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Editorial: AI and data analytics for climate data management

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Editorial on the Research Topic
AI and data analytics for climate data management

1 Introduction

The integration of data analytics and artificial intelligence (AI) is revolutionising the administration of climate data and provides a novel solution to the persistent challenges associated with environmental monitoring, remote sensing, and predictive modelling. This special collection explores the AI-driven methods for processing, integrating, and interpreting vast and diversified climate datasets with increased speed, accuracy, and reliability. Deep learning as AI enhances image classification and feature detection to enable precise mapping of land use changes and environmental anomalies in remote sensing. Machine learning facilitates the identification of trends, the modelling of complex systems, and the forecasting of extreme weather events for climate data analysis. AI also contributes to real-time monitoring, anomaly detection, and automated data validation to support decision-support systems for disaster response and policy planning. AI and data analytics are enabling a more informed, responsive, and sustainable approach to climate resilience by improving data quality, accessibility, and predictive capability in advancing environmental science and shaping climate action strategies. The integration of Artificial Intelligence (AI) and Data Analytics has transformed environmental informatics, remote sensing, and climate data management with precise, efficient, and real-time analysis of complex datasets. AI enhances environmental monitoring through deep learning for image classification, predictive modelling for climate trends, and automated anomaly detection for better data quality. These technologies support early warning systems, disaster response, and evidence-based policymaking. AI empowers sustainable land use, climate resilience, and informed decision-making along with data integration across multiple sources, including satellites and sensors (Schütze, 2024). AI and data analytics will play a vital role in forthcoming environmental science and sustainability research.

2 Background

Artificial intelligence (AI) and data analytics are useful tools for managing climate data. These technologies enable more accurate forecasting of extreme weather events, efficient tracking of emissions, and improved understanding of climate change impacts (Clarke et al., 2022). These technologies make it easier to understand climate issues and find better ways to deal with them. AI and data analytics enhance our understanding of the climate for a wide range of research and applications, like

- Predictive modelling: Use of machine learning to predict extreme weather events—like heatwaves, floods, and hurricanes—can improve disaster preparedness and response.
- Data interpretation: Processes satellite data to track climate impacts like sea level rise, vegetation changes, and ice cover loss.
- Monitoring and reduction of greenhouse gas emissions: Monitor and reduce greenhouse gases by optimising energy use and improving carbon capture methods.
- Climate adaptation: Creating adaptation strategies by identifying vulnerable areas and guiding protection plans for communities and infrastructure.
- Climate mitigation: Identifies and evaluates strategies like carbon capture, renewables, and efficiency to reduce emissions and slow climate change.
- Climate research: Enhances understanding of climate by studying ocean currents, atmospheric patterns, and regional variability.

The AI and data analytics for climate data management have a wide range of applications for mitigation and adaptation to the impacts of climate change by processing and analysing vast, complex datasets from satellites, sensors, and climate models (Huntingford et al., 2025; Schütze, 2024). It supports improved weather forecasting, real-time monitoring of environmental changes, and the development of predictive models for extreme events in building climate resilience and sustainable development strategies worldwide.

3 Research landscape of AI and data analytics for climate data management

The rising global unpredictability in the climate system stresses effective adaptation and mitigation with AI and data analytics approaches. This Research Topic, "AI and Data Analytics for Climate Data Management," highlights interdisciplinary usage of the new approaches to improve climate data analysis. The collection shows scalable, data-driven approaches for climate adaptation and sustainability to reflect the growing consensus for advancing climate resilience and guiding informed environmental policy (Saraswat and Kumar, 2016; Enríquez-de-Salamanca et al., 2017). The Research Topic emphasises shifting from reactive to predictive climate science, enhancing decision-making, early warnings, and policy worldwide. This integrates AI, machine learning, and climate science to manage and interpret complex environmental data.

4 Framing the research landscape

Climate data is complex, large-scale, and diverse, and it makes traditional approaches difficult to work efficiently with data from satellites, sensors, and climate models. However, challenges like model transparency, data quality, interpretability, and ethical concerns persist. AI expands efficiency to reveal hidden patterns in vast datasets (Wang et al., 2023; Weber et al., 2022; Li et al., 2024). The studies in this Research Topic show the issues and innovative approaches for climate science, practical applications, domain adaptation, and use-case demonstration.

5 Contributions in this topic

Machine learning models improve climate forecasts, and AI-driven fusion techniques consolidate data from satellites, sensors, and simulations. Remote sensing analysis supports tracking environmental changes, like deforestation and extreme weather (Clarke et al., 2022; Ya'acob et al., 2014; Cui et al., 2019). Open platforms democratize access to climate data and models for climate data management with enhanced prediction accuracy for real-time monitoring. These studies highlight how artificial intelligence has advanced climate science with the integration of environmental data, computational techniques, and policy-relevant applications. The theme comprises the following research collection for interdisciplinary integration.

5.1 Leveraging machine learning algorithms for improved disaster preparedness and response through accurate weather pattern and natural disaster prediction

This paper explores how machine learning enhances disaster preparation by accurately forecasting extreme weather and natural catastrophes like heatwaves, floods, and hurricanes. It demonstrates ML's advanced predictive capabilities and practical applications, offering insights that improve response systems. These accurate predictions enable governments and communities to take proactive measures, ultimately saving lives and minimizing damage.

5.2 Hydrogeochemical characterization and quality assessment of groundwater resources in the Upper-Doab region of Uttar Pradesh, India

This study maps groundwater quality in Uttar Pradesh's Upper-Doab region using physicochemical data and indices (WAWQI, CGQII) for domestic and irrigation suitability. It finds groundwater affected by urbanisation, with dominant Ca-Mg-HCO3 and Ca-Na-HCO_3 types controlled by rock-water interaction. Human activities link high nitrate and conductivity to poor quality in several districts. The study highlights the need for stricter industrial discharge control, reduced fertilizer use, and regular monitoring to ensure sustainable groundwater management.

5.3 Novel discrete grey Bernoulli seasonal model with a time power term for predicting monthly carbon dioxide emissions in the United States

A new forecasting method was developed to capture nonlinear, seasonal trends in monthly carbon dioxide emissions in the U.S. using two tuning terms (Bernoulli and time-power) and dummy variables to handle seasonality directly. Its parameters are optimised via the Marine Predators Algorithm (MPA). Trained on data from January 2003 through December 2020 and tested on 2021–2022 emissions, the model demonstrated better forecasting accuracy than traditional approaches like SARIMA, thanks to its simplicity and effectiveness in modelling both seasonality and nonlinear dynamics.

5.4 Digital government and carbon emissions: evidence from China

Digital government development in China significantly reduces carbon emissions, and this remains robust across statistical tests. It cuts emissions by helping to upgrade industrial structures and boost green innovation. The effect is strongest in eastern and central provinces and where there's greater government transparency, advanced digital government systems, and stricter environmental regulation.

5.5 Enhanced defluorination by nano-crystalline alum-doped hydroxyapatite and artificial intelligence (AI) modelling approach

A study investigated the fluoride removal capabilities of nano-hydroxyapatite (HAP) and alum-doped hydroxyapatite (AHAP) as eco-friendly adsorbents. Under acidic conditions (pH 2), AHAP removed up to 83% of fluoride, while HAP removed 74%. Alum doping enhanced AHAP's surface chemistry, improving its fluoride adsorption affinity. The adsorption process followed pseudo-second-order kinetics and Langmuir isotherm models. Thermodynamic analysis indicated a spontaneous and endothermic adsorption process. Additionally, an artificial neural network (ANN) model using MATLAB was employed to simulate AHAP's fluoride removal efficiency. The study concludes that AHAP is an effective adsorbent for defluorination.

5.6 Integrated flood risk assessment in Hunza-Nagar, Pakistan: unifying big climate data analytics and multi-criteria decision-making with GIS

A study assessed flood risk in Pakistan's Hunza-Nagar Valley using GIS-based Multi-Criteria Decision Analysis (MCDA) and climate data. Nine factors were considered: rainfall, temperature variation, proximity to rivers, elevation, slope, Normalized difference vegetation index (NDVI), topographic wetness index (TWI), land use, and soil type. The Analytical Hierarchy Process (AHP) weighed these factors, revealing that rainfall, distance to rivers, elevation, and slope were most influential. The resulting flood hazard map categorised areas as very high (6%), high (36%), moderate (41%), low (16%), and very low (1%) risk. The model demonstrated 77.3% accuracy (AUC = 0.773), aiding disaster preparedness in the region.

5.7 Assessing the effectiveness of national parks' policies and laws in promoting biodiversity conservation and ecological development in Pakistan

A study assessed the effectiveness of national park policies in Pakistan, focusing on 19 parks. Data from 300 participants were analysed using Smart Partial Least Squares (PLS) software. Findings indicate that policies promoting recreation, tourism, and research are more effective than those aimed at preserving ecological processes. The study recommends revising laws to better protect biodiversity and water resources, emphasising the need for awareness campaigns and sustainable tourism practices. It also highlights challenges such as limited stakeholder analysis and bureaucratic structures, suggesting the need for a dynamic approach to ecological policymaking.

5.8 Predicting climate change using an autoregressive long short-term memory model

A study developed a machine learning model using an autoregressive long short-term memory (LSTM) network to predict climate patterns. Trained on the ERA5 dataset, the model demonstrated the ability to forecast long-term climate trends and seasonal variations. While it achieved reasonable accuracy over extended periods, some limitations were noted, such as challenges in capturing smaller regional patterns and potential underfitting. The study suggests that enhancing model complexity and incorporating Explainable AI tools could improve performance and interpretability.

5.9 Assessing the existing guidelines of environmental impact assessment and mitigation measures for future hydropower projects in Pakistan

A study assessing Environmental Impact Assessment (EIA) practices for hydropower projects in Pakistan revealed several challenges. While donors like the Asian Development Bank support EIA implementation, over 20% of decision-makers questioned compliance with EIA frameworks, and 25% noted misalignment with international standards. Limited resources reduce EIA's influence on decisions. Recommendations include establishing expert think tanks, enhancing public awareness, and providing international training for authorities like WAPDA to improve future hydropower project assessments.

6 Other dimensions in climate data management

These innovations empower researchers, governments, and industries to make informed, data-driven decisions for climate adaptation, mitigation, and sustainable development. The contributions may span a wide range of domains within climate data management, like:

- Climate prediction and forecasting: Use machine learning to improve local and regional predictions of temperature extremes, rainfall, and droughts, enhancing short- and medium-term forecasts for risk mitigation.
- Remote sensing and land monitoring: AI frameworks to analyse satellite imagery to track land changes, heat islands, and vegetation shifts, enhancing spatial resolution and classification for detailed environmental monitoring.
- Data integration and uncertainty modelling: Combine diverse datasets using ensemble methods and deep learning to reduce uncertainty and enhance model robustness.
- Climate-informed decision support systems: AI tools to support urban planning, agriculture, water management, and disaster preparedness, highlighting their practical and policy impact.

7 Challenges in broader context and future outlook for climate data management

Climate data management faces challenges such as fragmented data sources, inconsistent standards, and limited access, especially in developing regions. These issues hinder effective integration and analysis to impact climate modelling and decision-making. It emphasises the need for standardised data formats, improved accessibility, and enhanced collaboration among stakeholders. Initiatives like the European Commission's "Destination Earth" project aim to create detailed digital twins of Earth to integrate, model, and simulate the planet's systems for proactive climate change mitigation and adaptation strategies.

8 Conclusion

TThe integration of artificial intelligence (AI) into climate data management has greatly enhanced our ability to tackle climate change challenges. However, it must evolve responsibly and inclusively for AI to be effective and equitable. This involves developing open-access datasets to ensure the model transparency, and investment in capacity building for the region's most vulnerable to climate impacts. Future research areas include explainable AI for climate models, edge AI for sensor-based climate monitoring, and the integration of AI with climate-resilient infrastructure planning. Moreover, deeper engagement with citizen science and participatory data platforms can help amplify local knowledge and foster community-based adaptation.

Author contributions

DK: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. SS: Data curation, Project administration, Resources, Writing – review and editing. TT: Data curation, Formal Analysis, Resources, Software, Visualization, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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