# Advancing climate resilience through nature-based solutions within the water circular economy

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Climate change mitigation and adaptation require integrated approaches that simultaneously address environmental degradation, resource efficiency, economic feasibility, and societal resilience. Nature-Based Solutions (NbS) have gained increasing attention as effective strategies for enhancing climate resilience while delivering multiple co-benefits, including improved water management, biodiversity conservation, ecosystem services, and carbon sequestration. In parallel, the valorisation of waste-derived materials represents a key pillar of the water circular economy, offering opportunities to reduce resource consumption, lower environmental impacts, and improve the cost-effectiveness of water-related interventions.

This study investigates the integration of waste-derived materials into water-related Nature-Based Solutions within the framework of the water circular economy. Waste materials originating from urban, agricultural, and industrial streams are incorporated into NbS applications such as water retention systems, filtration media, and nature-based treatment solutions. The combined use of natural processes and secondary raw materials enhances functional performance while promoting material circularity and reducing reliance on virgin resources.

To assess the economic feasibility of these solutions, a structured cost–benefit data collection approach is applied, based on the systematic review of scientific literature and selected sources. Key economic parameters, including capital expenditure (CAPEX), operational expenditure (OPEX), opportunity costs, benefit–cost ratios (BCR), and net present value (NPV), are analysed where data availability allows. Where sufficient information is available, comparative assessments of NbS and conventional grey infrastructure are conducted to highlight their relative economic performance and long-term value. The analysis prioritises European case studies, complemented by selected international examples where necessary.

In addition to economic performance, the carbon sequestration potential of the investigated NbS types is considered, based on their capacity to support vegetation growth and soil stabilisation. Solutions that enhance aboveground and belowground biomass contribute to long-term carbon storage and reduced greenhouse gas emissions, strengthening the climate mitigation potential of water-related NbS.

Table 1 provides an overview of representative waste-derived materials integrated into Nature-Based Solutions, highlighting their functional roles within the water circular economy and their contribution to climate resilience.

Table 1. Integration of waste-derived materials in water-related nature-based solutions

| No. | Waste-Derived Materials | NbS Application | Function in Water Circular Economy | References |
|---|---|---|---|---|
| 1 | Biochar from agricultural waste | Constructed wetlands | Pollutant adsorption and water reuse | (Cui *et al.*, 2022) |
| 2 | Compost from organic waste | Soil-based NbS | Nutrient recovery and water retention | (Rodrigues, Dias and Nunes, 2024) |
| 3 | Recycled concrete aggregates | Urban water retention systems | Stormwater management and flood mitigation | (Pitropova *et al.*, 2025) |
| 4 | Industrial by-product slag | Permeable reactive barriers | Heavy metal removal from water | (Deng *et al.*, 2026) |
| 5 | Waste-derived activated carbon | Nature-based filtration systems | Advanced water treatment and reuse | (Zuhara and McKay, 2024) |
| 6 | Agricultural residues (straw, husks) | Green infrastructure substrates | Enhanced infiltration and evapotranspiration | (Cao *et al.*, 2012) |
| 7 | Sewage sludge biochar | NbS for wastewater polishing | Nutrient capture and circular reuse | (Kenchannavar and Surenjan, 2022) |
| 8 | Recycled glass media | Nature-based filtration beds | Improved hydraulic performance and reuse | (Ahmad *et al.*, 2025) |

The research demonstrates that integrating waste-derived materials into NbS can simultaneously enhance environmental performance, economic viability, and climate resilience, thereby supporting sustainable and circular water management strategies.

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