

Editorial

Sustainable Water and Environmental Technologies of Global Relevance

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These are uncertain political and socio-economic times worldwide. The pressure on engineers and scientists to come up with new technological solutions to support society in addressing urgent water and environmental challenges is high. Some examples include the sustainable management of water and environmental resources, optimal water use in agricultural engineering, nature-based solutions for pollution control and wastewater treatment, software-driven decision support systems, storm water management to enhance flood control, sustainable energy mixes, photovoltaics, climate change adaptation measures and advanced artificial intelligence applications.

Therefore, this Special Issue on ‘Sustainable Water and Environmental Technologies of Global Relevance’ aimed to promote promising solutions to these complex international challenges. The highlighted original solutions (Contributions 1–9) had international applications and advanced at least one United Nations Sustainable Development Goal, such as clean water and sanitation, affordable and clean energy, sustainable cities and communities, and climate action.

This Special Issue provided an advanced forum for both researchers and professionals in water and environmental technologies to share and discuss the latest knowledge in technological studies. The technologies that were particularly targeted relate to monitoring, conservation or modeling-related advances associated with the Internet of Things, neural networks and machine learning. This Issue published timely communications of current and future global relevance, each with a clear soft and/or hard technology focus.

Engineers and scientists were invited to publish their technology-based experimental results and theoretical findings in as much detail as reasonably possible. Therefore, there was no restriction on the maximum length of submissions. Full experimental details were provided so that the results can be reproduced (Contributions 1–9). Software, technological drawings and experimental procedures were also published.

Six original research articles covered sustainable water technology advances. Vázquez-Cornejo et al. (Contribution 1) investigated the structure–performance relationship of Fe³⁺- and Zr⁴⁺-modified layered double hydroxides for fluoride removal from water. Mg–Al-layered double hydroxides with different metal loadings (Zr0.05, Zr0.1, Fe0.8 and Fe1) were synthesized. Among the synthesized materials, Zr0.05-layered double hydroxides exhibited the highest adsorption performance. Response surface methodology identified adsorbent dosage as the most influential parameter. Zr0.05-layered double hydroxides showed the largest specific surface area and a maximum adsorption capacity. Kinetic studies indicated rapid adsorption. Fluoride removal was governed primarily by inner-sphere complexation at Zr⁴⁺ and Fe³⁺ sites, accompanied by anion exchange and electrostatic interactions.



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Groundwater tests from Durango (Mexico) demonstrated effective fluoride reduction below Mexican and World Health Organization guideline limits, despite competing anions. These results demonstrate the potential of modified layered double hydroxides for fluoride-contaminated groundwater treatment (Contribution 1).

Caicedo Escorcia et al. (Contribution 2) highlighted that water quality monitoring is a critical challenge for achieving Sustainable Development Goal 6, particularly in rural and resource-constrained environments where conventional laboratory-based methods are costly and slow. They presented the development and field validation of an artificial intelligent ecosystem for intelligent, low-cost and real-time water quality assessment using edge computing and generative artificial intelligence.

Their new artificially intelligent system integrates a laboratory-developed multiparameter probe measuring temperature, pH, dissolved oxygen, and electrical conductivity with a mobile application and a cloud-based backend. Field validation was conducted in riverine environments in a municipality located in Colombia, where the system was deployed for in situ data acquisition and real-time inference. The best-performing model achieved 85% accuracy. Integration with a generative artificial intelligence backend provides contextual natural-language interpretations of measurements (Contribution 2).

Khamkure et al. (Contribution 3) stated that arsenic contamination demands innovative and sustainable remediation. Their study presents a fuzzy approach for synthesizing a magnetic biochar nanocomposite from pecan shell agricultural waste for efficient arsenic removal. Using a multi-input fuzzy rule emulated network, a systematic investigation of the synthesis process revealed that precursor type (biochar), Fe-precursor ratio (1:1) and iron salt type were the most significant parameters governing material crystallinity and adsorption performance, while particle size and N₂ atmosphere had minimal effects. The network-identified optimal material, the magnetic biochar composite, achieved >90% arsenic removal, outperforming the least efficient sample by 51%. Kinetic analysis confirmed chemisorption on a heterogeneous surface. Regeneration studies demonstrated high stability. Desorption occurs via ion exchange and electrostatic repulsion, with post-use analysis confirming structural integrity and resistance to oxidation.

Application to real groundwater proved highly effective (Contribution 3). The biochar composite maintained selectivity despite competing ions. By integrating artificial intelligence-driven optimization with reusability and real contaminated water, this study established a scalable framework for transforming agricultural waste into a high-performance adsorbent, supporting global clean water and sanitation goals.

Refadah et al. (Contribution 4) claimed that artificial neural networks offer considerable advantages in predicting evaporation, particularly in handling nonlinear relationships and complex interactions among factors like soil surface temperature and wind speed. In Al Medina (Saudi Arabia), the connections among wind speed, soil surface temperature at 5 cm, soil surface temperature at 10 cm and evaporation have been successfully modeled using an artificial neural network.

This study demonstrates the practical effectiveness and applicability of the approach in simulating complex nonlinear dynamics in real-life systems. The networks were further refined through the enumeration technique, ultimately selecting the most efficient network for forecasting evaporation values (Contribution 4).

The management of modern water supply systems requires a detailed analysis of consumption patterns to optimize pump operation schedules, reduce energy costs and support the development of intelligent management systems (Contribution 5). Kapanski et al. developed and validated a non-parametric method for clustering daily water consumption profiles. The proposed approach includes the automatic optimization of neighborhood radius and the minimum number of points required to form a cluster.

The model input data consisted of half-hourly water supply and electricity consumption values for the water supply system of Gomel (Republic of Belarus), supplemented with the time-of-day factor. As a result of the multidimensional clustering, two stable regimes were identified: a high-demand regime (6:30–22:30), covering about 46% of the data and accounting for more than half of the total water supply and electricity consumption, and a low-demand regime (0:30–6:00), representing about 21% of the data and forming around 15% of the resources. The obtained results make it possible to define the temporal boundaries of the regimes and to use them for data labeling in the development of predictive water consumption models (Contribution 5).

Finally, Bernabé et al. (Contribution 6) state that the modernization of irrigation networks has enhanced water use efficiency but increased energy demand and costs in agriculture. Energy recovery is possible by utilizing excess pressure to generate electricity with pumps used as turbines, offering a cost-effective alternative to traditional turbines. They successfully assessed the use of pumps as turbines in pressurized irrigation networks for recovering wasted hydraulic energy, employing the particle swarm optimization algorithm for pumps used as turbine sizing based on two single-objective functions.

The analysis focused on minimizing the payback period and maximizing energy recovery at specific excess pressure points. A sensitivity analysis on energy prices and installation costs was also performed to assess socioeconomic trends and volatility, examining their effects on both objective functions (Contribution 6).

Three original research articles and one review paper covered sustainable environmental technologies. Jiménez Borges et al. (Contribution 7) emphasized that the transition to sustainable energy systems in the agro-industrial sector requires rigorous methodologies that enable a comprehensive and quantitative assessment of the technical and economic viability and environmental impact of photovoltaic integration. They developed and validated a hybrid multi-criteria methodology structured in three phases: (i) analytical modeling of the load profile and preliminary sizing; (ii) advanced energy simulation for operational optimization and validation against empirical data; and (iii) environmental assessment using a life cycle analysis.

This novel methodology was applied to a Cuban agro-industrial plant. The robustness of the model was validated by comparison with historical records. Findings indicate a scientifically sound, replicable and adaptable tool for decision-making in advanced energy projects (Contribution 7).

Bouali et al. (Contribution 8) investigated the enhancement of $\text{Cu}_2\text{MnSnS}_4$ thin films' photocatalytic properties through potassium doping for rhodamine B degradation under visible light. Potassium-doped $\text{Cu}_2\text{MnSnS}_4$ films synthesized using spray pyrolysis technology achieved a 98% degradation efficiency within 120 min. The physical property improvements were quantitatively validated through X-ray diffraction analysis, which confirmed enhanced crystallinity. Scanning electron microscopy revealed significant modifications in surface morphology as a function of potassium content, highlighting its influence on film growth dynamics.

Optical characterization demonstrated a pronounced reduction in transmittance, suggesting superior light absorption capabilities. Photocatalytic performance was significantly enhanced. These enhancements collectively improved the material's light-harvesting capabilities and charge separation efficiency, positioning potassium-doped $\text{Cu}_2\text{MnSnS}_4$ as a highly effective photocatalyst (Contribution 8).

Furthermore, a synthesis and characterization of undoped and samarium-doped $\text{CuO-SnO}_2\text{:F}$ thin films using the spray pyrolysis technique was presented by Charrada et al. (Contribution 9). The effect of the samarium doping level on the physical properties of these films was thoroughly analyzed. X-ray diffraction patterns proved the successful

synthesis of pure CuO–SnO₂:F thin films, free from detectable impurities. The smallest crystallite size was observed in 6% Sm-doped CuO–SnO₂:F thin films. The 6% Sm-doped CuO–SnO₂ films demonstrated an increased surface area, highlighting improved textural properties, which was further validated by XPS analysis. Photoluminescence spectra revealed various emission peaks, suggesting a quenching effect.

A numerical simulation of a new solar cell based on FTO/ZnO/Sm–CuO–SnO₂:F/X/Mo was carried out by Charrada et al. using Silvaco Atlas software, where X represented an absorber layer. The results showed that the solar cell with an absorber layer based on copper, indium, gallium and selenide achieved the highest efficiency. Additionally, the thin films demonstrated strong photocatalytic performance. This investigation provided insights into the synthesis, properties and potential applications of Sm-doped CuO–SnO₂ thin films, particularly for solar energy and pharmaceutical applications (Contribution 9).

Finally, Quintella et al. (Contribution 10) highlighted in their review that the transition to a sustainable energy mix is essential to mitigate climate change. Enhanced oil recovery using low-salinity water has emerged as a promising strategy for reducing environmental impacts in the petroleum industry, producing a highly valuable energy source due to both its energy density and market value. The researchers critically reviewed intermediate technological readiness levels, applying a patent-based approach and a review of articles to analyze various aspects of smart water for enhanced oil recovery, including its composition. Patents from the European Patent Office and articles from Elsevier's Scopus database were analyzed, considering annual trends, country distribution, international collaborations, author and applicant affiliations, citation dependencies and factorial analyses. Both patents and articles show exponential growth. However, international collaboration is more frequent in the scientific literature, while patents remain concentrated in a few countries aligned with their markets.

Identified technologies are focused on, for example, wettability, surface complexation, carbon dioxide interactions, emulsification, aerogels, reinjection water treatment, carbonate reservoirs, effluent treatment and nano-fluidics. Recent topics include carbon dioxide associations, permeability, fractured reservoirs, gels, reservoir water, wettability alteration, and reservoir/oil heterogeneity. The findings indicate the need for multi-variate development of customized low-salinity waters to address complex interfacial synergistic mechanisms. International Joint Industry Projects and global regulations on the safe use and composition of hybrid injections are recommended to accelerate development, reduce environmental impacts, and enhance the efficient use of existing fields, alleviating the challenges of finding new reservoirs (Contribution 10).

In conclusion, the Special Issue supported original research in nine areas. Sustainable water technology advanced fluoride-contaminated groundwater treatment, intelligent water quality assessments, arsenic removal, evaporation prediction, clustering of water consumption profiles and the use of pumps as turbines in irrigation networks. Moreover, new environmental technology enhanced decision-making concerning the impact of photovoltaic integration, thin film photocatalytic properties, and the synthesis of undoped and samarium-doped CuO–SnO₂:F thin films.

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List of Contributions

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