Artificial intelligence, machine learning and GIS in environmental engineering: current trends

Inteligencia artificial, machine learning y SIG en ingeniería ambiental: tendencias actuales

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Keywords

Computational tools; database; water; energy; air; solutions.

Abstract

Recent advances in Artificial Intelligence (AI), Machine Learning (ML), and Geographic Information Systems (GIS) have significantly enhanced our understanding of environmental issues. This review analyzes publications from the IEEE Xplore Digital Library to assess the growing expertise in these fields. By applying filters based on year, technique, and keywords such as water, air, soil, climate change, energy, and waste, we visualize the evolving application of these technologies across key environmental topics. Our findings offer scientific guidance on the most relevant applications and highlight areas in need of further investigation. A detailed review of the literature also reveals the connection between different domains and their impact. This work intents to promote ongoing research and serve as a critical resource in the search for solutions to environmental challenges

Palabras clave

Herramientas computacionales; base de datos; agua; energía; aire; soluciones.

Resumen

Los avances recientes en inteligencia artificial (IA), aprendizaje automático (ML) y sistemas de información geográfica (SIG) han mejorado significativamente nuestra comprensión de los problemas ambientales. Esta revisión analiza las publicaciones de la Biblioteca Digital IEEE Xplore para evaluar la creciente experiencia en estos campos. Al aplicar filtros basados en año, técnica y palabras clave como agua, aire, suelo, cambio climático, energía y residuos, visualizamos la aplicación cambiante de estas tecnologías en temas ambientales clave. Nuestros hallazgos ofrecen orientación científica sobre las aplicaciones más relevantes y resaltan áreas que necesitan más investigación. Una revisión detallada de la literatura también revela la conexión entre diferentes dominios y su impacto. Este trabajo tiene como objetivo fomentar la investigación en curso y servir como un recurso crítico en la búsqueda de soluciones a los desafíos ambientales.

Introduction

There are three large groups of computational tools constantly mentioned in the field of environmental engineering for the management of scientific data in their areas of interest, these are: Artificial Intelligence (AI) [1], Machine Learning (ML) [2] and Geographic Information Systems (GIS) [3]. These tools facilitate data analysis and pattern recognition, facilitating cost-effective decision-making compared to traditional sampling and laboratory methods. They also aid in understanding large, interconnected territories and complex matrices, allowing for the early detection of environmental issues [4]-[7].

AI, ML and GIS have been used to address complex issues in areas of environmental engineering such as water quality [8]-[9], energy management [10], air and soil pollution [11]-[12], waste management [13] and climate change [14]-[15]. This work aims to promote the development of collaborative work solutions in the related areas of environmental and computational engineering by visualizing potential areas of their development, through a systematic literature review of publications in *IEEEXplore* Digital Library.

Methodology

The *IEEE Xplore* database was chosen because it makes interrelations between various engineering fields and is also a recognized editorial in technology publications. Likewise, enables to search not only with keywords, but with publication topics. A search was performed using keywords and selected publication topics, from 2012 to 2022 as an arbitrary time range, for three major groups of data treatment tools: AI, ML and GIS. For each of these tools, a search was carried out by areas of interest in environmental engineering according to [16]. Those areas are water, air, soil, climate change, energy and waste. The number of existing publications in the database was quantified for each year. The keywords used were: "tool" (e.g., "machine learning"), "environmental engineering" and "area" (e.g., "water"). The search was refined with the publication topics according to table 1.

Table 1. Publication topics used as filter in IEEE Xplore Digital Library for each area and tool.

Area	ML	AI	GIS
Water	learning (artificial intelligence), environmental science computing, water quality, regression analysis, remote sensing, water resources, Internet of Things, rivers, water supply, water pollution, environmental monitoring (geophysics), deep learning (artificial intelligence), lakes	learning (artificial intelligence), environmental science computing, water quality, neural nets, regression analysis, water resources, Internet of Things, deep learning (artificial intelligence), artificial intelligence, image classification, hydrological techniques, water supply, convolutional neural nets, feature extraction, water pollution, time series, rivers, wastewater treatment	geographic information systems, remote sensing, environmental science computing, water resources, water quality, rivers, hydrological techniques, water pollution, geophysical image processing, terrain mapping, groundwater, rain, geophysics computing, lakes, water supply, environmental monitoring (geophysics)
Air	learning (artificial intelligence), air pollution, environmental science computing, air quality, regression analysis, neural nets, Internet of Things, air pollution control, data analysis, deep learning (artificial intelligence), environmental monitoring (geophysics), air pollution measurement	learning (artificial intelligence), environmental science computing, air pollution, air quality, neural nets, deep learning (artificial intelligence), regression analysis, air pollution control, recurrent neural nets, Internet of Things, data analysis, artificial intelligence, air pollution.	geographic information systems, air pollution, environmental management, environmental science computing, remote sensing, Gaussian distribution, Gaussian processes, coal, contamination, environmental degradation, environmental factors, geophysical techniques
Soil	learning (artificial intelligence), soil, regression analysis, Internet of Things, fertilizers, random forests, remote sensing, environmental science computing, deep learning (artificial intelligence), agricultural products, mean square error methods	agriculture, artificial intelligence, crops, irrigation, soil, agrochemicals, deep learning (artificial intelligence), farming, fertilizers, learning (artificial intelligence), neural nets, pesticides, plant diseases, regression analysis	geographic information systems, remote sensing, land use planning, soil, terrain mapping, Global Positioning System, agricultural products, environmental degradation, erosion, forestry, geophysical image processing, geophysical techniques, geophysics computing, irrigation, planning

Area	ML	AI	GIS
Climate Change	learning (artificial intelligence), environmental science computing, neural nets, Internet of Things, regression analysis, climate mitigation, geophysical image processing, air pollution, global warming, remote sensing, data analysis, ecology, rivers	learning (artificial intelligence), neural nets, climate mitigation, deep learning (artificial intelligence), Internet of Things, artificial intelligence, remote sensing, ecology, global warming, regression analysis, convolutional neural nets, image classification, recurrent neural nets, support vector machines, environmental factors	geophysical information systems, remote sensing, climatology, terrain mapping, vegetation mapping, ecology, environmental science computing, geophysical image processing, vegetation, atmospheric precipitation, atmospheric temperature, climate mitigation, environmental management, floods, disasters, global warming
Energy	learning (artificial intelligence), energy consumption, optimization, environmental science computing, energy management systems	learning (artificial intelligence), deep learning (artificial intelligence), energy consumption, energy conservation, photovoltaic power systems, regression analysis, power grids, distributed power generation, renewable energy sources, energy management systems, load forecasting, Internet of Things, artificial intelligence	geographic information systems, bioenergy conversion, energy management systems, power engineering computing, power generation planning, power system management, power system planning, renewable energy sources, smart power grids
Waste	learning (artificial intelligence), environmental science computing, recycling, Internet of Things, waste management, refuse disposal, deep learning (artificial intelligence), image classification, waste disposal, regression analysis, artificial intelligence, waste recovery, waste reduction	learning (artificial intelligence), recycling, deep learning (artificial intelligence), waste management, Internet of Things, waste disposal, artificial intelligence, object detection, waste recovery, waste handling, feature extraction, waste reduction, industrial waste, municipal solid waste	geographic information systems, remote sensing, coal, environmental factors

Results and discussion

The analysis reveals an exponential increase in AI applications in environmental engineering over the past decade, particularly from 2018 (Figure 1). The primary application area is energy (40%), with notable trends in forecasting models, such as those for wind turbine energy production [17], energy consumption [18], and renewable energy generation [19]. Important studies on IA applications in energy management systems that propose environmental solutions are also found [20]-[21].

The second area of high IA publications in environmental engineering is air, representing 21% of the total. These applications include proposals based on pollution and quality data monitoring [22]-[23]. Additionally, water ranked third in the literature search, with publications such as monitoring and predictive models of water quality [24]-[25].

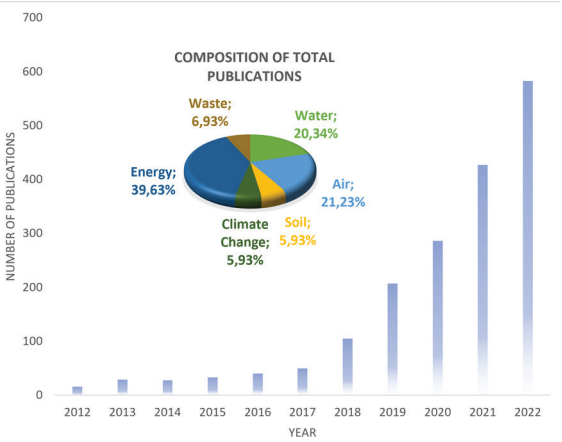

Figure 1. Number of publications of AI applications in environmental engineering found in IEEE Xplore Digital Library (access date: 08/26/2023). The inset shows the areas' composition of the total number of articles.

Figure 2 depicts the exponential growth in Machine Learning applications in environmental engineering, with a noticeable acceleration since 2018. These publications predominantly focus on energy (33%), air quality (25%), and water quality (19%).

In the energy sector, ML has been applied to enhance energy management and predict consumption for homes, buildings, and cities [26]-[32], including renewable energy sources [33]-[35]. For air quality, ML is applied to predict air pollution [36]-[40], often integrated with the Internet of Things (IoT) [41]-[43]. Other studies explore the link between air pollutants and diseases using ML [44]-[45]. Technical aspects of ML algorithms for air pollution prediction have been reviewed [46]. Water quality applications involve the use of IoT and ML for real-time monitoring and prediction [47]-[51]. Algorithms for river quality assessment have been developed [52]-[53], and ML is applied to analyze drinking water quality [54]-[57]. Gai and Yang [58] provide a comprehensive review of ML-based water quality prediction methods and discuss future trends.

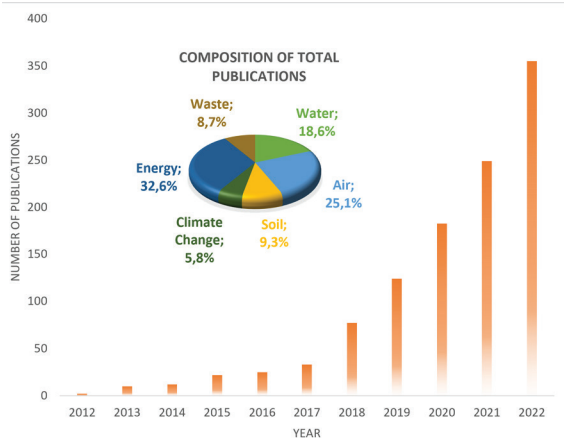

Figure 2. Number of publications of ML applications in environmental engineering found in IEEE Xplore Digital Library (access date: 08/26/2023). The inset shows the areas' composition of the total number of articles.

Regarding the trend in the number of publications in the database on applications of Geographic Information Systems (figure 3), this did not present an exponential growth as in the case of AI and ML. There was only a significant increase between the years 2018-2021. The water area

had the most publications (54%), with research on monitoring of water quality and prediction systems [59]-[60]. The energy area was the second highest incidence (15%), where GIS have been used largely for the selection of optimal locations for renewable energy systems [61]-[62].

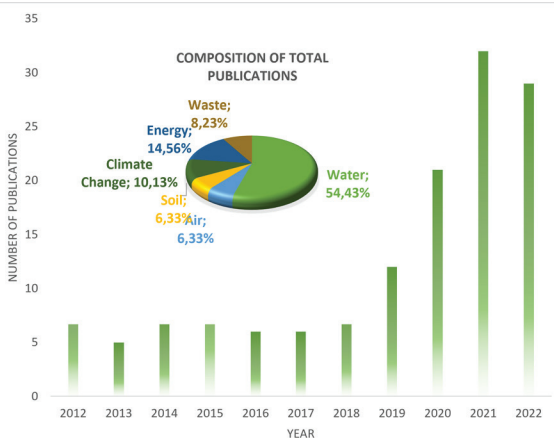

Figure 3. Number of publications of GIS applications in environmental engineering found in IEEE Xplore Digital Library (access date: 08/26/2023). The inset shows the areas' composition of the total number of articles.

Conclusions and recommendations

In this limited but detailed review experiment by topics, tool and area of knowledge, it is shown how the management and modeling of environmental information has intensified in the last decade, heading towards the main environmental and sustainability problems of the Earth. Although it is recommended to investigate other databases to analyze trends that are not so present in IEEE and extend the research to other computational tools, the results are provided to the scientific community to strengthen investigative work initiatives within the development framework of environmental and computational engineering and global concerns.

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