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Editorial

Artificial intelligence is transforming the research paradigm of environmental science and engineering

Artificial intelligence (AI), particularly through its data-crunching powerhouse, machine learning (ML), is revolutionizing the way we approach high-throughput data to obtain underlying mechanisms, characterizing, forecasting, and making evidence-based decisions in many fundamental science disciplines. However, a pressing question has emerged in the scientific community in recent years: How can we effectively interpret AI algorithms and gauge their contributions to fundamental research? This query is especially pertinent in the field of Environmental Science and Engineering (ESE), where the application of these novel scientific tools to specific research challenges is complicated by the limited number of environmental scientists proficient in AI methodologies. Moreover, the complexity and often opaque nature of many contemporary AI algorithms pose additional hurdles. These challenges make it difficult for ESE researchers to select appropriate algorithms at the outset, potentially hindering the efficient and effective application of AI in addressing their research problems. But where there is a challenge, there is an opportunity. ESE has the potential to capitalize on its existing domain knowledge and emerging AI capabilities to fuel the sustainable booming of the entire discipline in fantastic ways a very short time ago. At *Environmental Science and Ecotechnology*, we have curated a virtual special issue (VSI) of high-quality research, with ten original research articles selected. This VSI is dedicated to shed light on the infusion of AI into ESE, enabling the research and practice community to better understand how data science and information techniques can help in making predictions, extracting features, detecting anomalies, discovering properties, and other critical functionalities in broad ESE studies.

Air pollution is one of the greatest environmental risks to health. Therefore, outdoor air quality monitoring assumes a critical role and mainly depends on measurements from ground stations. Ground station-based monitoring is the most common measure as it has high precision and stability. However, their widespread deployment is hindered by the prohibitive costs associated with their sophisticated instrumentation, limiting the expanse of monitoring coverage. Also, forecasting the outdoor air quality trajectories requires collecting tremendous amounts of data on many different environmental variables; however, dealing with such a huge dataset is a big challenge. To solve this problem, one research article [1] develops an AI technique that combines a convolutional neural network and a long short-term memory algorithm (CNN-LSTM) and estimates outdoor air quality based on real-time surveillance images. Their experimental results demonstrate that the developed CNN-LSTM model exhibits commendable performance in daytime air quality estimation while markedly advancing night-time air quality predictions, thereby improving the overall estimation accuracy.

Catalysis is one of the most effective and economical technologies to mineralize refractory water contaminants completely. Despite this, it remains challenging to develop high-efficiency catalytic materials. The performance of a catalyst depends on various properties, including its composition, support, surface termination, particle size, particle morphology, atomic coordination environment, porous structure, and the dynamics within the reactor during the reaction among others. The inherent complexity of catalysis makes discovering and designing catalytic materials with favorable properties more dependent on intuition and experiment, which is costly and time-consuming. One research article [2] indicates that ML algorithms, such as artificial neural networks, when integrated with experimental and high-throughput screening technologies like fluorescence spectroscopy, can accelerate catalyst discovery by revealing the complex interactions between catalytic structure and catalytic performance. With this approach, researchers can build virtual laboratories to develop new catalysts and catalytic processes for advanced water purification and wastewater treatment.

Currently, AI has demonstrated superior performance over human capabilities in various well-defined tasks. For example, AI can aid the planning, design, operation, assessment, and anomaly detection of urban water systems thanks to its scalability and capacity to capture underlying patterns within large datasets, making it highly relevant in numerous applications. Two research articles [3,4] highlight the robustness and potential of AI-based techniques in detecting contamination events in water distribution systems and determining urban residential water consumption patterns, considering varying uncertainties in real-world situations. The other two studies [5,6] focus on the development of ML algorithms for modeling and forecasting performances of integrated water systems. Both claim emerging AI tools provide exciting opportunities to depict the complex interactions between ecological and artificial water purification processes. In recent years, waterborne viral epidemics have become a major threat to global public health. Increasing interest in wastewater reclamation makes understanding the health risks associated with potential microbial hazards important, particularly for reused water in direct contact with humans. One research article [7] emphasizes the identification of the viral epidemic patterns throughout municipal wastewater reclamation based on long-term, spatially explicit global literature data and model human health risks originating from multiple exposure pathways. This study advances our understanding of how massive literature data can be combined and repurposed to address emerging public health concerns encountered in urban water management.

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Over the past decades, ESE researchers have diligently endeavored to reveal and interpret the underlying mechanisms related to contaminant degradation and resource recovery processes. For example, the algal community structure is vital for aquatic ecosystem management. However, the complicated environmental and biological processes make modeling challenging. One research article [8] highlights the power of ML techniques in predicting complex algal community structures and provides insights into the model interpretability. Another example relates to the gas-to-particle conversion of airborne contaminants. It is well known that particulate nitrate is an essential component of fine particles. The gas-to-particle conversion plays a crucial role in regulating nitrate. The highly nonlinear relationships between the gas-to-particle conversion coefficient of nitrate and its drivers can be characterized by ML methods. However, common ML algorithms often yield results that are challenging to interpret since results lack evident physical meaning and even contradict physical/chemical mechanisms due to disturbance of ambient factors. The other study [9] proposes a new supervised ML algorithm (i.e., multilevel nested random forest guided by theory approach) to better interpret the effect by obtaining physically meaningful results. Waste valorization has been a research hotspot in recent years. An example of this is the utilization of xylanase for digesting corn straw, which facilitates the extraction of polysaccharides and promotes effective agricultural waste management. However, various combinations of enzymatic process variables indicate distinct effects on polysaccharide yield. An article [10] reports an ML-based modeling approach for understanding the complex effects of multiple variables and offering a reference for optimizing enzymatic polysaccharide production.

In short, we hope and believe that these high-quality articles will motivate environmental researchers to deeply understand the state-of-the-art applications of AI tools in dealing with different aspects of ESE, thereby promoting the continuous development of the discipline. Taking the present VSI as a starting point, we look forward to more publications on exciting breakthroughs and practical experiences of environmental intelligence in *Environmental Science and Ecotechnology*.

References

[1] X. Wang, M. Wang, X. Liu, Y. Mao, Y. Chen, S. Dai, Surveillance-image-based outdoor air quality monitoring, Environ.Sci. Ecotechnol. 18 (2024) 100319.

[2] M. Li, L. Fu, L. Deng, Y. Hu, Y. Yuan, C. Wu, A tailored and rapid approach for ozonation catalyst design, Environ.Sci. Ecotechnol. 15 (2023) 100244.

[3] Z. Li, H. Liu, C. Zhang, G. Fu, Generative adversarial networks for detecting contamination events in water distribution systems using multi-parameter, multi-site water quality monitoring, Environ.Sci. Ecotechnol. 14 (2023) 100231.

[4] J. Zhang, D. Savic, Q. Xu, K. Liu, Z. Qiang, Poisson rectangular pulse (PRP) model establishment based on uncertainty analysis of urban residential water consumption patterns, Environ.Sci. Ecotechnol. 18 (2024) 100317.

[5] B. Yang, Z. Xiao, Q. Meng, Y. Yuan, W. Wang, H. Wang, Y. Wang, X. Feng, Deep learning-based prediction of effluent quality of a constructed wetland, Environ.Sci. Ecotechnol. 13 (2023) 100207.

[6] Y. Li, L. Ma, J. Huang, M. Disse, W. Zhan, L. Li, T. Zhang, H. Sun, Y. Tian, Machine learning parallel system for integrated process-model calibration and accuracy enhancement in sewer-river system, Environ.Sci. Ecotechnol. 18 (2024) 100320.

[7] J.-X. Ma, X. Wang, Y.-R. Pan, Z.-Y. Wang, X. Guo, J. Liu, N.-Q. Ren, D. Butler, Data-driven systematic analysis of waterborne viruses and health risks during the wastewater reclamation process, Environ.Sci. Ecotechnol. 19 (2024) 100328.

[8] M. Liu, Y. Huang, J. Hu, J. He, X. Xiao, Algal community structure prediction by machine learning, Environ.Sci. Ecotechnol. 14 (2023) 100233.

[9] B. Xu, H. Yu, Z. Shi, J. Liu, Y. Wei, Z. Zhang, Y. Huangfu, H. Xu, Y. Li, L. Zhang, Y. Feng, G. Shi, Knowledge-guided machine learning reveals pivotal drivers for gas-to-particle conversion of atmospheric nitrate, Environ.Sci. Ecotechnol. 19 (2024) 100333.

[10] Y. Tian, X. Yang, N. Chen, C. Li, W. Yang, Data-driven interpretable analysis for polysaccharide yield prediction, Environ.Sci. Ecotechnol. 19 (2024) 100321.

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