resources (WHO, 2024).

Artificial Intelligence and Remote Sensing in Water Monitoring

Significant advances in remote sensing technologies have led to the availability of vast amounts of spatial data relating to water resources. Artificial intelligence has become an effective tool for analysing satellite imagery and detecting environmental changes associated with water quality.

Deep learning techniques are used to analyse satellite imagery to identify areas affected by pollution, monitor the spread of harmful algae, estimate concentrations of suspended matter, and track spatial changes in water bodies. These techniques also help to create accurate spatial maps that support more efficient environmental planning and water resource management (Singh et al., 2024).

4. Applications of Artificial Intelligence in Soil Pollution Assessment

Soil is one of the fundamental components of the ecosystem, as it is the primary medium for plant growth, food production, and the regulation of numerous biogeochemical processes associated with the cycles of elements, water, and energy. It also plays a pivotal role in maintaining biodiversity and the sustainability of natural and agricultural ecosystems. However, in recent decades, soil has become subject to increasing environmental pressures as a result of urban expansion and industrial, agricultural and mining activities, leading to rising levels of chemical, biological and physical pollution in many regions of the world (Hou et al., 2025).

Soil contamination is characterised by a high degree of complexity compared to many other forms of pollution, due to the heterogeneous nature of soil and the variation in its physical and chemical properties from one location to another, as well as the influence of climatic, hydrological and human factors on the movement, accumulation and transport of pollutants. Consequently, traditional methods based on limited field measurements have become insufficient for understanding the spatial distribution of pollutants or interpreting the complex relationships between pollution sources and various environmental characteristics (Longley et al., 2021).

The rapid development of artificial intelligence applications has led to the provision of advanced tools capable of analysing massive environmental databases relating to soil, detecting spatial patterns of pollutants, and building predictive models that assist in assessing environmental risks and identifying areas most vulnerable to environmental degradation (Li et al., 2024).

Artificial Intelligence and the Assessment of Chemical Soil Pollution

Chemical pollution is one of the most widespread types of soil pollution, encompassing the accumulation of heavy metals, toxic organic compounds, pesticides, chemical fertilisers and various industrial pollutants. These substances lead to the degradation of soil properties, a decline in agricultural productivity and a threat to human health and other living organisms.

Machine learning algorithms have been widely used to estimate concentrations of chemical pollutants in soil and to analyse the relationships between various environmental characteristics and pollution levels. Recent studies have shown that Random Forest, Gradient Boosting and artificial neural network models have achieved high levels of accuracy in explaining the spatial variation of heavy metals and producing accurate digital maps of pollution levels (Zhang et al., 2023)

Artificial Intelligence and Biological Soil Pollution

Biological contamination represents an important aspect of modern environmental studies due to its direct link to public health and the integrity of ecosystems. This type of contamination includes the presence of pathogenic microorganisms, bacteria, fungi and parasites resulting from sewage, solid waste and animal manure.

Environmental studies have shown that the distribution of biological contaminants within the soil is characterised by clear spatial variation linked to land use, population density, the level of environmental services, and various sources of pollution. In this context, artificial intelligence has aided in the analysis of complex microbial data and the identification of spatial patterns of biological contaminant distribution with greater accuracy compared to traditional methods (Almudhafar, 2020).

Artificial Intelligence and Heavy Metals in Soil

Heavy metals are considered among the most dangerous environmental pollutants due to their ability to persist for long periods in soil and to be transferred through the food chain to humans and animals. These elements include lead, cadmium, mercury, chromium, nickel, copper, zinc and other elements associated with industrial, agricultural and urban activities.

Artificial intelligence applications have offered significant potential for analysing the spatial distribution of heavy metals and identifying the factors influencing their accumulation and spread. These applications have also helped in producing environmental risk maps and identifying areas requiring urgent remediation or environmental rehabilitation (Chen et al., 2024).

Artificial Intelligence and the Production of Environmental Risk Maps

Environmental risk maps represent one of the most important practical outputs of artificial intelligence in the field of soil pollution. These maps rely on integrating field and laboratory data with spatial and satellite information to identify areas most vulnerable to pollution or environmental degradation.

Intelligent models are used to classify areas according to levels of environmental risk and to prioritise intervention, remediation and rehabilitation. These maps also support decision-makers and help direct resources towards sites most in need of environmental management (Li et al., 2024).

5. Artificial Intelligence, Geographic Information Systems and Remote Sensing in the Spatial Analysis of Environmental Pollution

Recent decades have witnessed significant developments in geospatial technologies, particularly Geographic Information Systems (GIS) and remote sensing techniques, leading to a fundamental shift in methods for studying environmental phenomena and analysing their spatial distribution patterns (These technologies have become the cornerstone of many modern environmental studies due to their ability to collect and analyse spatial data and link it to various natural and human variables (Longley et al., 2021).

With the rapid development of artificial intelligence technologies, a new scientific trend has emerged based on integrating intelligent algorithms with geographic information systems and remote sensing, with the aim of developing models better capable of interpreting complex environmental phenomena and predicting their future behaviour. This integration has provided advanced capabilities for analysing big environmental data and converting it into information that can be used in environmental planning and natural resource management (Li et al., 2024).

Artificial Intelligence and Geographic Information Systems

Geographic information systems (GIS) are among the most powerful tools that have come into use over the past decade for the study of spatial patterns in pollutants and the examination of the intersection between pollutant sources and the natural and human factors that affect them. These systems use spatial databases that store geographic information, which can be also linked to descriptive information, and support a range of spatial analysis operations.

AI has helped bring in newer aspects of GIS by creating algorithms that can automatically analyse spatial data to find hidden patterns and complex relationships between environmental variables. Co-optimizing comprehensive knowledge maps with pollution data also allows for modeling intelligent spatial spaces to identify pollution hotspots and predict spatial environmental risks and pollution areas at risk of environmental degradation to guide cleanup and protection measures (Wang et al., 2023).

Artificial Intelligence and Remote Sensing

Remote sensing technologies have become one of the most important sources of modern environmental data, due to the spatial and temporal information they provide, covering vast areas of the Earth's surface on a regular and systematic basis. These technologies rely on satellites, drones and aerial sensors to collect data on land cover, water, soil, vegetation and various environmental phenomena (Canty, 2025).

Artificial intelligence has significantly improved the efficiency of satellite image analysis through the use of deep learning techniques and artificial neural networks. These technologies are now capable of identifying environmental patterns, classifying land use, detecting environmental changes and monitoring areas affected by pollution with high accuracy (Singh et al., 2024).

Smart Maps and Environmental Decision-Making

Smart maps have become one of the most important outputs of artificial intelligence applications in environmental studies, as they allow environmental information to be represented visually, facilitating an understanding of spatial relationships and the identification of priority areas for environmental management. These maps are used to support decision- makers by identifying pollution hotspots and areas of environmental risk, and by guiding monitoring, remediation and environmental rehabilitation programmes.

It can therefore be said that the integration of artificial intelligence, geographic information systems and remote sensing represents one of the most significant scientific shifts in modern environmental studies, given the advanced capabilities it offers for monitoring, analysing, forecasting and managing environmental risks more accurately, efficiently and sustainably.

Artificial Intelligence, Environmental Risk Prediction and Natural Resource Management

The ability to predict environmental risks has become a fundamental requirement of modern environmental management, due to the continuous increase in human pressures on natural resources, the acceleration of climate change, and rising rates of pollution and environmental degradation. This reality has turned the discussion of environmental problems from just a describing perspective to a predicting one—either predicting future problems before they actually occur, or — predicting problems before they reach a critical threshold that is hard to deal with. In this respect, AI has become one of the most potent scientific tools to assist the proactive environmental management and efficiency of environmental decision-making process (UNEP, 2024).

It is the analysis of large amounts of spatial and temporal data collected from environmental monitoring stations, satellites, smart sensors and from long time series of climate and environmental data, which is used for modern environmental forecasting. AI algorithms are more efficient than conventional statistical analysis in creating predictive models for environmental risks because they are capable of working with this complicated information and discovering patterns and unseen connections that traditional statistics are unable to detect (Russell & Norvig, 2021).

Artificial Intelligence and Water Pollution Prediction

Water pollution is one of the most pressing environmental issues requiring effective predictive systems due to its direct impact on public health, food security and natural resources. Recent studies have demonstrated that machine learning algorithms are capable of predicting future changes in water quality based on prevailing physical, chemical and biological characteristics, as well as climatic and hydrological conditions.

These models are used to assess the likelihood of increased concentrations of chemical pollutants, the spread of bacterial contaminants and the deterioration of water quality before these events actually occur, thereby giving environmental authorities sufficient time to take appropriate preventive measures (Miller et al., 2025).

Artificial Intelligence and Predicting Soil Degradation

Artificial intelligence applications have become an effective tool for studying soil degradation and predicting levels of pollution, desertification, salinisation and erosion. These applications rely on integrating climatic, geological, hydrological and agricultural data into intelligent models capable of estimating the likelihood of future environmental degradation.

Studies have shown that these intelligent models achieve a high degree of accuracy in identifying areas at risk of loss of fertility, heavy metal accumulation or increased levels of biological contamination, thereby helping to direct environmental management programmes towards the area’s most in need of intervention, remediation and rehabilitation (FAO, 2023).

Artificial Intelligence and Natural Resource Management

The role of artificial intelligence is not limited to predicting environmental problems, but extends to supporting the sustainable management of natural resources by improving the efficiency of water, energy and agricultural land use. Smart systems have helped develop more efficient strategies for water resource management, prioritise environmental protection, and reduce the loss of natural resources.

AI applications also contribute to promoting the concept of smart environmental management, which relies on real-time data, continuous analysis and evidence-based decision-making, thereby enhancing the prospects of achieving sustainable development goals and preserving natural resources for future generations (United Nations, 2023; United Nations, 2024).

6. Critical Evaluation of Recent Studies and Contemporary Research Trends

A literature review of the scientific publications published in the period from 2020 to 2025 showed that use of artificial intelligence in environmental studies increased since 2020, especially in the field of monitoring water quality, assessing soil pollution and analyses of environmental risks. Most research has been conducted on the use of machine learning and deep learning for processing large environmental datasets, simulating environmental processes, and enhancing the precision of environmental assessments over traditional statistical approaches (Artificial Intelligence, 2021).

These studies provide a foundation that reveals AI applications have demonstrated significant successes in predicting water quality indicators and identifying chemical and biological pollution levels, and creating accurate spatial maps of environmental risks. Additionally, the studies indicated that the adoption of AI in conjunction with geographic information systems (GIS) and remote sensing has enhanced the effectiveness of spatial analysis and elevated the precision of environmental modeling.

Although these positive findings are reported, many studies have limited sample data or a limited geographical range which diminishes the capacity to extrapolate results to other environments. In addition, the application of intelligent models is restricted in some cases due to the difficulty in acquiring the required large tables in developing countries.

The literature reveals that there is no study that worked on the comprehensiveness of integrating artificial intelligence, spatial analysis and natural resource management in a single environmental domain, since most of the studies have been dedicated to applied aspects without keeping a comprehensive connection between the applied aspects of the various elements of the environmental domain.

Challenges and Obstacles Associated with the Application of Artificial Intelligence in Environmental Studies

AI technologies used in environmental sciences have demonstrated remarkable advancements, yet challenges in scientific, technical and methodological fields continue to create several obstacles that impact the reliability of outcomes and the effectiveness of the models utilized. One of the most important of these challenges is the quality of environmental data, which is the key for training and analysis used as the basis for AI algorithms, meaning that any inadequacy, error or pronounced variability in environmental data will directly impact the reliability of environmental results and predictions (Li et al., 2024).

Many developing countries also have difficulty with available long-term environmental data sets, as a result of weak environmental monitoring networks, insufficient number of specialised stations, and irregular data collection procedures. This makes it difficult to build accurate predictive models capable of correctly representing environmental reality (UNEP, 2024).

Another significant challenge is the high demand for the digital infrastructure required to implement artificial intelligence technologies, as the analysis of big data and high-resolution satellite imagery requires advanced computing power, large storage capacities and stable communication networks, which may not be available in many environmental organisations or research centres (Russell & Norvig, 2021).

Another issue is the interpretability of the results produced by intelligent models, particularly in deep learning applications that rely on complex computational processes that are difficult to interpret directly. This problem is referred to in the scientific literature as the ‘black box’ concept, whereby a model can produce accurate results without it being easy to explain the internal mechanisms that led to those results (Zhang et al., 2023).

7. Future Trends in Artificial Intelligence in Environmental Science

Recent research trends suggest that artificial intelligence will play a pivotal role in the future of environmental studies over the coming decades, driven by ongoing developments in machine learning, deep learning, big data, cloud computing and the Internet of Things. Traditional environmental monitoring systems are expected to evolve into interconnected smart networks capable of collecting, analysing and updating data in near real-time (UNEP, 2024).

One of the most prominent future trends is the expansion of the integration of artificial intelligence with modern satellites offering high spatial and temporal resolution, enabling the production of dynamic environmental maps that are continuously updated and reflect environmental changes as they occur. This integration is also expected to contribute to improved monitoring of water resources, soil pollution, desertification and climate change at local, regional and global levels (Jensen, 2016).

Recent studies are also moving towards the development of smart environmental systems based on the environmental Internet of Things, where field sensors and environmental monitoring stations are linked to digital analysis networks based on artificial intelligence, enabling real-time monitoring and continuous analysis of the physical, chemical and biological properties of water, soil and air.

Another promising trend is the development of advanced predictive models capable of simulating future environmental scenarios and estimating the likelihood of environmental risks before they occur, thereby enhancing the ability of environmental organisations to plan proactively and minimise losses resulting from natural disasters or environmental pollution.

8. Conclusions

The study concluded that artificial intelligence has become one of the most important modern technologies used in environmental science due to its high capacity to analyse big data and discover complex patterns and relationships between various environmental variables.

The scientific review showed that applications of machine learning, deep learning and artificial neural networks have clearly contributed to improving the accuracy of assessing water and soil pollution and predicting environmental risks compared to traditional methods.

Recent research showed the successful implementation of AI in GIS and remote sensing had resulted in creating sophisticated spatial models with the capacity of analyzing pollutant spatial distribution and creating smart maps to support environmental planning and decision-making.

The study also revealed that smart systems have proven to be a powerful and effective instrument to build environmental pollution early warning system, the natural disaster early warning system, and the climate change early warning system and thus able to empower environmental institutions seriously to tackle environmental issues proactively.

The review showed that the quality of environmental data and digital infrastructure plays the most important role in the success of AI applications in the environmental field.

The study was focused on the integration of artificial intelligence and spatial analysis as one of the most important trends of the future in environmental sciences, because of the high level of capabilities that could be obtained in the corresponding areas of monitoring, forecasting, natural resource management and sustainable development.

9. Recommendations

a. Increase adoption of AI technologies in environmental monitoring programmes (water, soil and air).
b. Construct conventional/normalised digital environmental databases in order to build smart models and enhance forecast precision of environmental assessments.
c. Utilize more geographically information systems and remote sensing techniques, combined with Artificial Intelligence, for environmental studies and spatial planning.
d. Promote STH projects addressing environment and develop water, soil and air monitoring networks to be smart.
e. Highlight interdisciplinary study between environmental and geographical sciences and computer sciences & artificial intelligence.
f. Establishing early warning systems using Artificial Intelligence to alert for environmental hazards and forecast future trends.
g. Provide capacity building and training opportunities for researchers and staff at environmental institute groups on AI and spatial analysis.
h. Focusing on opportunities for greater collaboration between universities, environmental institutions

and artificial intelligence centres for the creation of novel environmental solutions to sustain the SDGs.

i. Guide future research to create integrated, spatial models connecting parameters related to water, soil, climate and activities.

j. Incorporating smart technologies into national action plans to address the problem of environment protection, natural resource management and environment sustainability.

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