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To cite this article: S. Owjimehr, M. Emami Meybodi & K. Asadian Falahieh (2024) The impact of socioeconomic factors on water stress: insights from global analysis, Water International, 49:6, 738-759, DOI: [10.1080/02508060.2024.2364373](https://doi.org/10.1080/02508060.2024.2364373)

To link to this article: <https://doi.org/10.1080/02508060.2024.2364373>



Published online: 02 Jul 2024.



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RESEARCH ARTICLE



The impact of socioeconomic factors on water stress: insights from global analysis

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ABSTRACT

By utilizing a socioeconomic framework, this paper contributes to the water stress literature. Employing the instrumental variable quantile regression model on 81 countries from 2000 to 2019, our findings reveal financial development can alleviate high levels of water stress. Good governance consistently reduces water stress but human development exacerbates water stress, indicating a conflicting relationship between improving human development and reducing water stress. The moderating effect of good governance reveals that when combined with human development, it can effectively reduce water stress.

ARTICLE HISTORY

Received 12 November 2023
Accepted 2 Jun 2024

KEYWORDS

Water stress; HDI; financial development; good governance; quantile regression

Introduction

The adoption of the 2030 Agenda for Sustainable Development by the United Nations Development Summit marked a significant milestone in global efforts towards sustainable development. This agenda includes 17 Sustainable Development Goals (SDGs), each addressing a specific aspect of sustainability. The sixth goal of the SDGs focuses on ensuring the availability and sustainable management of water and sanitation for all people (United Nations, 2015). In order to show the global status in SDG6, the United Nations annually analyses the indicators of ‘drinking water’, ‘sanitation’, ‘hygiene’, ‘wastewater’, ‘water quality’, ‘efficiency’, ‘water stress’, ‘water management’, ‘transboundary’, ‘ecosystems’, ‘cooperation’ and ‘participation’.¹ Given the vital role of water in human life, the economy and sustainable development, numerous socioeconomic researchers have conducted studies using these indicators in the context of water research. One significant area of investigation involves exploring the relationship between water use (consumption or withdrawal) and economic growth. Researchers such as Wang and Wang (2020, 2021), Kong et al. (2021), Pastor and Fullerton (2020), Hu et al. (2019), Li et al. (2017), Zhao et al. (2017), Yue et al. (2017), Cazcarro et al. (2013), Yoo (2007) and Cole (2004) have contributed to this field by examining the impact of water use on economic growth. Additionally, the impact of water scarcity on economic growth and development has been a topic of significant interest. Studies conducted by Yang et al. (2021), Nahar Alrwis et al. (2021), Ferasso et al. (2021),

Zhou et al. (2017), Distefano and Kelly (2017), Ngoran et al. (2016) and Blignaut and Heerden (2009) have shed light on the consequences of water scarcity on economic growth and development. These studies have played a crucial role in highlighting the importance of addressing water scarcity as a global issue.

Unfortunately, with the growing population, economic growth, increased demand for irrigated agriculture and changing consumption patterns, water scarcity has become a pressing global concern (D. Wang et al., 2021). Many regions around the world are currently facing water shortages, and it is estimated that a significant portion of the global population will reside in water-stressed areas in the future (Islam et al., 2007; Sun et al., 2019; Vorosmarty et al., 2000; Wada et al., 2011). Malin Falkenmark showed that water-scarce countries are mostly among the most vulnerable and poorest countries in the world, and population growth without development pushes them further towards absolute water scarcity, as more people must share each unit of water (Rockström et al., 2024). These challenges have prompted researchers to focus their attention on analysing water stress and its contributing factors in recent years. Based on the SDG indicator 6.4.2, 2020,² as the water stress indicator, 18% of the world's renewable water resources is being withdrawn, after taking into account environmental flow requirements.

Water stress refers to the impact of high-water use, whether through withdrawals or consumption, in relation to water availability (Kummu et al., 2016). Water stress can be investigated with the two approaches of water use and water withdrawn. From the water use approach, stress can be viewed from two aspects: demand-driven scarcity and the large population that causes scarcity. Although these two aspects are usually considered separately, they are combined in Falkenmark's seminal work (Falkenmark, 2013, 1997; Falkenmark et al., 2007). Generally, the water stress index is measured through per-capita water consumption (Kummu et al., 2016):

$$\text{Water Stress} = \frac{\text{Water Use}}{\text{Water Availability}} \quad (1)$$

From the water withdrawn approach, according to the United Nations SDG Global Database,³ water stress is defined as the rate of freshwater withdrawal by all economic activities compared to the total available renewable freshwater resources⁴:

$$\text{Water Stress} = \frac{\text{Freshwater Withdrawal}}{\text{Total Available Renewable Freshwater Resources}} \quad (2)$$

Although various studies have examined the factors influencing water stress, such as hydroclimatic variability and socioeconomic conditions, recent research suggests that the role of economic activities in exacerbating water stress is more significant than that of climate change alone (Schlosser et al., 2014). Esen et al. (2020) conducted a study on the Eurozone, using a panel threshold regression model to analyse the threshold effects of economic growth on water stress. Their findings indicate that there is a specific threshold level of real gross domestic product per-capita growth, beyond which the intensifying effect on water scarcity tends to increase. In other words, as economic growth surpasses this threshold, the impact on water stress becomes more significant. Similarly, Y. Wang et al. (2022) employed a Spatial Durbin model to investigate the relationship between new urbanization and water stress. Their research revealed a spatial correlation between

new urbanization and water stress, suggesting that new urbanization can contribute to increased water stress in neighbouring provinces.

Therefore, it appears that in water stress studies, only economic growth and urbanization have been mentioned as socioeconomic dimensions that have an impact on water stress. However, variables such as human development, financial development and governance quality can also be influential. In the following, the channels through which these variables can impact water stress have been examined.

The mechanism of the impact of the Human Development Index on water stress

As a world-leading international hydrologist, Professor Malin Falkenmark advocates global water monitoring as a fundamental step towards human development (Rockström et al., 2024). She had developed in the literature the role of water in creating socioecological resilience, both in terms of mitigation, adaptation and social transformation (Rockström et al., 2012, 2014). The Human Development Report of 2006 emphasized the critical role of water access and utilization as a productive resource throughout history. Water is essential for both household needs and livelihoods, forming the foundation of human development (UNDP: Human Development Report, 2006). Redhu and Jain (2023) have also emphasized the importance of access to water for achieving socioeconomic development. However, considering the limited availability of water resources, promoting economic growth to improve living standards can exacerbate water scarcity issues (Kong et al., 2021). As a result, the conflict between increasing water demand for human development and water scarcity is expected to intensify in the near future. Nonetheless, enhancing the Human Development Index (HDI) remains a necessity for sustainable economic development in countries. Furthermore, the role of a moderator variable might mitigate the positive impact of human development on water stress. According to Zetland (2011), countries with low ranks in the HDI and governance tend to have limited access to water, including clean water, whereas countries with higher HDI and better governance values often have improved access to water supplies.

The mechanism of the impact of financial development on water stress

Debaere and Kapral (2021) have highlighted the significant financial requirements of approximately \$1.7 trillion to achieve the United Nations SDG in the water sector by 2030. This substantial amount is primarily needed for purposes including the reduction of water loss, improvement of water quality, construction of reservoirs and dams, implementation of better water storage practices, establishment of online desalination and recycling facilities, as well as the acquisition of water rights or permits.

Furthermore, Wang and Wang (2020) have emphasized the crucial role of financial support in the development of water-saving technologies in China to effectively manage water stress. In the economic literature, there is an index known as financial development, which potentially has an impact on water scarcity. Surprisingly, this aspect has not been thoroughly explored in the existing literature. However, according to Yang et al. (2021), although financial development may contribute to technological advancements

and improve water efficiency, it can also have adverse effects such as increased water resource consumption and the creation of a rebound effect.

The mechanism of the impact of the good governance on water stress

Transparency International's (2008) annual report on governance and corruption dedicated a significant portion to the water sector, highlighting the correlation between World Bank governance indicators and access to water in 170 countries. The report found that there is a correlation coefficient of 0.66 between these two factors. It is important to note that correlation does not imply causality, but it does suggest that better governance can contribute to improved water supplies (Transparency International, 2008). Additionally, Krause (2003) conducted a study focusing on 69 developing countries and concluded that higher levels of democratic participation have a positive impact on water and sanitation coverage. These findings indicate that good governance can act as a moderator, influencing the effect of the human development index on water stress.

These studies highlight the crucial role of governance in the water sector. Improved governance practices, such as transparency, accountability and democratic participation, can contribute to better access to water and sanitation services. By promoting good governance, policymakers and stakeholders can work towards mitigating water stress and ensuring sustainable water management for the well-being of communities worldwide.

The research gap pertaining to the role of human development, good governance and financial development in water stress has prompted this study to address this significant aspect. The primary objective of this study is to examine the impact of socioeconomic factors on water stress. Specifically, it aims to investigate the influence of financial development and human development on water stress, taking into account the potential moderating effect of good governance. To accomplish this objective, the study employs the instrumental variable quantile regression model for panel data analysis.

The following sections of the article are as follows. The methodology is presented in the next section. The following sections provide data and empirical results, discussion, and conclusions and recommendations.⁵

Methodology

In their study, Esen et al. (2020) focused on examining the impact of economic growth on water stress using a specific model. Building upon Esen et al.'s (2020) model, we aim to enhance it by incorporating additional variables alongside economic growth. These variables encompass socioeconomic factors known to affect water stress, such as good governance, the HDI, financial development and urbanization. Additionally, we include the dummy variable of proximity to the sea as a control for climate-related factors. Although this study analysed water stress determinants through a socioeconomic lens, environmental conditions also play a key role in this natural issue and should not be disregarded. For our model, we included proximity to the sea as a control variable, recognizing Pereira et al.'s (2009) valid point – intensified agriculture and industry along coasts burden adjacent aquifers. When groundwater extraction from such aquifers exceeds recharge rates, seawater intrudes and compromises freshwater quality. Hence,

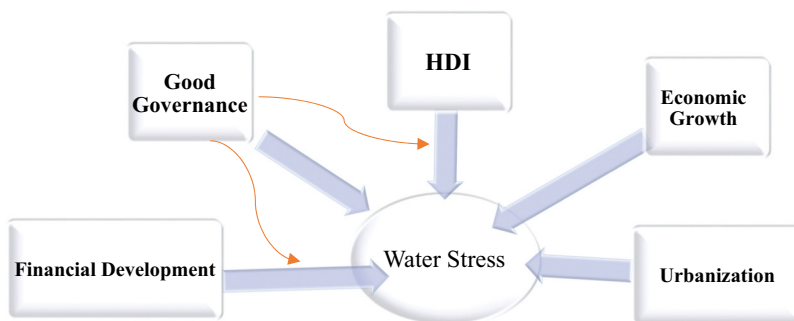


Figure 1. Analytical framework.

coastal proximity could exacerbate water strain. However, proximity also enables desalination technologies and freshwater generation to significantly supplement water resources.

The specification of our model is presented in Equation (3).

$$WS_{it} = \beta_0 + \beta_1 GOV_{it} + \beta_2 HDI_{it} + \beta_3 EG_{it} + \beta_4 UR_{it} + \beta_5 FDI_{it} + \beta_6 GOV_{it} * HDI_{it} + \beta_7 GOV_{it} * FDI_{it} + \beta_8 SEA_{it} + \varepsilon_{it} \quad (3)$$

where WS_{it} , GOV_{it} , EG_{it} , UR_{it} , FD_{it} and SEA_{it} are level of water stress, good governance, economic growth, urbanization, financial development and proximity to sea, respectively, which related to the i th country in year t . β_i show coefficient and β_6 and β_7 indicate the moderating effects of good governance. ε_{it} is the error term. Figure 1 shows the analytical framework of the research.

The selection of an appropriate methodology for estimating Equation (3) relies on several factors, including the statistical characteristics of the dependent variable. In this study, the dependent variable is the level of water stress in the examined countries. Because the distribution of water stress levels does not follow a normal distribution, non-parametric methods are recommended for estimating the model. One prominent non-parametric method is quantile regression, which allows for the analysis of the heterogeneous effects of explanatory variables (Koenker & Bassett, 1978). However, it should be noted that the classic quantile regression model has its limitations, particularly when the explanatory variables are endogenous. In our analysis, we conducted the Durbin–Wu–Hausman test for all explanatory variables and found that the HDI is indeed endogenous. As a result, we employ the instrumental variable quantile regression model proposed by Chernozhukov and Hansen (2005) to address this endogeneity issue. In the instrumental variable quantile regression model, potential real-valued outcome influenced by variation of observation units is calculated against potential treatment $d \in \{0, 1\}$ and represented as y_d . The potential outcomes of y_d are latent and reflect the chosen treatment d .

$q(d, x, \tau)$ is the potential outcome of specific quantiles τ under potential treatment d , conditional on some observed characteristics $X = x$. the quantile treatment effects, defined as Equation (4):

$$q(1, x, \tau) - q(0, x, \tau) \quad (4)$$

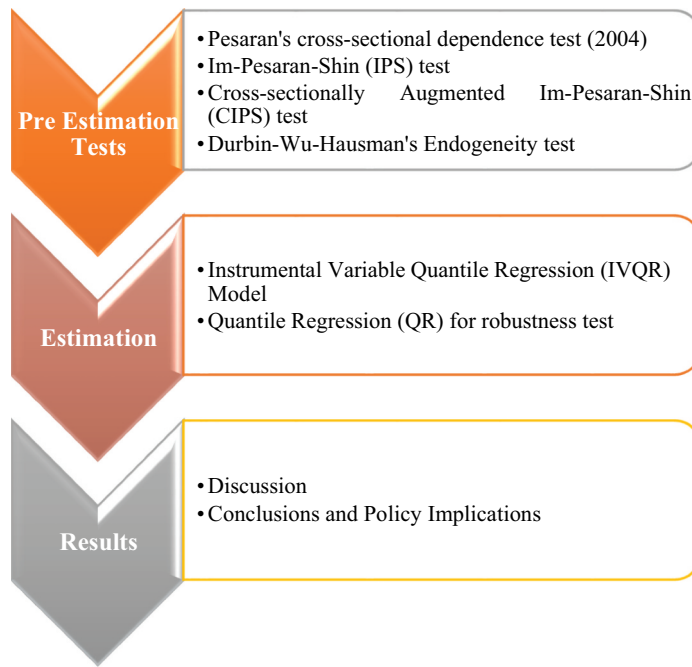


Figure 2. Empirical analysis framework.

Equation (4) shows the difference in the impact of treatment on each quantile of potential outcomes.

To solve the endogeneity problem, we use an instrument that affects the realized treatment but is independent of the potential outcome. A condition is determined as in Equation (5). By considering it, the quantiles of latent outcomes through the non-linear quantile-type conditional moment restrictions are estimated:

$$P[y \leq q(D, X, \tau) | X, Z] = \tau \quad (5)$$

Figure 2 presents the research methodology framework. Initially, pre-estimation tests are conducted, including cross-sectional independence, stationarity and endogeneity tests. Subsequently, the model is estimated using the instrumental variable quantile regression approach. Following the estimation, a robustness test is performed, and finally, conclusions are presented.

Data and empirical results

Data

The sample for this study consists of countries with an average precipitation depth⁶ of less than 1000 mm per year during the period 2000–2019 (as reported by the Food and Agriculture Organization through electronic files and its website⁷). The rationale behind selecting this statistical sample is to evaluate the efficacy of socioeconomic factors in mitigating water stress within a cohort of countries that exhibit homogeneity in terms of precipitation patterns.⁸

Table 1. Different levels of water stress.

Level of water stress	Statue
0–25	No stress
25–50	Low
50–75	Medium
75–100	High
>100	Critical

Source: United Nations website.¹⁰

The first step is to determine which of these low rainfall countries experience water stress. To accomplish this, we refer to [Table 1](#), sourced from the United Nations site,⁹ which provides data on average water stress between 2000 and 2019 for the countries in our sample. The countries included in our sample are as follows: Afghanistan, Algeria, Argentina, Armenia, Australia, Azerbaijan, Bahrain, Belarus, Belgium, Botswana, Bulgaria, Burkina Faso, Canada, Cabo Verde, Chad, China, Comoros, Cyprus, Czechia, Denmark, Djibouti, Egypt, Eritrea, Estonia, Ethiopia, Finland, France, Gambia, Germany, Greece, Hungary, Iran, Iraq, Israel, Italy, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Latvia, Lebanon, Lesotho, Libya, Lithuania, Luxembourg, Mali, Malta, Mauritania, Mexico, Mongolia, Morocco, Namibia, the Netherlands, Niger, Oman, Pakistan, Poland, Portugal, Qatar, Romania, Russian Federation, Saudi Arabia, Senegal, Slovakia, Somalia, South Africa, Spain, Sudan, Sweden, Syria, Tajikistan, Tunisia, Turkey, Turkmenistan, Ukraine, United Arab Emirates, United States of America, Uzbekistan, Yemen, Zimbabwe. As depicted in [Figure 3](#), approximately 44% of the countries included in the study do not experience water stress. Conversely, 35% of the countries exhibit a water stress level exceeding 50, indicating critical, high or medium levels of water stress.

[Figure 4](#) illustrates that over 70% of countries experiencing significant water stress (above 50) are located in Asia. According to the United Nations report from 2019, Western Asian countries such as Kuwait, the United Arab Emirates, Saudi Arabia and Qatar have the highest levels of water stress globally. This highlights the critical water scarcity issues faced by these countries in the region.

Due to the potential influence of various factors, such as humidity and low water evaporation, it was observed that 44% of countries with low rainfall did not experience

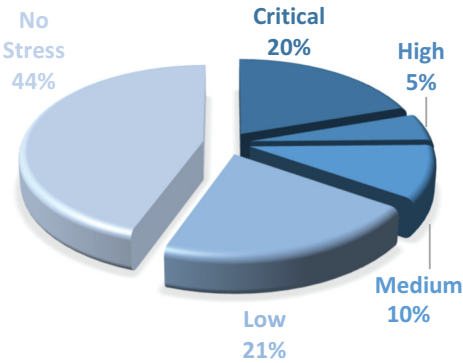


Figure 3. Status of level of water stress.

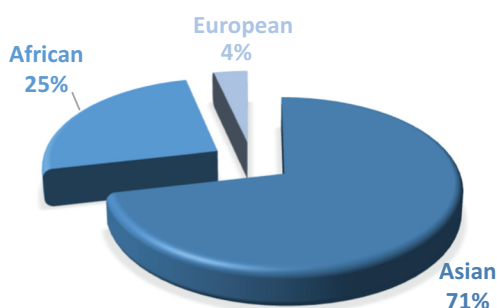


Figure 4. Status in different regions of level of water stress.

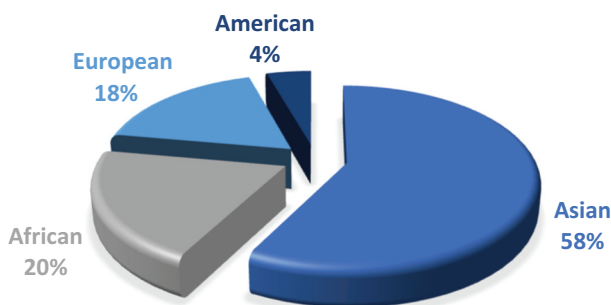


Figure 5. Status in different regions of level of water stress (excluding the countries without water stress).

water stress. In order to account for this, these countries were excluded from the sample, resulting in a reduction in the sample size from 81 to 45 countries.

Continuing the analysis, the remaining countries were once again categorized by continent, as depicted in [Figure 5](#). Consistent with previous findings, Asian countries continue to exhibit the largest proportion of water stress. However, an interesting observation can be made regarding the share of European countries in experiencing water stress, as depicted in [Figure 5](#). Although it is true that most European countries have relatively low levels of water stress, it is still important to address this issue within the green continent of Europe. Despite the overall favourable situation, there are certain European countries that face notable water stress.

For instance, Belgium is categorized as having a medium water stress level, with an average stress level of 70. Additionally, Spain, Germany, and Bulgaria are also facing challenges, as they have a water stress level exceeding 40. It is crucial to recognize and address these issues in order to ensure sustainable water management and conservation in Europe.

Our study focuses on several key variables, which are outlined in [Table 2](#) along with their definitions and corresponding statistical databases.

Our main variable is water stress. According to the United Nations Global SDG Database,¹¹ the level of water stress is defined as the ratio of freshwater withdrawal to available freshwater resources, taking into account the total freshwater withdrawn by all

Table 2. Introduction of variables.

Variables	Description	Source
Water stress	Freshwater withdrawal as a proportion of available freshwater resources	United Nations (https://sdg6data.org/en/tables)
Good governance	An average of six sub-indices: voice and accountability, political stability and absence of violence, government effectiveness, rule of law, regularity quality and control of corruption	World Bank (https://www.worldbank.org/en/publication/worldwide-governance-indicators)
Economic growth	GDP growth (annual %)	World Bank (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG)
Urbanization	Urban population growth (annual %)	World Bank (https://data.worldbank.org/indicator/SP.URB.GROW)
HDI	A combination of three indicators: a long and healthy life (life expectancy), access to education and a decent standard of living ¹²	United Nations Development Programme (https://ourworldindata.org/human-development-index) ¹³
Financial development	Domestic credit to private sector (% of GDP) ¹⁴	World Bank (https://data.worldbank.org/indicator/FS.AST.PRVT.GD.ZS)

major sectors and the total renewable freshwater resources, while also considering environmental water requirements. It is noteworthy that Kummu et al. (2016) employed a slightly different indicator for water stress, defining it as the blue water stress indicator, which is the ratio of water use to availability. They argued that using consumption rather than withdrawals provides a more accurate representation of water stress, as water ‘use’ implies that the water is no longer available for other users. They believed that using withdrawals risks overestimating the actual stress, as a substantial portion of the withdrawals may be available for downstream users as return flows. In this research, we have adopted the first definition provided by the United Nations Global SDG Database, because the UN utilizes this measure in tracking progress towards crucial sustainability agendas, making our findings compatible with other researches using the same internationally standardized metric.

Empirical results

According to Table 3, the descriptive statistics provide insights into the model variables. The average water stress level across the countries is quite high, with an average of 126.92. It is worth noting that Kuwait has consistently experienced the highest level of water stress, reaching 3850.5 for three consecutive years. On the other end of the spectrum, Comoros recorded the lowest water stress level of 0.833 in 2000. In terms of good governance, Finland performed the best with the highest governance index in 2003. Conversely, Somalia had the lowest governance index in 2016, indicating challenges in governance practices. Examining economic growth rates, Libya experienced the highest

Table 3. Descriptive statistics.

Descriptive statistics	Water stress	Good Governance	Economic Growth	Urbanization	HDI	Financial Development
Mean	126.92	0.007	3.791	2.151	0.71	55.60
Maximum	3850.50	1.969	86.826	17.763	0.947	254.66
Minimum	0.833	−2.12	−50.34	−6.511	0.346	1.26
Jarque-Bera	99,128.2***	56.64***	5433.06***	3953.7***	132.34***	438.49***

Note: ***, **, * denote significance at 1%, 5% and 10% level, respectively.

growth rate of 86% in 2012. Conversely, in 2011, the country witnessed a significant decline in economic growth with a rate of -50%. These fluctuations suggest a volatile economic landscape. When it comes to urbanization, Romania recorded the highest urbanization growth rate in 2007, indicating rapid urban development. In contrast, Sweden had the lowest urbanization growth rate in 2014, suggesting a slower pace of urbanization. Analysing the HDI, Germany had the highest HDI value in 2014, indicating a well-developed and high standard of living. Conversely, Ethiopia had the lowest HDI value in 2000, highlighting challenges in human development. In terms of financial development, Cyprus had the highest financial development index (FDI) value in 2013, indicating a well-established and sophisticated financial sector. On the other hand, Iraq had the lowest financial development index value in 2004, suggesting limitations in financial accessibility and development.

Another crucial statistic reported in Table 3 is the Jarque-Bera statistic, which tests the hypothesis that the distribution of a variable is normal. In this case, the null hypothesis of a normal distribution has been rejected for all the data. This suggests that the water stress level and possibly other variables do not follow a normal distribution. As shown in Figure 6, the distribution of the water stress level further confirms this observation. The non-normal distribution of the water stress level and other variables indicates that using non-parametric models would be more appropriate for estimating and analysing such data.

Prior to estimating the model, it is important to ensure the independence of the cross-sectional level, stationarity, and exogeneity of the variables. The results of Pesaran's cross-sectional dependence test (2007), CD test, are presented in Table 4. According to these results, Good Governance, Economic Growth, Financial Development and HDI reject the null hypothesis of independence. As a result, we employ the Cross-sectionally Augmented Im-Pesaran-Shin (CIPS) test to examine the stationarity of these variables. For the remaining two variables, we utilize the Im-Pesaran-Shin (IPS) test. In both tests, the null hypothesis is that the variable has a unit root. The findings listed in Table 4 indicate that this hypothesis was rejected for all variables in both tests, suggesting that all the variables are stationary at the level.

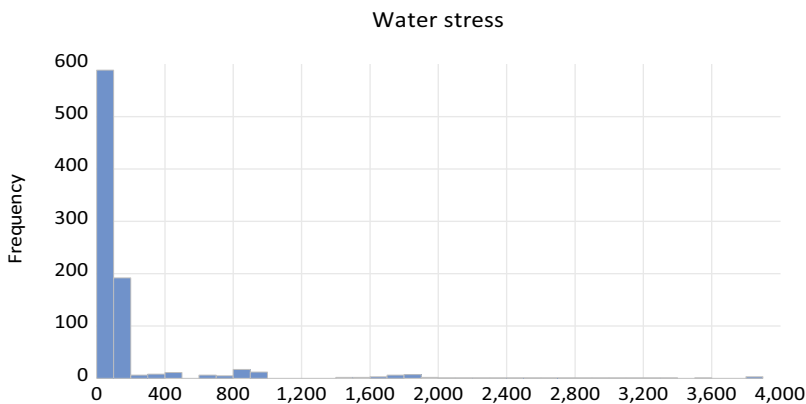


Figure 6. Distribution graph of water stress level.

Table 4. Result of pre-estimation tests. Cross-sectionally augmented Im–Pesaran–Shin test to examine the stationarity of these variables. For the remaining two variables, we utilize the Im–Pesaran–Shin.

Variables	CD Test	Cross-sectionally Augmented Im–Pesaran–Shin Test	Im–Pesaran–Shin Test	Wu–Hausman Statistic
Water stress	0.85	–	–4.49***	–
Good governance	11.114***	–2.42**	–	1.072
Economic growth	49.55***	–2.95**	–	0.0034
Urbanization	0.055	–	–6.99***	0.033
Financial development	36.05***	–3.91**	–	1.077
HDI	32.69***	–3.87**	–	5.5***

Note: ***, **, * denote significance at 1%, 5% and 10% level, respectively.

The third pre-estimation test conducted is Durbin–Wu–Hausman’s endogeneity test. The results presented in Table 4 indicate that the null hypothesis of exogeneity for the variables is only rejected for HDI. Thus, HDI is considered endogenous. Ignoring the endogeneity of variables can lead to inconsistent estimators. To address this issue, instrumental variables should be used. Although the use of instrumental variables may reduce the efficiency of the model, it increases consistency. Therefore, in this research, we employ the instrumental variable quantile regression model to address the endogeneity of variables.

Table 5. Results of estimated models by instrumental variable quantile regression (IVQR).

Variables	Quantile	Model 1 Estimated by IVQR	Model 2 Estimated by IVQR	Model 3 Estimated by IVQR
Intercept	0.250	–0.214***	–0.166***	–0.181**
	0.500	–0.333***	–0.333***	–0.301***
	0.750	–0.184**	–0.202***	–0.293***
Good governance	0.250	–0.1138***	–0.0733***	–0.00971
	0.500	–0.243***	–0.247***	0.0446
	0.750	–0.270***	–0.2600***	0.064
Economic growth	0.250	0.0039**	0.0029*	0.00380**
	0.500	0.0008	0.00068	0.0016
	0.750	0.0109***	0.01061***	0.0091***
Urbanization	0.250	0.0043	0.0023	0.00387
	0.500	0.0061	0.00632	0.0046
	0.750	–0.015***	–0.0139***	–0.0156***
HDI	0.250	0.2648***	0.198**	0.239***
	0.500	0.720***	0.725***	0.733***
	0.750	0.816***	0.828***	1.070153***
Financial development	0.250	0.00139***	0.00183***	0.00141***
	0.500	0.00038	0.00028	0.00056
	0.750	–0.003***	–0.0021***	–0.00221***
Dummy variable (proximity to the sea)	0.250	0.092***	0.089***	0.0945***
	0.500	0.223***	0.223***	0.2090***
	0.750	0.704***	0.695***	0.659***
Financial development × Good governance	0.250	–	–0.00057***	–
	0.500	–	0.000080	–
	0.750	–	–0.00042	–
HDI × Good Governance	0.250	–	–	–0.1356***
	0.500	–	–	–0.384***
	0.750	–	–	–0.538***

Note: (a) ***, **, * denote significance at 1%, 5% and 10% level, respectively.

(b) Models 1, 2 and 3 are estimated with a sample of 81 countries and the IVQR method. In models 2 and 3, the moderating effects of Good governance on the coefficient of Financial development and Human development (respectively) are considered. This is while model 1 is estimated without these effects.

Table 5 presents the results of the estimated models, which were conducted using a sample of 81 countries and the instrumental variable quantile regression method. Three models were estimated: Models 1, 2 and 3. Models 2 and 3 consider the moderating effects of good governance on the coefficient of financial development and human development, respectively, whereas Model 1 does not include these effects.

The findings indicate that good governance consistently reduces water stress across all quantiles, with a greater impact observed in the higher quantiles. In more detail, for every unit improvement in good governance, there is a reduction of 0.1138 in water stress in the lowest quantile. Furthermore, in the 0.75 quantile, the impact of good governance is even greater, with a reduction of 0.270 in water stress for every unit improvement in good governance (in Model 1).¹⁵

Urbanization in the upper quantile (0.75) can also play a role in mitigating water stress. In Model 1, it is observed that with an increase of one unit in urbanization, water stress decreases by 0.015 units. On the other hand, economic growth in the higher quantiles exacerbates water stress. Specifically, in the upper quantile, an increase of one unit in economic growth leads to a nearly 0.01 unit increase in water stress. It is important to note that this variable does not have a significant effect on water stress in the middle quantiles.

The relationship between the financial development index and water stress varies across different quantiles. In the lower quantiles, the financial development index exacerbates water stress, whereas in the higher quantiles, it has a reducing effect. Model 2 takes into account the moderating effects of good governance on financial development. In this model, the coefficient for the financial development index is 0.00183. However, when considering the interaction effects of good governance and financial development, the coefficient is negative and significant (-0.00057) specifically in the lower quantile. This indicates that improving good governance can help mitigate the detrimental effects of the financial development index in this quantile.

The HDI and the proximity to the sea dummy variable consistently have a positive impact on water stress in all models. This raises the question of whether the HDI and the goals of sustainable development are moving in opposite directions and if there is a solution to this problem.

In Model 3, the moderating effect of good governance on the HDI is added. The results demonstrate that the interaction effects of good governance and HDI significantly reduce the incremental effects of HDI in all quantiles, yielding negative coefficients. This implies that when accompanied by improved good governance, the HDI can contribute to a reduction in water stress.

Models 4–6 in Table 6 serve as robustness tests for Models 1–3. These additional models were estimated using the simple quantile method. The results indicate that although the size of the coefficients in Models 4–6 is not significantly different from Models 1–3, the significance of the coefficients is better in the latter set of models. In other words, the estimated coefficients in Models 1–3 provide more reliable and statistically significant results compared to Models 4–6.

Figure 7 presents the quantile process estimates of the model. The red lines represent the 95% confidence intervals and the blue lines represent the estimated parameters for the 0.25–0.75 quantiles. As depicted in Figure 7, the HDI and the proximity to the sea

Table 6. Results of estimated models by the quantile method (QR)

Variables	Quantile	Model (4) Estimated by QR	Model (5) Estimated by QR	Model (6) Estimated by QR
Intercept	0.250	−0.072***	−0.034	−0.092***
	0.500	−0.195***	−0.192***	−0.209***
	0.750	−0.0406	−0.076	−0.209***
Good governance	0.250	−0.073***	−0.031*	−0.010
	0.500	−0.215***	−0.207***	0.022
	0.750	−0.253***	−0.244***	0.034
Economic growth	0.250	0.0029	0.0018	0.003
	0.500	0.0008	0.0009	0.0005
	0.750	0.011	0.012	0.006
Urbanization	0.250	0.0071**	0.002	0.007*
	0.500	0.005079	0.005	0.004
	0.750	−0.022***	−0.021***	−0.017**
HDI	0.250	0.057	0.010	0.090*
	0.500	0.489***	0.479***	0.551***
	0.750	0.60***	0.643***	0.932***
Financial development	0.250	0.0014***	0.002***	0.0014***
	0.500	0.0003	0.0004	0.0004
	0.750	−0.0028***	−0.0023***	−0.0022***
Dummy variable (proximity to the sea)	0.250	0.073***	0.071***	0.080***
	0.500	0.257***	0.257***	0.274***
	0.750	0.736***	0.727***	0.679***
Financial development × Good governance	0.250	–	−0.0008***	–
	0.500	–	−0.0001	–
	0.750	–	−0.0004	–
HDI × Good governance	0.250	–	–	−0.086***
	0.500	–	–	−0.329***
	0.750	–	–	−0.493***
Wald Test	–	615.95***	629.07***	624.24***

Note: (a) ***, **, * denote significance at 1%, 5% and 10% level, respectively.

(b) Models 4, 5 and 6 are estimated with a sample of 81 countries and the QR method. In models 5 and 6, the moderating effects of Good governance on the coefficient of Financial development and Human development (respectively) are considered. This is while model 4 is estimated without these effects.

consistently exhibit a positive effect on water stress across all quantiles. This is supported by the narrowness of the confidence intervals at the 95% level, indicating the statistical significance of these variables.

On the other hand, the broken lines representing urbanization, good governance, financial development and economic growth illustrate the varying impact of these variables in the lower and upper quantiles compared to the middle quantiles. Furthermore, the coefficients of HDI × good governance and financial development × good governance are consistently negative across all quantiles. This suggests that the interaction effects of good governance with HDI and financial development have a mitigating effect on the relationship between these variables and water stress.

Discussion

Figure 8 presents water stress trends in 81 countries. Contrary to popular belief, the figure reveals that water stress levels are not universally worsening across all nations. Although approximately 45% of countries exhibit an increasing trend in water stress (e.g., Algeria, Ethiopia, Greece and Kuwait), around 39.5% experience a decreasing trend (e.g.,

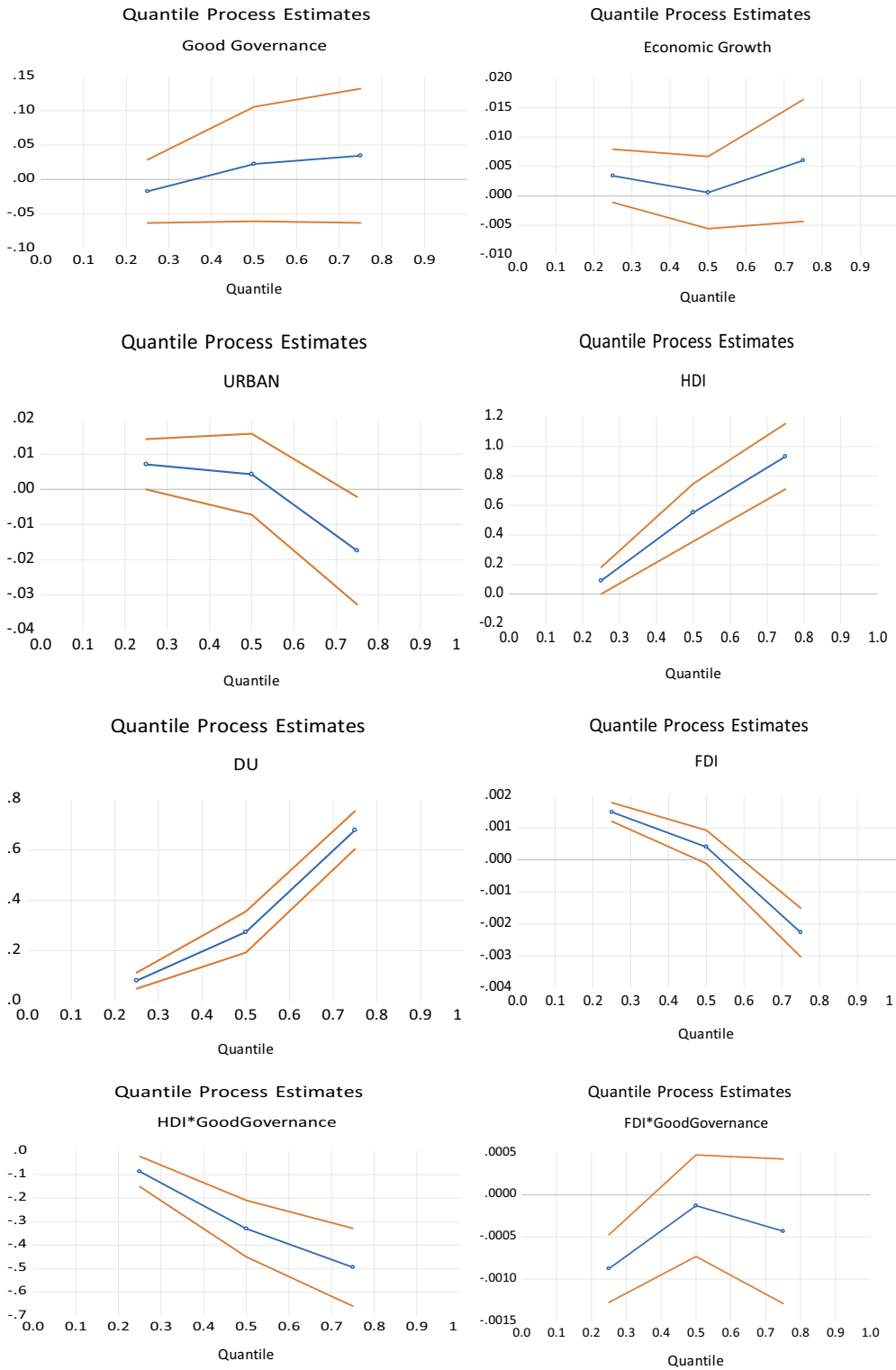


Figure 7. Quantile process estimates of model. Note: Red lines show 95% confidence intervals and the blue lines show the estimated parameters for 0.25–0.75 quantiles. Note: DU, Dummy variable (proximity to the sea).

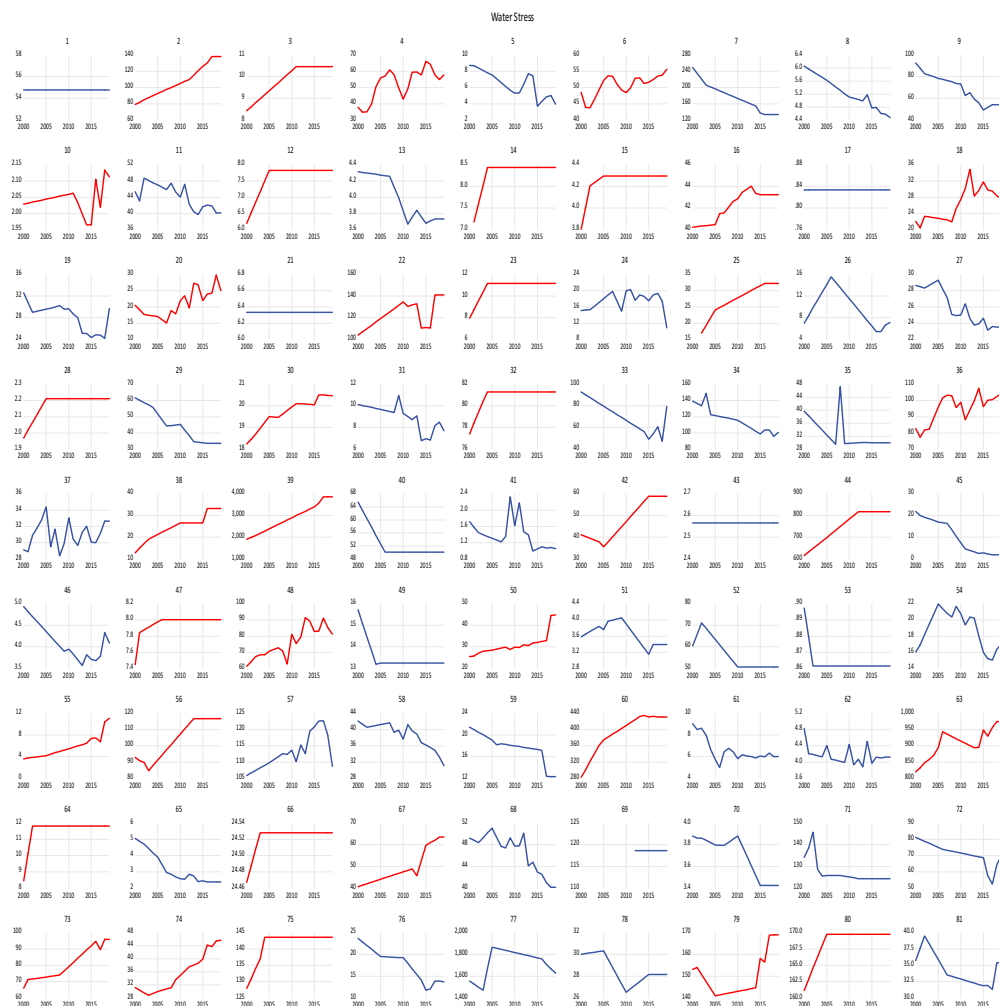


Figure 8. Water stress graphs for 81 countries separately. Source: Research findings. Note: (a) Red graphs have an increasing trend and blue graphs have a decreasing or constant trend. (b) These countries are (1) Afghanistan, (2) Algeria, (3) Argentina, (4) Armenia, (5) Australia, (6) Azerbaijan, (7) Bahrain, (8) Belarus, (9) Belgium, (10) Botswana, (11) Bulgaria, (12) Burkina Faso, (13) Canada, (14) Cabo Verde, (15) Chad, (16) China, (17) Comoros, (18) Cyprus, (19) Czechia, (20) Denmark, (21) Djibouti, (22) Egypt, (23) Eritrea, (24) Estonia, (25) Ethiopia, (26) Finland, (27) France, (28) Gambia, (29) Germany, (30) Greece, (31) Hungary, (32) Iran, (33) Iraq, (34) Israel, (35) Italy, (36) Jordan, (37) Kazakhstan, (38) Kenya, (39) Kuwait, (40) Kyrgyzstan, (41) Latvia, (42) Lebanon, (43) Lesotho, (44) Libya, (45) Lithuania, (46) Luxembourg, (47) Mali, (48) Malta, (49) Mauritania, (50) Mexico, (51) Mongolia, (52) Morocco, (53) Namibia, (54) the Netherlands, (55) Niger, (56) Oman, (57) Pakistan, (58) Poland, (59) Portugal, (60) Qatar, (61) Romania, (62) Russian Federation, (63) Saudi Arabia, (64) Senegal, (65) Slovakia, (66) Somalia, (67) South Africa, (68) Spain, (69) Sudan, (70) Sweden, (71) Syria, (72) Tajikistan, (73) Tunisia, (74) Turkey, (75) Turkmenistan, (76) Ukraine, (77) United Arab Emirates, (78) United States of America, (79) Uzbekistan, (80) Yemen, (81) Zimbabwe.

Bahrain, Belarus, Belgium and Slovakia). For certain countries like Italy, the Netherlands, Russia and Kyrgyzstan, water stress fluctuates without a specific trend. This research aims to investigate the reasons behind these divergent trends in water stress. Whereas climate change and geographical factors are often cited as explanations, this study focuses on exploring the socioeconomic perspective.

The study examines the impact of the good governance index, HDI, economic growth and urban population growth rate as socioeconomic factors. Additionally, proximity to the sea is treated as a control variable. The findings of this study shed light on the relationship between these factors and water stress.

The role of good governance

The results indicate that good governance has a mitigating effect on water stress. This finding aligns with expectations, as strong institutions can effectively manage scarce resources and meet the needs of society members. Ramzy et al. (2019) support this notion by highlighting how water, being a precious and scarce resource, necessitates efficient governance for sustainable management.

Financial development and water stress

The study reveals an asymmetric relationship between financial development and water stress. In the low quantile, financial development exacerbates water stress, whereas in the high quantile, it leads to a reduction in stress. Heterogeneous results have been observed in previous studies.

Some researchers, such as Zakaria and Bibi (2019) and A. Kumar et al. (2021), suggest that financial development, due to increased energy-intensive investment, negatively affects environmental sustainability. Conversely, Ullah et al. (2022), Kirikkaleli and Adebayo (2021), and Zafar et al. (2019) demonstrate that improved financial development, coupled with investments in environmental projects, can enhance environmental sustainability.

Interaction effects of good governance and financial development

The study finds that the interaction effects of good governance and financial development have a negative and significant impact on water stress in the low quantile. This implies that when financial development is accompanied by improved governance, it can help reduce water stress levels. A. Kumar et al. (2021) also support this notion in their study, highlighting the moderating effect of institutional quality on the relationship between financial development and environmental quality.

HDI and water stress

Across all models, the HDI exacerbates water stress. This aligns with the findings of M. D. Kumar et al. (2008), who identified a significant two-way relationship between water use and HDI.

Moderating effect of good governance on HDI

Interestingly, the study reveals that good governance moderates the effect of the HDI on water stress. The increasing effect of HDI on water stress is reduced when governance is improved. This finding is consistent with Zetland (2011), who highlights those countries with higher rankings in HDI and good governance tend to have better access to improved water supplies. Transparency International (2008) and Krause (2003) also support this, suggesting that better governance contributes to improved water supplies, thus suggesting that better governance contributes to improved water supplies.

Urbanization and water stress

In all instances, urbanization in the lower quantiles contributes to an increase in water stress, whereas in the upper quantiles, it actually leads to a reduction in water stress. Our findings align with a study conducted by Wang et al. in 2022, where they employed a threshold panel model to demonstrate that the introduction of new urbanization can effectively mitigate water stress if accompanied by industrial structural changes.

Economic growth and water stress

In certain models, economic growth results in an escalation of water stress in both low and high quantiles, while having no discernible impact on other quantiles. Esen et al. (2020) have also obtained similar results in their study encompassing nine European countries. Their findings indicate that economic growth only heightens water stress levels when they surpass a specific threshold.

Proximity to the sea and water stress

Across all models, proximity to the sea exacerbates water stress. This outcome is consistent with the research conducted by El Kharraz et al. (2012) and Pereira et al. (2009). The intensification of agricultural and industrial activities along coastal regions places significant strain on coastal aquifers. The extraction of groundwater from these aquifers leads to the intrusion of seawater, which adversely impacts the quality of freshwater (Pereira et al., 2009). Consequently, this issue contributes to the escalation of water stress.

Conclusions and policy implications

The primary findings of this study indicate that an improvement in good governance across all quantiles leads to a reduction in water stress levels. Notably, the mitigating effect of good governance on water stress becomes more pronounced in higher quantiles, suggesting that countries with better governance practices are more effective in alleviating severe water stress conditions. As a result, enhancing each of the sub-indicators related to governance, including Regulatory Quality, Government Effectiveness, Voice and Accountability, Political Stability, Rule of Law and Control of Corruption, can significantly aid countries in effectively managing the water crisis. Another noteworthy

result is that the HDI is positively correlated with water stress. However, when combined with good governance, the interaction between HDI and governance can actually lead to a reduction in water stress. Therefore, it is evident that good governance not only has direct effects but also influences the impact of HDI on water stress. Based on these findings, it is highly recommended that policymakers prioritize the strengthening of good governance indicators alongside promoting human development.

In terms of the impact of financial development on water stress, the results suggest that at high levels of stress, enhancing financial development and increasing investments in environmentally sustainable initiatives can effectively reduce water stress. However, at low levels of water stress, financial development should be encouraged only if appropriate institutional conditions are in place.

The final recommendation pertains to economic growth in countries experiencing high and critical levels of water stress. According to the research findings, economic growth in these countries exacerbates water stress. In order to address this issue, it is crucial for these countries to transition from traditional economic growth to green economic growth. Green economic growth entails achieving economic development while ensuring the preservation of natural assets that are essential for people's well-being. To achieve green economic growth, there should be a focus on accelerating investments and fostering innovation, as these factors serve as the foundation for sustainable growth.¹⁶

The final point is that, like any other research, this study has faced limitations and challenges, with the most significant ones being the lack of new resources and relevant theoretical foundations on the subject. This limitation has prevented the analysis from being sufficiently in-depth. Therefore, it is recommended for future studies to not only focus more on the economic and social dimensions that impact water stress but also to strive to strengthen the existing literature in this field. Additionally, by employing methodologies such as system dynamics, researchers can analyse the complex relationships between variables, particularly those related to human development and water stress, from various perspectives.

Notes

1. <https://www.sdg6data.org/en>.
2. <https://www.sdg6data.org/en>.
3. <https://www.sdg6data.org/en/indicator/6.4.2>.
4. In this research, we have adopted the definition provided by the United Nations Global SDG Database.
5. Due to the limited word count and the scarcity of studies specifically addressing water stress, as mentioned in the Introduction, we refrained from including a separate literature review section. However, we have conducted thorough research on water-related studies in economics, which can be provided if necessary.
6. The long-term spatial and temporal mean depth of annual precipitation in a given country is referred to as the average precipitation.
7. <https://data.worldbank.org/indicator/AG.LND.PRCP.MM>.
8. It is noteworthy that certain regions with abundant rainfall may also grapple with water stress, a phenomenon that warrants further investigation as a significant research endeavour in the future.
9. <https://sdg6data.org/en/indicator/6.4.2>.

10. <https://sdg6data.org/indicator/6.4.2>.
11. <https://sdg6data.org/en/tables>.
12. Human development is a broad, multidimensional concept encompassing longevity and health, education and standard of living indicators. Specifically, life expectancy represents longevity, mean and expected years of schooling capture education levels, and gross national income per capita reflects income. These four factors are standardized to a common scale from 0 to 1 for comparability. Minimum/maximum thresholds establish normalized scoring. To calculate the composite HDI value, knowledge metrics are first averaged, then all dimensions are geometrically averaged. This methodology aggregates objective data on core quality of life dimensions into a single comparative measure ranking nations on a 0–1 scale of human progress.
13. UNDP.
14. There are different indicators for financial development; the reason for using this definition is that this indicator is more accessible for our sample.
15. Given that the numerical expression of the coefficients in all models complicates the analysis, only the most crucial cases have been mentioned.
16. <https://www.oecd.org/greengrowth/>.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

There was no external funding.

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Data Availability Statement

<https://ourworldindata.org/human-development-index> and <https://data.worldbank.org/indicator/AG.LND.PRCP.MM>, <https://sdg6data.org/en/indicator/6.4.2>

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