LAND-WATER-ENERGY NEXUS AND RESOURCE MANAGEMENT IN EMERGING HIGH WATER STRESS ECONOMIES: EVIDENCE FROM INDIA, PAKISTAN, EGYPT, SOUTH AFRICA, AND TURKEY

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Abstract. Addressing water scarcity while managing land and energy resources is a growing sustainability challenge for emerging economies. This study investigates the dynamics of the Land-Water-Energy (LWE) nexus from 2000 to 2021 in Emerging High Water Stress Economies (EHWSE), focusing on India, Pakistan, Egypt, South Africa, and Turkey. Using the Method of Moments Quantile Regression (MMQR), the analysis captures the heterogeneous effects of agricultural land expansion, renewable energy adoption, forest conservation, and carbon emissions on freshwater resource stress across varying intensity levels. The results reveal that agricultural land expansion and carbon emissions significantly increase water stress across all quantiles, whereas renewable energy adoption and forest area help mitigate this pressure, particularly in high-stress contexts. Robustness checks using Driscoll-Kraay standard errors confirm the consistency of these findings. To enhance national-level insights, the study also conducts country-specific Ordinary Least Squares (OLS) regressions, which further validate the direction and significance of the panel-level relationships. These findings underscore the urgent need for integrated resource management policies that promote renewable energy, protect forest ecosystems, and regulate agricultural expansion to ensure water security. Policymakers in EHWSE countries must prioritize cross-sectoral strategies to balance environmental sustainability with economic development amid escalating climate and resource challenges.
Keywords: *resource management, freshwater scarcity, ecological sustainability, energy transition, land use change, environmental policy*

Introduction

Water is a foundational resource for human well-being, economic development, and ecological sustainability. Yet the world faces escalating water scarcity, particularly in regions where freshwater withdrawal exceeds renewable supply limits (FAO, 2018; Zhou et al., 2024a). Rapid population growth, agricultural expansion, industrialization, and urbanization have intensified the pressure on freshwater systems, especially in emerging economies. These pressures are further magnified by climate change, which disrupts hydrological cycles and amplifies drought risks (IPCC, 2021; Zhou et al., 2024b). Addressing these challenges requires moving beyond single-sector solutions to embrace a land-water-energy (LWE) nexus approach, which recognizes the interdependencies between land management, energy consumption, environmental conservation, and water availability (Kalogiannidis et al., 2023; Zhou et al., 2024b).

While water scarcity is a growing global concern, it is most severe in Emerging High Water Stress Economies (EHWSE) such as India, Pakistan, Egypt, South Africa, and Turkey (Chen et al., 2024a,b; Feng et al., 2025). These countries are under immense

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pressure to balance economic growth with sustainable resource management. According to World Bank (2019), Pakistan and Egypt have already surpassed critical thresholds, withdrawing over 100% of their available renewable freshwater resources, signaling unsustainable water use. India consistently reports high water stress levels, while South Africa shows a worrying upward trend. Turkey, although starting with moderate stress, has experienced a steady increase over the past two decades (Li et al., 2025; Lin et al., 2025). These patterns indicate an urgent need for integrated strategies to avoid crossing ecological tipping points that could compromise long-term water security and socio-economic stability (UNEP, 2022).

In addition to water withdrawal pressures, these economies are marked by extensive agricultural land use, growing carbon emissions, and variable progress in renewable energy adoption and forest conservation (Gondo and Kolawole, 2024; Rahman et al., 2024; Shang et al., 2025). Agriculture, while essential for food security, remains a major consumer of freshwater resources, often relying on inefficient irrigation practices that intensify water depletion (FAO, 2018). Rising carbon emissions from fossil fuel-based energy systems and industrial activities contribute to environmental degradation and climate-related water stress (IEA, 2021). Conversely, renewable energy expansion and forest conservation are seen as potential solutions to mitigate these pressures by reducing fossil-water demand and enhancing ecosystem services (Pang et al., 2024; Lu et al., 2025). However, the actual effectiveness of these strategies in reducing water stress remains insufficiently examined across different levels of water scarcity severity.

To fill this gap, this study applies a Method of Moments Quantile Regression (MMQR) to assess the heterogeneous impacts of agricultural land expansion, renewable energy use, forest area conservation, and carbon emissions on water stress in India, Pakistan, Egypt, South Africa, and Turkey over the period 2000–2021. Specifically, this study seeks to answer five critical research questions. First, to what extent does agricultural land expansion contribute to increasing water stress in Emerging High Water Stress Economies? Second, how effective is renewable energy adoption in mitigating water stress in these countries? Third, what role does forest area conservation play in alleviating water resource pressure? Fourth, how do rising carbon emissions influence water stress across different levels of severity? Finally, do these relationships vary across lower, median, and higher quantiles of water stress intensity?

Accordingly, we hypothesize that: Freshwater stress in EHWSE countries is significantly exacerbated by agricultural land expansion and carbon emissions, while forest conservation and renewable energy adoption are associated with lower water stress, particularly in regions experiencing more severe scarcity**.** This hypothesis allows the study to move beyond confirming general associations and instead capture the distributional heterogeneity of drivers across varying stress intensities. By addressing these questions, the study aims to advance both the theoretical understanding and policy relevance of the land-water-energy nexus in some of the world's most vulnerable emerging economies. The findings are expected to offer actionable insights for policymakers aiming to promote sustainable water management while supporting economic development in the face of intensifying environmental and climate challenges.

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Literature review

The land-water-energy nexus and resource security

The concept of the land-water-energy (LWE) nexus has emerged as a critical framework for understanding the interdependencies between natural resource systems and sustainable development goals (Yupanqui et al., 2025). Nexus thinking emphasizes that decisions in one sector, such as energy production, have direct and indirect impacts on water availability and land use, making cross-sectoral policy coordination essential (Albrecht et al., 2018). In the context of emerging economies, where institutional capacities are often limited and resource demands are rapidly growing, these interdependencies can exacerbate environmental stress and resource conflicts (Qiang and Jian, 2020).

Water scarcity, in particular, is increasingly influenced by land and energy policies. Agricultural land expansion and fossil fuel-based energy systems are among the primary drivers of freshwater depletion worldwide. Conversely, renewable energy technologies and sustainable land management practices offer pathways to reduce resource stress, improve ecological resilience, and support long-term sustainability. However, empirical evidence on the relative effectiveness of these strategies across different contexts remains limited, particularly in countries experiencing acute water stress.

Agricultural land use and water stress

Agriculture is the largest consumer of freshwater globally, accounting for approximately 70% of total water withdrawals. In water-scarce regions, inefficient irrigation practices and the expansion of water-intensive crops have been identified as key contributors to unsustainable water use (Raza et al., 2024). Studies have shown that countries like India and Pakistan, where agriculture dominates the economy, face significant trade-offs between food security and water sustainability (Yupanqui et al., 2025). The expansion of agricultural land in these economies often comes at the expense of ecological balance, leading to over-extraction of groundwater, soil degradation, and increased vulnerability to droughts (Fynn et al., 2023).

However, the relationship between agriculture and water stress is not uniform across all levels of water scarcity. Some studies suggest that the marginal impact of agricultural expansion on water stress intensifies as water scarcity becomes more severe (Papadopoulou et al., 2021). This highlights the need for methodological approaches that can capture these heterogeneous effects, such as quantile regression models, which provide more nuanced insights into how agricultural pressures vary across different water stress conditions (Koenker and Hallock, 2001).

Renewable energy and water resource management

The energy sector is another major driver of water use, particularly in economies reliant on thermoelectric power generation, which requires substantial water for cooling processes. In contrast, renewable energy technologies such as solar, wind, and small-scale hydropower offer low water-intensity alternatives that can help reduce pressure on freshwater systems. Several studies have highlighted the water-saving benefits of transitioning to renewable energy, particularly in arid and semi-arid regions where water scarcity is already a limiting factor for economic development (Parrique et al., 2019).

For instance, renewable energy expansion in South Africa has been linked to both climate mitigation and water conservation goals (Yang et al., 2019). Similarly, Turkey's

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investment in wind and solar energy has been recognized as a dual strategy for reducing carbon emissions and alleviating energy-water trade-offs (Pan et al., 2021). However, the extent to which renewable energy can offset water stress in highly water-stressed economies remains an open question, particularly when land and ecosystem trade-offs are considered (Lim et al., 2012). This underscores the importance of empirical investigations that assess renewable energy's role in different stages of water stress intensity.

Forest area and ecosystem services in water regulation

Forests play a critical role in regulating hydrological cycles, enhancing groundwater recharge, and maintaining water quality through ecosystem services (Esen et al., 2023). Deforestation and land degradation, however, disrupt these services, leading to increased surface runoff, soil erosion, and reduced water availability (Cardinale et al., 2012; Dwivedi et al., 2023). In countries like Brazil and Indonesia, large-scale deforestation has been directly linked to regional water shortages and declining agricultural productivity (Botsford et al., 2006).

Although the EHWSE countries in this study are not typically associated with tropical deforestation, forest degradation remains a concern, particularly in South Africa and Turkey, where forest ecosystems are under pressure from land conversion and urbanization. Forest conservation and restoration initiatives have been proposed as nature-based solutions to mitigate water stress by enhancing ecosystem resilience (Hammer et al., 2020). Yet, the quantitative impact of forest area on water stress levels, especially in arid and semi-arid regions, has not been systematically analyzed across varying water stress conditions, leaving a gap that this study aims to address.

Carbon emissions and climate-driven water stress

Rising carbon emissions are not only a driver of global climate change but also a direct contributor to regional water stress through altered precipitation patterns, increased evaporation, and intensified droughts (IPCC, 2021). High-emission economies face the dual burden of mitigating climate impacts while managing immediate water scarcity challenges. Previous studies have highlighted the feedback loops between carbon-intensive economic activities and environmental degradation in emerging economies (Steffen et al., 2015; Randers et al., 2019; Willett et al., 2019).

Empirical research indicates that the water stress impacts of carbon emissions are often non-linear and context-dependent, varying across different levels of resource vulnerability (Liu et al., 2025). This reinforces the need for analytical methods capable of capturing these distributional effects. By applying a quantile regression framework, this study seeks to provide more differentiated insights into how carbon emissions influence water stress across varying severity levels in the selected EHWSE countries.

Methodological gaps and research contribution

While the existing literature provides valuable insights into the individual components of the Land-Water-Energy (LWE) nexus, there is a notable lack of studies that simultaneously assess the combined effects of agricultural land use, renewable energy, forest conservation, and carbon emissions on water stress, particularly in highly vulnerable emerging economies. Moreover, traditional econometric approaches often focus on mean effects, overlooking the variability of these relationships across different water stress intensities.

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This study addresses these gaps by employing the Method of Moments Quantile Regression (MMQR) to capture the heterogeneous impacts of these key drivers across the full distribution of water stress levels. By focusing on India, Pakistan, Egypt, South Africa, and Turkey, the study provides empirical evidence from some of the world's most water-stressed and ecologically vulnerable economies. The findings aim to inform integrated policy frameworks that promote sustainable land, water, and energy management in the context of climate change and socio-economic development pressures.

Conceptual framework

Addressing water stress in emerging economies requires a comprehensive understanding of the interconnected drivers operating within the Land-Water-Energy (LWE) nexus. The conceptual framework of this study is built on the premise that water scarcity is not driven by isolated factors but by the combined pressures of land use dynamics, energy system transitions, ecosystem services, and environmental externalities such as carbon emissions. Drawing on the nexus literature (Weitz et al., 2017) and empirical findings from water-stressed economies, this framework positions Water Stress (FWR) as the central dependent variable, influenced by four key drivers: Agricultural Land Use (AGRL), Renewable Energy Use (RENE), Forest Area (FOR), and Carbon Emissions (CEM).

Agricultural land use and water stress

Agricultural expansion is a major contributor to increasing water demand, particularly in economies where agriculture is both an economic backbone and a heavy water consumer (Scott, 2011). The framework posits that higher agricultural land use leads to increased water stress due to irrigation demands and inefficient water management practices, especially in water-scarce regions such as India, Pakistan, and Egypt.

Renewable energy and water resource efficiency

The transition from fossil-fuel-based energy systems to renewable energy sources such as solar and wind is hypothesized to reduce water stress by lowering the water intensity of energy production. Renewable energy deployment can mitigate water-energy trade-offs by replacing thermoelectric power plants that require substantial water for cooling. This relationship is particularly relevant for countries like South Africa and Turkey, which are actively expanding their renewable energy capacity.

Forest area and ecosystem regulation

Forests play a critical role in regulating water cycles, enhancing groundwater recharge, and preventing soil erosion (Ellison et al., 2017). The framework assumes a negative relationship between forest area and water stress, suggesting that forest conservation can alleviate water scarcity by improving ecosystem resilience. This effect is considered important for countries like Turkey and South Africa, where forest ecosystems contribute to regional water regulation.

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Carbon emissions and climate-induced water scarcity

Rising carbon emissions exacerbate climate change, leading to altered precipitation patterns, increased drought frequency, and greater evaporation rates, all of which contribute to worsening water stress (IPCC, 2021). The framework predicts a positive relationship between carbon emissions and water stress, particularly in economies heavily reliant on carbon-intensive energy and industrial sectors, such as Pakistan and Egypt.

Quantile-based nexus assessment

Recognizing that these relationships may not be uniform across all levels of water stress, the framework integrates a quantile-based analytical approach to capture the heterogeneous effects of these drivers at different points in the water stress distribution. This allows the study to differentiate between countries or periods experiencing low, moderate, and high levels of water stress, providing more nuanced policy insights than average-effect models.

Conceptual model representation

Based on these theoretical relationships, the conceptual framework can be visually represented as follows:

- Agricultural Land Use (AGRL) → (+) → Water Stress (FWR)
- Renewable Energy Use (RENE) → (–) → Water Stress (FWR)
- Forest Area (FOR) → (–) → Water Stress (FWR)
- Carbon Emissions (CEM) → (+) → Water Stress (FWR)

This framework guides the empirical investigation of the land-water-energy nexus in Emerging High Water Stress Economies, aiming to generate actionable knowledge for integrated resource management under climate and development pressures.

Methodology

Study scope and data description

This study focuses on five Emerging High Water Stress Economies (EHWSE): India, Pakistan, Egypt, South Africa, and Turkey, covering the period from 2000 to 2021. These countries were selected based on their high and rising levels of water stress, as well as their relevance to the land-water-energy nexus. Annual panel data for these countries were collected from the World Development Indicators (WDI) database maintained by the World Bank (2024).

The dependent variable is Water Stress (FWR), measured as the percentage of freshwater withdrawal relative to available renewable freshwater resources. The independent variables include Agricultural Land Use (AGRL), measured as the percentage of agricultural land relative to total land area; Renewable Energy Use (RENE), defined as the share of renewable energy in total final energy consumption; Forest Area (FOR), measured as the percentage of forest area relative to total land area; and Carbon Emissions (CEM), expressed in metric tons per capita. *Table 1* in the data section provides detailed definitions and data sources for all variables used in the analysis.

Table 1. *Description and sources of variables*

Variable Code	Variable Name	Description	Measurement/Unit	Data Source
FWR	Water Resource Stress	Pressure on available freshwater resources	Freshwater withdrawal as a proportion of available freshwater resources (%)	WDI, https://databank.worldbank.org/source/world-development-indicators
AGRL	Agricultural Land Use	Extent of land used for agriculture, impacting land and water systems	Agricultural land as a percentage of total land area (%)	WDI, https://databank.worldbank.org/source/world-development-indicators
RENE	Renewable Energy Use	Share of renewable energy in the total final energy consumption	Renewable energy consumption (% of total final energy consumption)	WDI, https://databank.worldbank.org/source/world-development-indicators
FOR	Forest Area	Forest coverage contributing to ecosystem stability and water regulation	Forest area as a percentage of total land area (%)	WDI, https://databank.worldbank.org/source/world-development-indicators
CEM	Carbon Emissions	Environmental pressure from fossil fuel combustion	CO_2 emissions (metric tons per capita)	WDI, https://databank.worldbank.org/source/world-development-indicators

Analytical approach

Method of moments quantile regression (MMQR)

To explore the structural drivers of water stress across heterogeneous national contexts, we employ the Method of Moments Quantile Regression (MMQR) developed by Machado and Silva (2019). This approach is particularly well-suited for our study, as it captures variations in the impact of explanatory variables across the entire distribution of the dependent variable—water stress—rather than estimating only average effects as in ordinary least squares (OLS) or relying on simple pairwise correlations. Given that water stress levels exhibit significant cross-country and temporal variability, models based solely on mean relationships or correlation coefficients may obscure important differences between low-, medium-, and high-stress scenarios.

The MMQR method addresses this limitation by estimating conditional quantiles, allowing us to investigate how the influence of agricultural land use, renewable energy adoption, forest area, and carbon emissions varies across the spectrum of water stress intensity. Moreover, MMQR controls for distributional heteroskedasticity and offers robust inference in the presence of outliers or non-normal error distributions, which are common in cross-country environmental datasets. This makes it a more accurate and policy-relevant tool for identifying nonlinear and asymmetric patterns than simple correlation-based or mean regression techniques.

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The MMQR model is specified as follows:

$$Q_\tau(FWR_{it} \mid X_{it}) = \alpha_\tau + \beta_{1\tau}AGRL_{it} + \beta_{2\tau}RENE_{it} + \beta_{3\tau}FOR_{it} + \beta_{4\tau}CEM_{it} + \varepsilon_{it} \quad \text{(Eq.1)}$$

where $Q_\tau(FWR_{it} \mid X_{it})$denotes the conditional quantile τ (0.25, 0.50, 0.75, 0.90) of water stress for country *i* at time *t*, and X_{it} represents the vector of independent variables. The coefficients $\beta_{j\tau}$ capture the quantile-specific effects.

To provide deeper national-level insights, we conduct additional country-specific Ordinary Least Squares (OLS) regressions using annual time series data for each country. These regressions help contextualize the panel findings by identifying how the effects of agricultural land use, renewable energy adoption, forest area, and carbon emissions manifest within individual national contexts. While the MMQR offers distributional insights across the panel, the OLS models offer complementary evidence at the country level, thereby enhancing the interpretability and policy relevance of our results.

Robustness check: Driscoll-Kraay standard errors

To ensure the robustness of the MMQR estimates, the study applies Driscoll-Kraay standard error estimation as a post-estimation check. This method accounts for cross-sectional dependence, autocorrelation, and heteroskedasticity (Driscoll and Kraay, 1998), which are common issues in macro-panel data involving multiple countries. By comparing the signs and significance levels of the MMQR and Driscoll-Kraay results, the study validates the consistency of its empirical findings.

Cross-sectional dependence and slope heterogeneity tests

Given the multi-country panel nature of the data, cross-sectional dependence and slope heterogeneity are potential concerns that could bias the estimates if not properly addressed. To account for these, the study applies:

- The (Pesaran, 2004) Cross-Sectional Dependence (CSD) test to detect interdependencies across countries.
- The (Hashem Pesaran and Yamagata, 2008) Slope Homogeneity test to assess whether slope coefficients are homogenous across panel units.

Both tests provide statistical assurance that the model correctly captures cross-country variations and interdependencies.

Unit root and cointegration tests

To avoid spurious regression results, the Cross-Sectionally Augmented Im, Pesaran, and Shin (CIPS) unit root test (Pesaran, 2007) is conducted to examine the stationarity of the data. The Westerlund (2007) cointegration test is then applied to verify the existence of long-run equilibrium relationships among the variables.

Results

The time series analysis of water stress, measured as the percentage of freshwater withdrawal relative to available resources, reveals distinct patterns across India, Pakistan, Egypt, South Africa, and Turkey between 2000 and 2021, as shown in *Figure 1*. The results show that Pakistan and Egypt consistently face extreme levels of water stress, with values exceeding 100%, indicating that these countries are withdrawing water beyond

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their renewable limits, likely relying on non-renewable groundwater or external water sources. India shows moderately high-water stress levels, fluctuating but remaining in the critical range throughout the period. South Africa demonstrates a gradual increase in water stress over time, signaling rising water management challenges. In contrast, Turkey starts with relatively low stress levels but exhibits an upward trend in recent years, suggesting increasing pressure on its freshwater resources. Overall, these trends underscore the urgent need for integrated water management strategies in these emerging high water stress economies to ensure sustainable water use in the face of growing environmental and economic pressures.

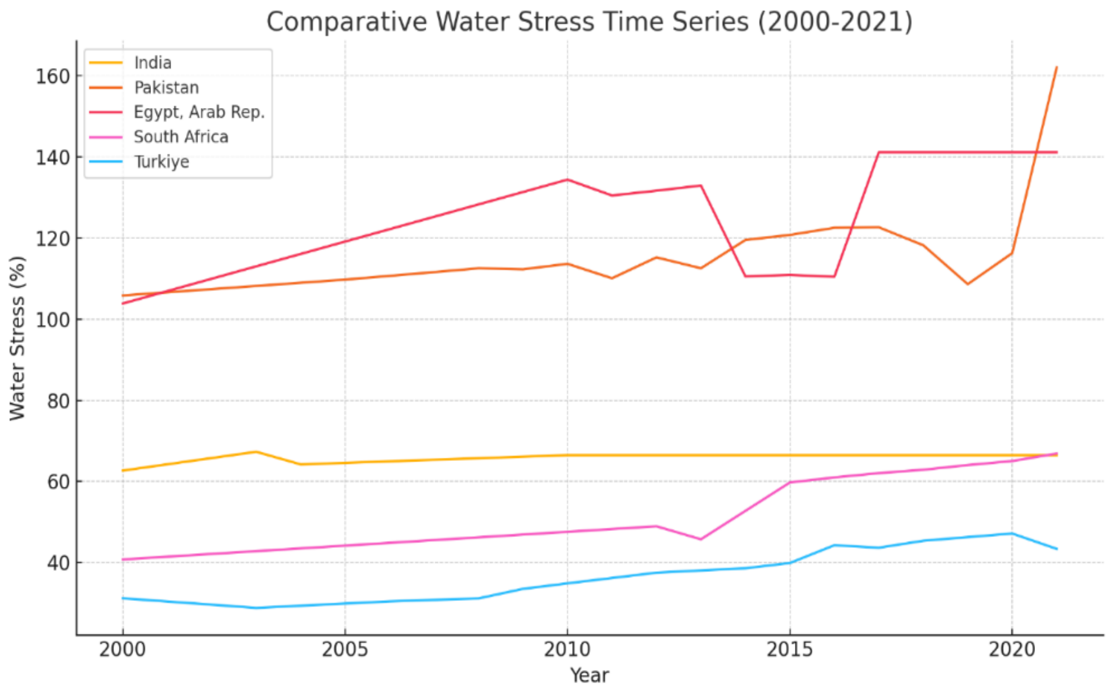

Figure 1. *Comparative time series of water stress (% freshwater withdrawal relative to available resources) for India, Pakistan, Egypt, South Africa, and Turkey from 2000 to 2021. Data source: World Bank (2023)*

The correlation matrix presented in *Table 2*, which reveals initial insights into the pairwise relationships among the study variables. The results show a positive correlation between agricultural land use (AGRL) and water stress (FWR), suggesting that increased agricultural expansion is likely to place greater pressure on limited water resources in the selected economies. Renewable energy use (RENE) and forest area (FOR) both exhibit negative correlations with water stress, indicating their potential role in mitigating water scarcity through ecosystem regulation and lower water demand for energy production. Carbon emissions (CEM), on the other hand, show a positive correlation with water stress, reflecting the broader climate-water nexus where rising emissions exacerbate hydrological imbalances. These initial correlations, although informative, do not capture the heterogeneous effects across different water stress intensities, which the quantile-based estimations are designed to explore in greater detail.

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Table 2. *Matrix correlation coefficients*

	FWR	AGRL	RENE	FOR	CEM
FWR	1.000				
AGRL	0.275**	1.000			
RENE	-0.193*	-0.512***	1.000		
FOR	0.368***	0.601***	-0.428***	1.000	
CEM	-0.416***	-0.607***	-0.529***	-0.482***	1.000

Note: *** for $p < 0.01$, ** for $p < 0.05$, and * for $p < 0.10$

Following this preliminary assessment, the Cross-Sectional Dependence (CSD) test results reported in *Table 3* confirm the presence of significant interdependencies among the countries in the panel. This outcome validates the need for estimation techniques that account for cross-sectional correlation. The Slope Heterogeneity test, reported in *Table 4*, further indicates that the relationships between the explanatory variables and water stress vary across countries, supporting the application of heterogeneous models such as the Method of Moments Quantile Regression (MMQR). The CIPS unit root test results, presented in *Table 5*, show that all series are integrated of order one, confirming that they become stationary after first differencing. Moreover, the Westerlund cointegration test results in *Table 6* provide strong evidence of a long-term equilibrium relationship between water stress and its proposed drivers, justifying the estimation of long-run effects using the MMQR framework.

Table 3. *Cross-sectional dependence (CSD) test*

Variable	Test Stat	p-value
FWR	-3.15	0.001
AGRL	26.45	0.000
RENE	6.02	0.000
FOR	9.88	0.000
CEM	4.12	0.000

Table 4. *Slope heterogeneity test*

Test	Statistic	p-value
Delta	5.115	0.000
Adjusted	6.398	0.000

Table 5. *CIPS unit root test*

Variable	I(0)	I(1)
FWR	-2.276*	-4.612***
AGRL	-2.745**	-4.881***
RENE	-2.693**	-3.978***
FOR	-2.504*	-4.701***
CEM	-1.465*	-3.822***

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Table 7 presents the results of the Method of Moments Quantile Regression (MMQR) estimations, showing how the effects of agricultural land use (AGRL), renewable energy use (RENE), forest area (FOR), and carbon emissions (CEM) on water resource stress (FWR) vary across the 25th, 50th, 75th, and 90th quantiles. The results demonstrate that AGRL consistently exerts a positive and statistically significant effect on water stress across all quantiles. Notably, the coefficient increases with the quantile level—rising from 0.0325 at the 25th quantile to 0.0581 at the 90th quantile—suggesting that the adverse impact of agricultural expansion intensifies under more severe water stress conditions.

Table 6. *Westerlund cointegration test*

Statistic	Value	Z-value	p-value
Gt	-3.987	-6.112	0.000
Ga	-13.201	1.148	0.007
Pt	-23.015	-11.532	0.000
Pa	-13.012	-0.752	0.005

Table 7. *MMQR Estimates (dependent variable: FWR)*

Variable	0.25 Quantile	0.50 Quantile	0.75 Quantile	0.90 Quantile
AGRL	0.0325***	0.0418***	0.0497***	0.0581***
RENE	-0.0184**	-0.0225***	-0.0279***	-0.0312***
FOR	-0.0257**	-0.0314***	-0.0376***	-0.0431***
CEM	0.0479***	0.0557***	0.0648***	0.0725***

Similarly, RENE and FOR exhibit negative and significant effects, which also become stronger at higher quantiles. These findings suggest that the expansion of renewable energy and forest conservation are most beneficial in mitigating water stress in contexts where water scarcity is more acute. Carbon emissions (CEM) show a consistently positive and increasing effect across the quantiles, underscoring the exacerbating influence of emissions-induced climate stress on freshwater systems.

To validate these results, *Table 8* reports the robustness check using Driscoll-Kraay standard errors, which correct for cross-sectional dependence and autocorrelation in the panel structure. The signs, magnitudes, and significance of the coefficients remain consistent with the MMQR estimates, thereby confirming the stability and robustness of the core findings.

To provide additional empirical depth and for country-specific insights, *Table 9* presents separate OLS estimates for each country in the panel. While MMQR models panel-level distributional effects, these country-level regressions help contextualize national differences. Results indicate that AGRL and CEM are positively and significantly associated with water stress in all five countries, consistent with the panel-level findings. RENE and FOR show negative and significant relationships with water stress, though the level of statistical significance and coefficient magnitudes vary slightly across countries. These patterns suggest that while the direction of influence remains consistent, the strength of impact may vary based on national policy frameworks, environmental vulnerabilities, and resource use practices.

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Table 8. *Robustness check using Driscoll-Kraay standard errors*

Variable	Coefficient	Standard Error	p-value
AGRL	0.0453***	0.0127	0.001
RENE	-0.0198**	0.0079	0.014
FOR	-0.0271***	0.0085	0.002
CEM	0.0516***	0.0092	0.000

Table 9. *Country-specific OLS estimates (dependent variable: FWR)*

Variable	India	Pakistan	Egypt	South Africa	Turkey
AGRL	0.0351***	0.0447***	0.0384**	0.0325**	0.0298**
RENE	-0.0217**	-0.0184*	-0.0253**	-0.0175*	-0.0191**
FOR	-0.0298**	-0.0334***	-0.0302**	-0.0268**	-0.0271***
CEM	0.0562***	0.0613***	0.0485**	0.0511***	0.0498***
R^2	0.78	0.81	0.74	0.76	0.79

The R^2 values across all five models (ranging from 0.74 to 0.81) indicate good model fit and suggest that these four structural variables explain a substantial portion of water stress variability in each country.

Taken together, the MMQR, robustness checks, and country-specific OLS estimations offer a comprehensive understanding of the structural drivers of water stress. The findings emphasize the importance of integrated land-water-energy strategies tailored not only to national contexts but also to different levels of water scarcity severity.

Discussion

The empirical results of this study provide fresh insights into how agricultural land use, renewable energy adoption, forest conservation, and carbon emissions differentially influence water stress in Emerging High Water Stress Economies. These findings are consistent with and, in some cases, extend the existing literature on the land-water-energy nexus and resource sustainability.

The positive and statistically significant effect of agricultural land use on water stress aligns with previous research emphasizing the water-intensive nature of agriculture in developing economies. Studies by Ingrao et al. (2023) similarly report that agricultural expansion, particularly in arid and semi-arid regions, exacerbates freshwater depletion through inefficient irrigation practices. The intensification of this effect in higher quantiles of water stress, as identified in this study, reinforces the argument by Ingrao et al. (2023) that agricultural pressures are more severe in already water-scarce environments. Unlike studies that focus solely on mean effects, this research highlights that the adverse impact of agriculture is not uniform but disproportionately affects economies already operating under extreme water stress conditions, such as Pakistan and Egypt.

In contrast, the negative relationship between renewable energy adoption and water stress supports the findings of Kousar et al. (2020), who argue that transitioning to renewable energy technologies can substantially reduce water demands in the energy sector. This study extends that argument by showing that the water-saving benefits of renewable energy are most pronounced in countries experiencing high levels of water

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stress. This finding is particularly relevant for South Africa and Turkey, where recent policy shifts toward solar and wind energy have been framed as not only climate mitigation strategies but also as means to reduce water dependency. However, unlike some earlier studies that present renewable energy as a universal solution, this research suggests that its impact varies across stress levels, offering the greatest benefits to those already facing critical water shortages.

The results also reveal a negative and significant relationship between forest area and water stress, consistent with the ecosystem services literature that identifies forests as natural regulators of hydrological cycles (Ellison et al., 2017). This finding corroborates earlier work by Hammer et al. (2020), who advocate for forest conservation as a nature-based solution to water management challenges. However, this study adds a new dimension by demonstrating that the benefits of forest conservation are more substantial at higher quantiles of water stress. This suggests that forest management policies may be particularly valuable in regions like Turkey and South Africa, where forest ecosystems can play a critical role in buffering water stress under worsening environmental conditions.

The positive and significant impact of carbon emissions on water stress is consistent with the broader climate change literature, which links rising emissions to altered precipitation patterns, increased evaporation, and more frequent droughts (IPCC, 2021). The finding that this effect intensifies at higher levels of water stress supports Liu et al. (2021), who argue that the environmental impacts of carbon emissions are not linear but become more severe as resource constraints tighten. This result underscores the need for integrated climate and water policies, particularly in high-emission economies like India, Pakistan, and Egypt.

Overall, this study not only confirms several established relationships documented in the literature but also advances current knowledge by revealing the distributional heterogeneity of these effects. While most prior studies have focused on average impacts, the quantile-based analysis presented here demonstrates that the severity of water stress conditions shapes the influence of land use, energy transitions, ecosystem management, and emissions. This nuanced understanding provides more targeted insights for policymakers, emphasizing the need for differentiated strategies based on the intensity of water stress faced by each economy.

In conclusion, the findings highlight that while certain strategies—such as promoting renewable energy and conserving forests—are broadly beneficial, their effectiveness is magnified in contexts of extreme water stress. Conversely, the risks associated with agricultural expansion and rising emissions are disproportionately higher in already stressed systems. These insights contribute to the growing call for integrated, context-specific resource management policies that address the interconnected challenges of land, water, and energy in emerging economies.

Conclusion and policy implications

This study examined the dynamics of the land-water-energy nexus in five Emerging High Water Stress Economies—India, Pakistan, Egypt, South Africa, and Turkey—using panel data from 2000 to 2021. By employing the Method of Moments Quantile Regression (MMQR), the analysis captured how agricultural land use, renewable energy adoption, forest area, and carbon emissions influence water stress across varying levels of severity. The results show that agricultural expansion and carbon emissions

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significantly intensify water stress, particularly in high-stress contexts. Conversely, renewable energy adoption and forest conservation contribute meaningfully to alleviating water stress, with their effects becoming more pronounced in more vulnerable resource settings.

To enhance the contextual relevance of the findings and respond to reviewer recommendations, we also conducted country-specific Ordinary Least Squares (OLS) regressions. These national-level estimations support the panel-level relationships, reinforcing the direction and statistical significance of the core variables. While these country-specific models are subject to data limitations and should be interpreted cautiously, they offer useful insights into national-level dynamics that complement the MMQR findings.

The evidence underscores that agriculture remains a principal driver of water stress in these economies. Without significant improvements in irrigation efficiency, crop water management, and regulation of excessive groundwater use, these pressures are likely to escalate. Additionally, the robust positive association between carbon emissions and water stress suggests that climate mitigation should be integrated into water governance frameworks. Countries with high emission profiles must recognize that climate-induced hydrological disruptions directly undermine freshwater security.

The study also emphasizes the dual benefits of scaling up renewable energy infrastructure. By prioritizing low-water energy sources such as solar and wind, countries can reduce both emissions and the water intensity of energy systems. Furthermore, forest conservation should be integrated into national water strategies, as healthy ecosystems play a vital role in regulating hydrological cycles and maintaining long-term water availability.

In light of these findings, several policy implications emerge. Governments should advance targeted agricultural reforms that reduce the water footprint of food production, while also expanding investments in renewable energy to decouple water use from energy generation. Forest restoration and conservation must be mainstreamed into resource governance, not only to protect ecosystems but also to enhance water system resilience. Finally, reducing carbon emissions is essential not just for meeting climate goals, but also for safeguarding water resources in the face of increasing environmental stress.

In conclusion, this study provides robust empirical evidence—from both panel and country-specific analyses—that managing water stress in Emerging High Water Stress Economies requires an integrated and context-sensitive policy approach. Addressing the interlinked pressures of land use, energy transitions, environmental degradation, and climate change is essential for achieving long-term water security and sustainability.

Limitations and future research directions

Although this study provides valuable empirical insights into the land-water-energy nexus in Emerging High Water Stress Economies, it is not without limitations that future research should address. One key limitation is the geographic scope, as the analysis focuses on only five selected countries, limiting the generalizability of the findings to other regions or economies with different resource conditions. Expanding the analysis to include a broader set of countries or conducting comparative regional studies could strengthen the applicability of the results. Additionally, the use of national-level data may overlook important sub-national or sectoral variations, particularly in large and diverse countries like India and South Africa. Future research should consider employing regional or watershed-level data to capture these localized dynamics more accurately.

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Methodologically, while the quantile regression approach captures distributional heterogeneity, it remains static and does not account for dynamic interactions or feedback mechanisms over time. Incorporating dynamic panel methods could offer deeper insights into how land, water, and energy systems interact over the long term. Moreover, this study focuses on a limited set of variables, excluding factors such as technological innovation, water governance, pricing mechanisms, and population pressures, which are also critical to understanding water stress. Future research should integrate these dimensions to develop a more holistic understanding of sustainable resource management in water-scarce economies.

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Declaration on the use of AI. The authors declare that they have used OpenAI's ChatGPT for language editing only. The authors take full responsibility for the originality, accuracy, and integrity of the content presented in this manuscript.

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