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Sustainable water–energy–land–food nexus in BRICS agriculture: evaluating technological adaptation and climate-resilient practices for enhanced food security

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Abstract

Growing climatic unpredictability and resource scarcity threaten food security in rapidly developing nations. The study examines the water, energy, land, and food (WELF) nexus in BRICS (Brazil, Russia, India, China, and South Africa) agriculture. It investigates the dynamic effects of freshwater withdrawal (FWW), primary energy use (PEU), land use availability (LUA), and carbon emissions (CO_2) on food security (FC) through a panel quantile regression method using data from 2010 to 2022. Moreover, it examines the moderation effects of digital adaptation on the relationship between FWW, PEU, LUA, and CO_2 with food security among the BRICS countries. While nexus techniques are frequently investigated, their interplay with technological adoption in BRICS agriculture remains

underexplored. Key results show: (1) Freshwater availability is vital for high-yield regions, while unsustainable irrigation practices threaten long-term resilience, especially where rising temperatures surpass crop tolerances and carbon emissions worsen productivity declines. (2) Fertilizer use significantly boosts output in low-productivity areas; however, its benefits diminish in advanced agricultural systems, underlining the need for precision nutrient management aligned with sustainable intensification principles. (3) Digital adaptation alters the relationships between food security and water resources management, emphasizing the necessity for integrated technology and policy solutions. The study advances WELF nexus theory by integrating Climate-Smart Agriculture, demonstrating how BRICS nations can balance trade-offs through targeted policies: climate-smart practices, and technology-integrated resource management. These findings provide actionable pathways to synchronize food production, environmental sustainability, and socioeconomic growth under CO_2 conditions. © The Author(s) 2026.

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Abstract

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