WATER SCARCITY: ITS PRESENT, FUTURE, AND POSSIBLE MITIGATION THROUGH TECHNOLOGY

MASTER'S THESIS

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PRAGUE, CZECH REPUBLIC

JULY 2025

Title: Water Scarcity: Its Present, Future, and Possible Mitigation Through Technology

Název: Nedostatek vody: současnost, budoucnost a možnosti jeho zmírnění pomocí technologií

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Academic year: 2024/2025

Bibliographic note

GUZMÁN FREDES, Mario. *Water scarcity: Presence, future, and possible mitigation through technology*. Prague 2025. 28,495 words. Master thesis. Center for Economic Research and Graduate Education– Economics Institute, a joint workplace of Charles University, and the Economics Institute of the Czech Academy of Sciences. Thesis supervisor: Sebastian Ottinger, PhD

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This research did not involve human or animal subjects, nor did it involve the collection of personal or sensitive data. Therefore, no formal ethical approval was required for this study.

This research was conducted as part of the author's academic program and did not receive any external funding, grants, or financial support from public, commercial, or not-for-profit agencies.

AI Assistance Disclosure

The author acknowledges the use of artificial intelligence tools during the preparation of this thesis, primarily for the purpose of language editing, grammar checking, and stylistic refinement. Tools such as DeepL, Grammarly, Copilot, and Paperpal were used to improve the clarity, readability, and academic tone of the text. However, all research content, analysis, interpretations, and conclusions were developed independently by the author. These tools were not used to generate substantive academic content or to replace critical thinking and scholarly judgment.

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July 16, 2025

Abstract

This thesis examines the impact of water scarcity on GDP per capita using a panel dataset spanning more than 120 countries from 1995 to 2020. Employing a two-way fixed effects model, the study exploits within-country variation over time while controlling for unobserved heterogeneity and global shocks. This analysis incorporates mitigation mechanisms directly into the empirical strategy, specifically through interactions between water stress and desalination capacity. The results indicate that a one-point increase in the Water Stress Index (scaled 0–100) is associated with a 2% to 5.9% decline in real GDP per capita. However, these adverse effects are significantly mitigated in countries with advanced desalination infrastructure: those in the top decile of desalination capacity offset up to 83% of the expected losses. The effectiveness of this buffering mechanism depends on governance quality, energy affordability, and institutional capacity. These findings illustrate the importance of integrated adaptation strategies that combine technological investment with institutional resilience in water-scarce economies.

Keywords: Water Scarcity, Water Stress Index, GDP, Two Way Fixed Effects, Desalination

Abstrakt

Tato diplomová práce zkoumá dopad nedostatku vody na hrubý domácí produkt na obyvatele (HDP per capita) pomocí panelového datového souboru zahrnujícího více než 120 zemí v období 1995 až 2020. Pomocí modelu s dvojitými fixními efekty analýza využívá vnitrostátní variabilitu v čase při současné kontrole nepozorované heterogenity a globálních šoků. Tato analýza přímo začleňuje mitigační mechanismy do empirické strategie, zejména prostřednictvím interakcí mezi vodním stresem a kapacitou odsolování. Výsledky ukazují, že zvýšení indexu vodního stresu o jeden bod (na škále 0–100) souvisí s poklesem HDP per capita přibližně o 2 % až 5,9 %. Tyto negativní dopady jsou však výrazně zmírněny v zemích s rozvinutou odsolovací infrastrukturou: státy v nejvyšším decilu odsolovací kapacity dokáží kompenzovat až 83 % očekávaných ztrát. Účinnost tohoto tlumicího mechanismu závisí na kvalitě správy, dostupnosti energie a institucionální kapacitě. Tato zjištění ilustrují důležitost integrovaných adaptačních strategií, které kombinují technologické investice s institucionální odolností v oblastech trpících nedostatkem vody.

Klíčová slova: nedostatek vody, index vodního stresu, HDP, model s dvojitými fixními efekty, odsolování

Acknowledgments

I would also like to express my gratitude to Sebastian Ottinger for his help and ability to inspire passion for economics. I want to thank all the support received during these years by my mathematician colleagues, Tonino Costa, Leandro Aroca, Christian Villarroel, Leonardo Oyarzún, Daniel Guía, my friends at CERGE-EI, the team of the Environmental Centre of Charles University, and to my family, especially, Kristina and Bruno for their love and for inspiring me to research ways to contribute to create a better and happier world.

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Prague, Czech Republic

July, 2025

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1. Introduction

Water scarcity is a condition where the available freshwater resources are insufficient to meet the demands of a population, either due to physical limitations or institutional constraints. It manifests as physical scarcity when natural water supply is inadequate, and economic scarcity when infrastructure or governance fail to deliver water effectively. This scarcity threatens agriculture, public health, and industrial productivity, making it a constraint on long-term economic development. In poor countries, where institutional capacity and infrastructure are often weak, water stress can quickly translate into economic stagnation, food insecurity, and public health crises.

Water scarcity is increasingly recognized as a global development constraint, yet its direct macroeconomic effects remain underexplored. While prior research has examined local or sectoral impacts, especially in agriculture, few studies have quantified how water scarcity translates into reduced economic performance at the country level, nor evaluated the effectiveness of technological adaptation in mitigating such losses.

To address this gap, this thesis explores the economic consequences of water scarcity, analysing its potential impact on real GDP per capita**.** I employ a panel dataset of over 120 countries covering the years 1995 to 2020 and estimate a two-way fixed effects model of log real GDP per capita on a Water Stress Index (WSI), controlling for demographic structure, climatic variability, governance quality, and sectoral GDP composition. The main explanatory variable, WSI, is sourced from the Sustainable Development Goal indicator 6.4.2. of the United Nations and operationalized as freshwater withdrawals relative to renewable water availability.

To identify the control for time-invariant country-level confounders and country-invariant year-level confounders of water scarcity on economic output while addressing potential endogeneity concerns, I employ a panel data approach with two-way fixed effects to control for unobserved heterogeneity across countries and over time. Additionally, I use a set of time-varying country-level controls including temperature, precipitation, governance indicators, and trade openness to mitigate omitted variable bias. By leveraging within-country variation over time and including year dummies to capture global shocks, this strategy strengthens the credibility of my estimated relationship between water stress and GDP.

The findings show that a one-unit increase in the scaled Water Stress Index (WSI), corresponding to a 100-percentage point rise in water stress is associated with a 5.9% reduction in real GDP per capita in the baseline model, and a 2% reduction when additional controls are included in the full model. These results emerge from two-way fixed effects regressions and remain robust across a range of specifications, including Driscoll-Kraay corrections, functional form adjustments, placebo tests, and subsample analyses.

Compared to estimates from international organizations using Computable General Equilibrium (CGE) models — such as those by the World Bank — which simulate economy-wide interactions under environmental stressors and project a global GDP reduction of 6% to 18% due to water scarcity by the year 2050, the results of this study are of similar magnitude, though derived using a different methodology: Panel econometric techniques with fixed effects and robustness checks

Can technology help countries face this environmental shock? My analysis finds that the economic buffering effect of desalination is highly heterogeneous across countries. Nonetheless, the impact of water scarcity is significantly mitigated in countries with advanced desalination infrastructure: those in the top decile of desalination capacity offset up to 83% of the expected losses.

While most countries exhibit modest mitigation effects, a small subset, approximately 22 of 113 countries analysed achieves mitigation rates exceeding 10% of the water stress penalty, with a few countries not only fully offsetting the negative economic impact of water scarcity, but reversing it, generating net GDP gains under high desalination capacity. This heterogeneity illustrates that the protective potential of desalination depends on the scale of technological deployment, institutional quality, and local water stress conditions.

Several limitations of this analysis require consideration. First, while the two-way fixed effects model controls for unobserved country-specific and time-specific factors, endogeneity remains a concern, particularly regarding desalination capacity, which is likely determined alongside economic development and institutional strength. Although robustness checks such as dynamic panel estimation and placebo tests support the results, instrumental variable approaches were not viable due to weak instruments, limiting causal inference. Second, the model assumes a uniform marginal effect of desalination, but in reality, its effectiveness may vary with governance, energy costs, and infrastructure quality—heterogeneities not fully captured in the analysis. Third, data on desalination are limited, especially for developing countries, and rely on proxies that may introduce measurement error. Additionally, country-level aggregation may mask subnational variation in water stress and access to technology.

Finally, the GDP gains observed in high-desalination countries such as the UAE, Qatar, and Israel likely reflect not only desalination but also broader institutional and fiscal advantages. As such, the estimated effects should be interpreted as associations with causal plausibility, rather than definitive causal impacts. In addition, due to weak instruments, causal claims are limited, and estimates should be interpreted with caution.

This thesis contributes to the literature in several ways. First, it provides a systematic empirical assessment of the relationship between water scarcity and economic performance, using a global panel dataset and a two-way fixed effects framework. By focusing on within-country variation over time, the analysis offers a perspective on how rising water stress is associated with changes in real GDP per capita, complementing existing projections from other studies.

Second, the paper examines the role of desalination as a potential adaptation strategy, showing that while its economic buffering effect is limited in most countries, a subset of nations with high desalination capacity appears to experience significantly reduced losses and, in some cases, even positive economic outcomes under high water stress. This suggests that technological adaptation may play a meaningful role in certain contexts, though its effectiveness likely depends on broader institutional and infrastructural conditions.

Third, by integrating measures of governance, climate, and sectoral structure, the analysis highlights the multidimensional nature of water-related economic vulnerability. Rather than presenting desalination as a universal solution, the findings invite further reflection on how technological, institutional, and policy factors interact in shaping resilience to water scarcity.

2. Motivation for a country-level study

The rationale for studying water scarcity at the country level is based on three key considerations. First, economic relevance: Water availability is directly tied to industrial output, agricultural productivity, and energy production, all of which operate at a national level and influence overall GDP performance. Second, policy and governance: National governments play a central role in managing water resources, funding desalination infrastructure, and regulating agricultural irrigation. Institutional responses to scarcity often shape each country’s economic consequences. Third, data availability: Cross-country panel data offer the most comprehensive way to simultaneously analyse variations in water scarcity, mitigation strategies, and economic output over time.

Technological adaptation, particularly desalination, is a key strategy for offsetting water scarcity in arid and water-stressed economies. Large-scale desalination infrastructure has been widely adopted in regions including the Middle East, Australia, and Southern Europe, and can enable continued economic activity despite declining freshwater availability. However, desalination is not without drawbacks: it requires substantial energy inputs, involves high operational costs, and has negative environmental implications. Therefore, the effectiveness of desalination in sustaining economic growth remains an empirical question this study aims to address.

Beyond desalination, improvements in agricultural irrigation efficiency and water governance can also serve as mitigation mechanisms. In this study, these factors are incorporated into an econometric framework to test whether nations that invest in water augmentation technologies and institutional resilience experience less severe economic losses from water scarcity.

Rather than treating technological adoption as a universal solution, this thesis evaluates its role within a broader economic context and explores whether technology can significantly buffer the negative effects of scarcity or whether policy interventions and governance structures play a greater role.

3. Limitations of the study

This study aims to assess the macroeconomic consequences of water scarcity and evaluate the potential mitigating role of desalination technologies. The approach is empirical, drawing on panel data for a global sample of countries over a 25-year period. Emphasis is placed on identifying within-country variation in economic performance as a function of hydrological stress, with particular attention to whether technological adaptation specifically, expansion of desalination capacity attenuates the negative economic impact.

The empirical analysis is conducted at the country level using an unbalanced panel of over 120 countries, with annual observations spanning from 1995 to 2020. The temporal boundaries are driven by the availability of consistent data for key variables such as GDP per capita, population, climatic indicators (temperature and precipitation), and the water stress indices compiled by global environmental databases. The inclusion of desalination-related variables is constrained to countries for which reliable estimates or proxies of desalination activity such as total installed capacity or regional presence can be constructed.

The dependent variable in this model is real GDP per capita, measured in constant US dollars. The main explanatory variables include high-resolution indices of water scarcity, particularly the Water Stress Index (WSI) and the Falkenmark indicator, supplemented by climate control variables (e.g., mean surface temperature and precipitation), institutional quality metrics, and sectoral composition of output. Mitigation is captured through the inclusion of desalination as an explanatory and interactive variable. Where possible, governance and adaptation capacity are proxied through Governance Indicators and irrigated agricultural value added.

This thesis examines the relationship between water stress and economic output, with a particular focus on the potential mitigating effects of technological adaptations such as desalination. The econometric strategy employed is based on two-way fixed effects (TWFE) and interaction terms to identify within-country variation over time. However, caution must be exercised in the interpretation of coefficients. The empirical analysis aims to uncover robust associations and, where feasible, approximate causal effects. Nonetheless, several limitations must be acknowledged.

First, despite I implement a series of robustness checks, including placebo regressions using lagged variables, dynamic panel estimation through Arellano-Bond GMM, and functional form sensitivity using Box-Cox and PPML specifications, some regressors may still remain endogenous. A remarkable example is desalination capacity, which is plausibly determined jointly with income levels, governance quality, and broader adaptive institutional capacity. Whereas my initial attempts to address this through instrumental variables (IVs) were conceptually sound, the instruments were ultimately discarded due to statistical weakness and lack of robustness. I acknowledge that TWFE panel model without an exogenous shock or IV weakens causal claims, especially in non-random, time-varying settings.

Second, although TWFE is a powerful and widely used method to control for unobserved heterogeneity, recent methodological contributions have highlighted its limitations in the presence of treatment effect heterogeneity or staggered adoption (see Goodman-Bacon, 2021; Barrios, 2021). These concerns are particularly relevant when interaction terms (e.g., desalination × WSI) may themselves be influenced by latent trends or selection dynamics.

Taken together, these limitations imply that the estimates presented here should be interpreted as correlations with causal plausibility, rather than definitive causal effects. The results are consistent with a causal interpretation under reasonable assumptions, but further identification strategies such as valid IVs or quasi-experimental designs would be necessary to fully establish causality (see 7.3. Future Research).

This study faces several limitations that should be acknowledged. First, data availability remains uneven, particularly in developing countries where desalination efforts are either recent or poorly documented. This creates a potential measurement error in the desalination proxy and may introduce bias if desalination is endogenous to unobserved shocks. Second, while panel fixed effects help control for time-invariant heterogeneity, they do not address omitted variables that vary over time, and which may be correlated with both water stress and economic performance. Third, the resolution of environmental indices, though improving, may still mask important sub-national variation, especially in large countries. Finally, the causal interpretation of mitigation effectiveness rests on the assumption that the interaction term between desalination and water stress is not confounded by third factors such as institutional reform, international aid, or concurrent infrastructure investments.

While this study finds that a small group of countries with advanced desalination capacity appear to not only offset but even reverse the negative GDP impacts of water scarcity, it is important to clarify that these findings should not be interpreted as conclusive evidence of a purely causal effect. Countries demonstrating such reversal including the UAE, Qatar, and Israel also tend to exhibit high governance quality, and fiscal capacity, suggesting institutional capabilities that support effective water management and economic adaptation. These factors may interact with desalination in ways that amplify its effectiveness or independently contribute to economic resilience under water stress. Therefore, while the association between high desalination capacity and GDP gains under water scarcity is robust in the data, it is likely that this relationship reflects a combination of direct mitigation effects and correlated advantages stemming from broader structural and institutional strengths.

Another limitation is that this analysis implicitly assumes technological neutrality in the economic effects of desalination, treating its impact per unit of capacity as homogeneous across contexts. In practice, the marginal effectiveness of desalination likely varies depending on governance quality, energy costs, and local water pricing structures. Future research could explore these heterogeneities to better understand where desalination is most effective as a mitigation strategy.

The observed reversal of the economic impact of water scarcity in high-capacity desalination contexts raises potential concerns regarding endogeneity. Specifically, countries that invest heavily in desalination infrastructure often do so alongside broader initiatives in infrastructure, governance reform, and energy system development, which may simultaneously enhance economic growth and resilience. As such, desalination capacity may be endogenous to unobserved shocks or long-term development trajectories that also influence GDP outcomes. Although this study controls for key institutional and macroeconomic variables within a fixed-effects framework to mitigate bias, the possibility remains that the estimated mitigation and reversal effects partially capture correlated improvements in governance, energy affordability, and institutional quality rather than the isolated impact of desalination. Future research using quasi-experimental or dynamic panel approaches could help to disentangle these effects and provide clearer causal attribution.

Despite these limitations, this study contributes to the literature by applying a transparent and replicable econometric strategy to a globally relevant question, pushing forward the empirical integration of environmental constraints, technological adaptation, and macroeconomic outcomes.

4. Literature Review: Economic Impacts of Water Scarcity and Mitigation Technologies

In this section, I describe the current state of knowledge regarding water scarcity in both environmental and economic sustainability contexts. Although institutions such as FAO and the World Bank have historically focused on water-related issues primarily through the lens of agricultural productivity, hydrological planning, and environmental externalities, economic analyses of water scarcity, particularly in relation to macroeconomic outcomes and technological mitigation strategies, remain scarce.

Most contributions in this space have emerged from disciplines outside of economics, particularly from hydrology and civil engineering, and focus on basin-scale modelling and localized technical assessments. For example, a large body of work has focused on hydrological stress in river basins and climate-induced water variability, though there have been only limited attempts to rigorously estimate the economic impact of water shortages across countries or over time. Even when water is analysed in economic terms, it is typically embedded within Computable General Equilibrium (CGE) models that, while useful for scenario simulation, suffer from black-box criticisms due to their complexity and sensitivity to calibration assumptions (Böhringer, Rutherford, & Wiegard, 2003). In addition, CGE approaches are meant to simulate future scenarios, while the estimates of this thesis reflect historical impacts.

This thesis contributes a novel econometric approach that complements and challenges prevailing modelling frameworks. First, I focus on estimating the macroeconomic impact of water scarcity using panel econometric techniques, particularly two-way fixed effects (TWFE) models that isolate within-country variation over time.

While the econometric framework of this thesis, panel fixed effects and instrumental variable estimation is well established in development and environmental economics, its application to global water stress and technological mitigation remains rare, especially in desalination contexts. The thesis aims to explore the causal effects of water stress on GDP by assembling a novel multi-source panel and adapting both technological and climate-based variables. The integration of interaction terms with desalination capacity further advances the literature by empirically quantifying the buffering role of infrastructure adaptation in macroeconomic outcomes. To the best of my knowledge, this is the first cross-country study to include only macroeconomic indicators, desalination technologies, and climate variables together in the same panel.

Secondly, this thesis aims to innovate by incorporating mitigation technologies namely desalination into the econometric model. Desalination is increasingly promoted as a strategic solution for bridging water supply-demand gaps, particularly in arid and high-income coastal regions (World Bank, 2019). However, as emphasized by the World Bank and others, most empirical literature on desalination remains highly technical, with a focus on engineering design, plant-level cost structures, and environmental impacts, rather than an evaluation of its macroeconomic role in enabling resilience or economic continuity in the face of water stress

Finally, inclusion of governance indicators and sectoral economic variables namely the share of GDP derived from irrigated agricultural produce offers a richer, policy-relevant perspective. Prior studies that do incorporate economic variables tend to overlook these channels, which are central to understanding differential vulnerability and adaptive capacity across countries.

In summary, this dissertation makes three main contributions to the literature on water and economic development: (1) Applying robust econometric identification strategies to a question often dominated by simulations and forecasts; (2) Integrating high-resolution environmental and mitigation data into macroeconomic models; and (3) Empirically evaluating the effectiveness of desalination and governance quality as moderating factors. Together, these contributions offer a policy-relevant framework for understanding not only the costs of water scarcity but also the economic value of technologies designed to mitigate it.

5. Concept and Definition of Water Scarcity

In this section I aim to explain the most important concepts related to water scarcity. In a general approximation, The United Nations, in its Sustainable Development Goal 6 framework, defines water scarcity as "the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully" (UNESCO, 2018, p. 10).

This definition recognizes scarcity not only as a mismatch between supply and demand, but also as a function of institutions—laws, infrastructure, and governance—that shape allocation and access. This is in line with the growing body of environmental economics that understands natural resource constraints through the lens of institutional capacity.

The main challenge of this topic is that conceptualization and measurement of water scarcity remains contested amongst scholars and reflects a diverse range of disciplinary priorities. From hydrologists to institutional economists, researchers have attempted to define and quantify water scarcity in ways that are both policy-relevant and empirically tractable. However, for economic analysis, indicators must capture constraints on productive capacity and resource use.

This thesis therefore relies on two complementary measures: the **Water Stress Index (WSI)** and the **Falkenmark indicator** (Total Renewable Water Resources per capita, TRWR). WSI, used under Sustainable Development Goal 6.4.2, quantifies annual freshwater withdrawals relative to the renewable supply, highlighting countries where water is being consumed at potentially unsustainable rates, which can directly limit economic activity. In contrast, the Falkenmark index emphasizes structural water endowment, offering a long-term view of resource availability per person. Together, these indicators reflect both demand-side pressure and supply-side scarcity and provide a coherent framework to study their macroeconomic consequences. To maintain a focus on the economic aspects of the study rather than its hydrological aspects, further explanations can be found in Appendix 2 of this thesis.

5.1 Falkenmark Indicator or Total Renewable Water Resources

The most widely cited benchmark for water scarcity in the global literature is the Falkenmark or Total Renewable Water Resources per capita (m^3/year), which categorizes scarcity according to per capita annual renewable water availability. The classification thresholds are as follows: less than 1,700 cubic meters (m^3) per person per year indicates "water stress," less than 1,000 m^3 indicates "water scarcity," and less than 500 m^3 denotes "absolute scarcity" (Damkjaer & Taylor, 2017). The values of 1,700 and 1,000 m^3 thresholds do not represent exact physiological needs but reflect socio-economic vulnerability to water stress (UNESCO, 2024).

To contextualize these thresholds, consider that the minimum human physiological requirement for drinking water is roughly 2–3 litres per day, or about 1 cubic meter (m^3) per year (Gleick, 1996). However, total water use per person, including for food production, sanitation, energy, and industrial processes, is significantly higher. According to the World Health Organization (WHO, 2005), the minimum requirement for drinking and basic hygiene is approximately 50–100 litres per person per day, which corresponds to 18–36 cubic meters per year. However, when accounting for agricultural, industrial, and ecosystem demands, total water use per capita in high-income countries often exceeds 1,000 m^3 annually (FAO, 2022). Indeed, the average person in a high-income country indirectly consumes 2,000–5,000 litres of water per day through food, goods, and services, amounting to 700–1,800 m^3 per year (UNESCO, 2023). This means that the Falkenmark threshold of 1,700 m^3 per capita per year roughly corresponds to the minimum level needed to sustain a modern economy and basic human well-being. Falling below this level implies that water scarcity may begin to constrain agricultural output, energy systems, and public health infrastructure in addition to basic human hydration needs.

This index has been influential because of its simplicity and scalability across countries and times. However, its widespread use has also been criticized for its lack of empirical validation. As Damkjaer and Taylor (2017) emphasize, “The values of 1,700 and 1,000 m³ per capita year have been uncritically adopted and assimilated in the mainstream literature without an empirical basis’ (p. 516).

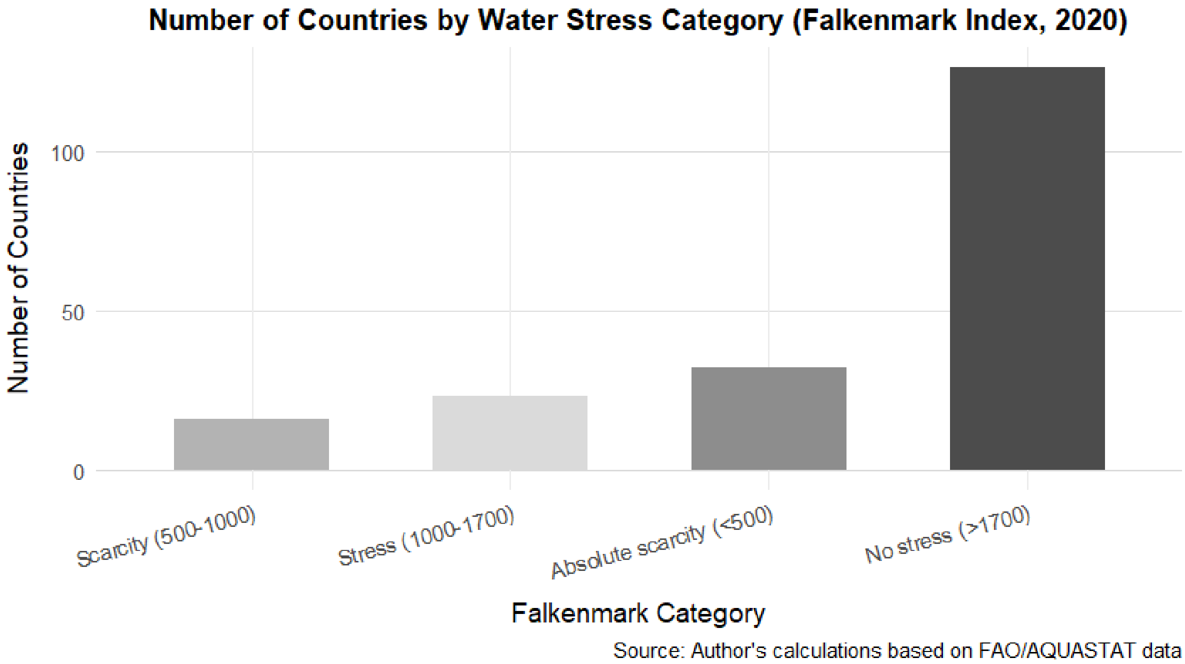

Figure 1. Distribution of Countries by Water Stress Category (Falkenmark Index, 2020)
According to the Falkenmark Index classification, the majority of countries (approximately 125) currently face no water stress, with annual renewable water availability above 1700 m³ per capita. In contrast, just over 25 countries fall into the “absolute scarcity” column (<500 m³), while smaller groups fall within the scarcity (500–1,000 m³) and stress (1,000–1,700 m³) thresholds. The distribution reflects a pronounced asymmetry in freshwater endowment, with a relatively small subset of countries bearing the brunt of water scarcity.

Figure 2 presents the distribution of countries by water stress category in 2020. More than 60% of the countries analysed are currently not experiencing water stress, with annual renewable resources exceeding 1,700 m³ per capita. This suggests that physical scarcity is not a universal constraint and that policy responses must be geographically differentiated. However, the lower tail of the distribution is of particular concern. More than 25 countries fall into the “absolute scarcity” category, defined by availability below 500 m³ per capita, a range in which fundamental human and ecological needs may not be met. An additional group of countries faces moderate to severe scarcity (500–1,700 m³), often driven by population growth, agricultural intensity, and urban water demands.

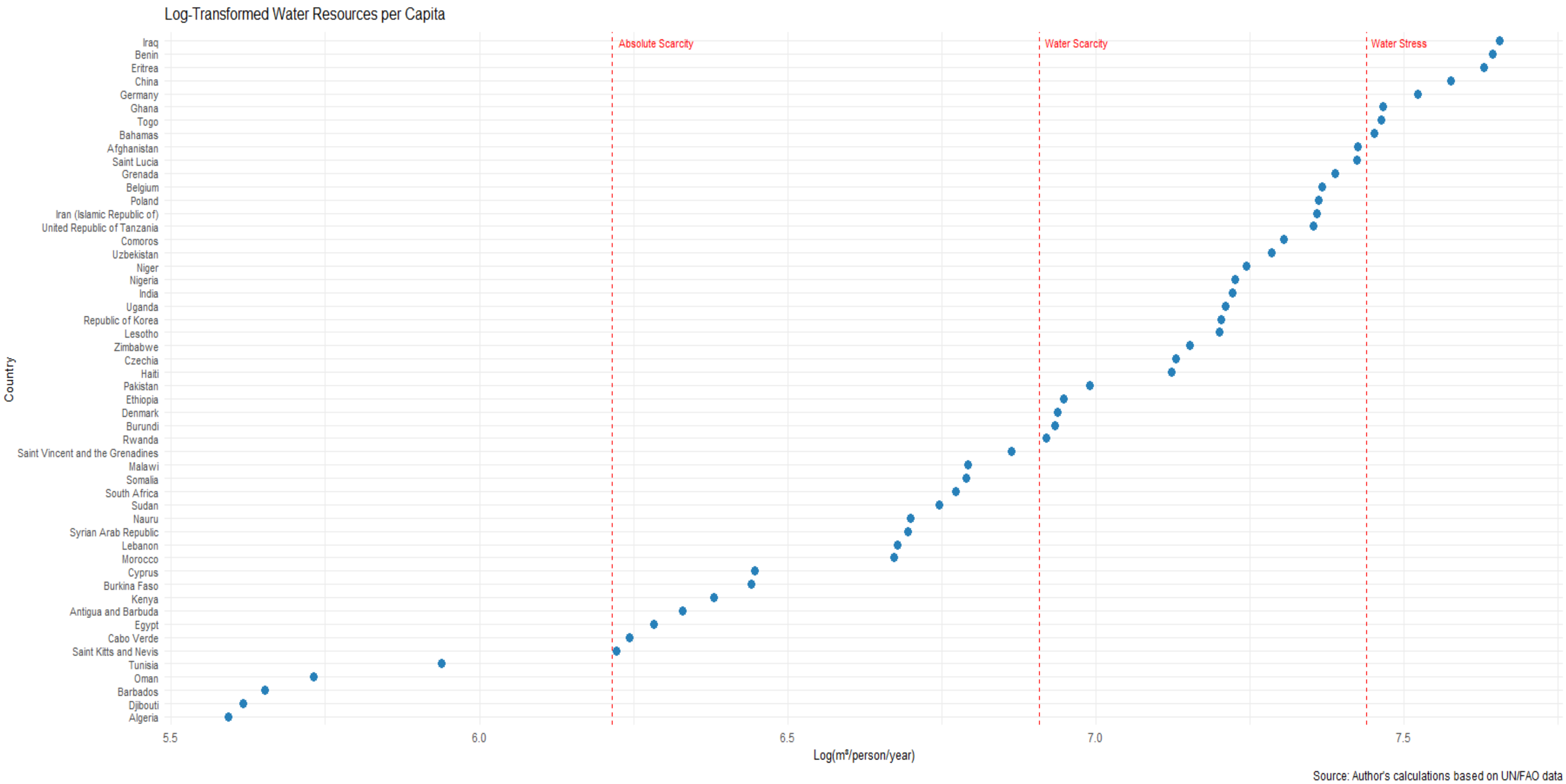

Figure 2 Global Water Availability per Capita (Log-Transformed). *This scatter plot displays the log-transformed water resources per capita across 50 countries centred around the log value 6.5. This allows comparison of water availability across nations, highlighting those facing severe scarcity or stress. The logarithmic scale helps manage large variations in water resources between countries.*

While these categories represent a minority in numerical terms, they include highly populated and economically significant regions including the Middle East and North Africa (MENA) and parts of South Asia. These results show extreme inequality in in per capita water endowments. The fact that a majority of countries do not suffer from water stress does not diminish the acute economic and developmental risks faced by those that do.

Unlike many other development indicators, TRWR per capita is not strongly correlated with GDP (UNESCO, 2024, *World Water Development Report*). Rather, it is overwhelmingly shaped by geography, especially climate, hydrology, and population density. Countries in tropical rainforest zones or alpine regions tend to have more abundant rainfall and rivers, whereas arid and semi-arid countries face natural constraints on water supply.

This geographic determinism has two important implications. First, countries cannot "grow" their renewable water base in the same way they can accumulate capital or labour. Second, the policy space for mitigating water scarcity must focus on adaptation through technology, imports, and/or institutional reform rather than expansion of natural supply.

The data also show that even countries with considerable absolute water availability can become water stressed when population size is considered. For instance, India and China are both water-rich in aggregate terms, yet due to their enormous populations, they experience water stress challenges. Wealth is not protective against natural scarcity. Several members — including Israel, Singapore, Kuwait, Qatar, and the UAE — have among the lowest TRWR per capita in the world yet maintain high standards of living and can boast of well-developed urban systems. What distinguishes these countries is not natural abundance, but institutional and technological capacity.

Israel, for instance, has offset natural scarcity through world-leading investments in desalination, wastewater reuse, and drip irrigation. Similarly, Gulf countries rely heavily on desalination and virtual water imports (i.e., importing water-intensive goods rather than producing them domestically). These cases emphasize a critical economic insight: natural scarcity can be mitigated (though not eliminated) by capital investment and institutional innovation.

Regional trends reflect broader development challenges. In Latin America, I observe relatively high TRWR per capita across most countries. This reflects a combination of low population densities and high rainfall, especially in the Amazon basin and Andean regions. However, despite this natural abundance, many countries in the region face issues of water access, inequality, and pollution, indicating that abundance does not necessarily equate to equitable or sustainable use.

Europe shows a clear north-south gradient. Nordic countries enjoy higher endowments of water, while Mediterranean countries including Spain, Italy, and France tend to face water scarcity challenges. This situation mirrors broader environmental and climatic patterns and aligns with the increasing concern over drought and agricultural water availability in southern Europe.

Finally, countries in Sub-Saharan Africa are spread across the spectrum are extremely water-rich (e.g., Congo, Gabon), while others (e.g., Sudan, Eritrea) face severe scarcity. This spatial variation reflects the continent's vast ecological diversity and reinforces the need for sub-regional water policies.

TRWR per capita is a national average and does not capture spatial or social inequalities in water distribution and access. A country may exhibit high per capita water availability while still experiencing localized scarcity, poor infrastructure, or unequal access across regions and income groups. This shows the advantages of combining broad national indicators with measures that capture institutional quality and how water resources are distributed within countries.

This analysis of TRWR per capita across countries highlights how geography, population pressure, and economic adaptation interact in shaping global patterns of water scarcity. In this sense, the Falkenmark Index offers a convenient scalar for international comparisons as a supply side measure. However, it does not account for institutional responses, adaptive behaviour, or the social and economic infrastructure that mediates water use.

5.2. Water stress index (WSI)

In contrast to the Falkenmark approach (which relies on absolute per capita thresholds), the Water Stress Index (WSI), also known as the Withdrawal-to-Availability Ratio (WTA), measures the proportion of total annual renewable water resources withdrawn for human use. This refers to the amount of freshwater extracted from sources such as rivers, lakes, and aquifers to support agriculture, industry, and households.

The WSI is calculated by dividing the total water withdrawals of a country by the TRWR (Falkenmark) and multiplying it by 100[1]. In other words, the index measures:

$$WSI = \frac{total\ water\ withdrawals}{Total\ renewable\ water\ resources} * 100$$

This thesis follows the United Nations approach of the Sustainable Development Goal 6.4.2. (UN-Water, 2021), also known as "Level of water stress: freshwater withdrawal as a proportion of available freshwater resources"[2]. According to this approach, water stress levels are categorized based on the proportion of a country's annual freshwater withdrawals relative to its total renewable water resources. Thus, the country is considered to experience **low stress** when water use is below 25%. In a low stress scenario, water use is generally sustainable, and ecosystems are not significantly harmed under normal conditions. **Moderate stress** is defined as usage between 25% and 50%, and signals growing pressure: countries may begin to face regional or seasonal shortages, especially during droughts, making this a warning zone for policy action. When withdrawals reach between 50% and 70%, the country enters a state of **high stress**, where more than half of renewable supplies are consumed. This can compromise the flows needed to sustain healthy ecosystems, a clear indicator of overuse.

Finally, **very high stress** occurs when water use reaches or exceeds 75% of renewable resources, indicating near-depletion and growing dependence on non-renewable sources or on unsustainable virtual water imports—that is, water embedded in imported goods and services.[3] This level of stress reflects a critical condition requiring immediate and structural intervention.

This formula suggests a convergence between absolute and relative water scarcity approaches in terms of interpretative categories. Nonetheless, despite its intuitive appeal, the WSI suffers from several limitations.

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[1] It is important to note that throughout this thesis, I adopt the FAO perspective, treating the Water Stress Index (WSI) and the Withdrawal-to-Availability Ratio (WTA) as interchangeable terms. However, some literature views the WSI as a composite index that encompasses additional social factors like vulnerability or adaptive capacity. For the sake of clarity and simplicity, I do not incorporate these interpretations in this thesis.
Nonetheless, it is worth noting that scholars often provide other thresholds, for instance, in some cases, countries are classified as "water stressed" if their annual withdrawals lie between 20% and 40% of available freshwater, and "severely water stressed" when they exceed 40% (White, 2012). The WTA thus offers a relative measure of water system strain. these thresholds are often aligned with the Falkenmark benchmarks.

[2] https://unstats.un.org/sdgs/metadata/files/Metadata-06-04-01.pdf

[3] Virtual water imports refer to the volume of freshwater embedded in imported goods, particularly agricultural and industrial products, which require water during production. By importing these water-intensive commodities, especially food crops, water-scarce countries effectively "import" water, thereby alleviating pressure on their domestic resources (Hoekstra & Chapagain, 2008).

First, this index relies on the Total Renewable Water Resources, which is a Mean Annual Renewable Resources (MARR) metric. Because the MARR serves as a denominator, it can underestimate or misrepresent critical temporal and spatial variability in water availability. Damkjaer and Taylor (2017) caution that: "The use of MARR to characterise freshwater resources means that the WTA approach, like the WSI, masks seasonality and inter-annual variability in freshwater resources" (p. 518).

Second, the WSI does not differentiate between water withdrawals and actual consumption. A portion of withdrawn water (especially in agriculture) is often returned to the environment, albeit at different levels of quality. Finally, the WTA metric does not account for a country's **adaptive capacity:** its ability to cope with stress through technology, institutions, or infrastructure (White, 2012). As such, two countries with the same WTA ratio may face vastly different economic and ecological risks depending on their underlying capabilities.

The Water Stress Index (WSI) comparisons for 1995 and 2020 (see figure 4 below) highlight significant changes in global freshwater dynamics. Over this 25-year period, one of the most notable trends has been the intensification of water stress, particularly in middle-income and fast-growing economies. Over this 25-year period, one of the most notable trends has been the intensification of water stress, particularly in middle-income and fast-growing economies. These estimates are based on WSI data computed from AQUASTAT indicators and harmonized using population-weighted averages per country-year. A detailed description of data sources and construction methodology is provided in Section 4.1.3 (Data sources and compilation) of this thesis.

Regions classified under "Very High-Water Stress," where annual water withdrawals meet or exceed 70% of renewable resources, have grown considerably since 1995. Initially concentrated in arid zones of the Middle East and North Africa (MENA) and parts of South Asia, by 2020, this severe stress is also evident in Sub-Saharan Africa (e.g., Sudan, South Africa), South and Central Asia (e.g., India, Pakistan, Uzbekistan), and areas of Latin America like northern Mexico. These patterns reveal the combined effects of population growth, economic transformation, and insufficient water governance or infrastructure.

Meanwhile, some nations have maintained relatively stable water stress levels. Countries like Canada, Brazil, Indonesia, Russia, and those in Northern and Central Europe fall into the "Low Stress" category (0–25%). This stability is primarily due to favourable natural water availability, lower population densities, and/or effective management of water extraction and consumption. However, such stability often reflects natural advantages rather than superior water governance and may mask inefficiencies in specific sectors.

Emerging water stress in countries not previously affected highlights additional challenges. China's shift from moderate to high water stress demonstrates how rapid industrialization and agricultural expansion can outpace institutional capacity for water allocation. Similar trends are observed in Turkey, parts of eastern Spain, and regions in Central America and the Andes.

An additional development is the spread of water stress into regions not traditionally associated with aridity. While the 1995 distribution aligned more closely with climatic patterns, by 2020, water scarcity also reflects economic and institutional factors. This shift marks a transition from rainfall-driven scarcity to one determined by competing sectoral demands and governance challenges.

Amid these trends, there are examples of improvement. Portugal offers a case in point. Previously experiencing moderate to high water stress, by 2020, the country had shifted to lower stress levels. Contributing factors include the implementation of the European Union Water Framework Directive, transitioning to more water-efficient agricultural practices, and a broader economic shift toward service industries. Similar dynamics can be seen in France and Germany, where environmental regulation, efficiency improvements, and structural economic changes have stabilized or reduced water stress.

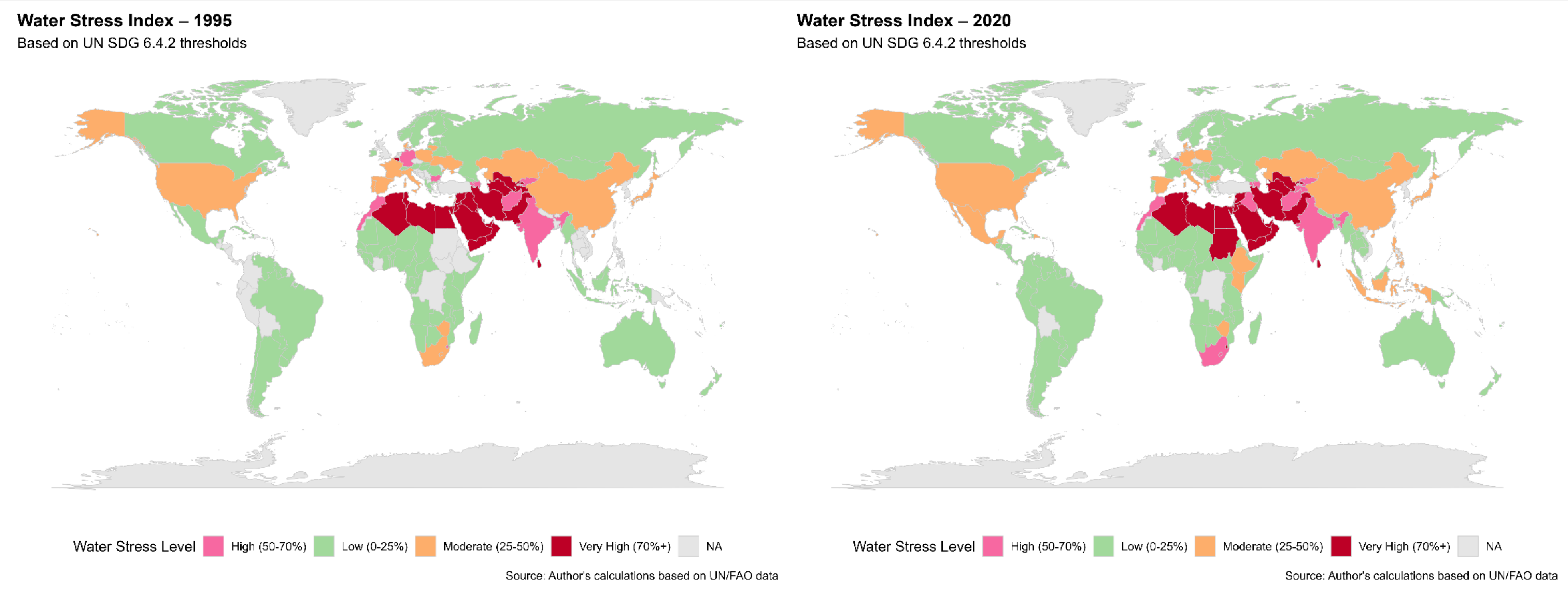

Figure 4 – Global Water Stress Index (1995 vs 2020). This figure illustrates the global progression of freshwater pressure through the Water Stress Index (WSI). Countries are grouped into four stress categories: low (0–25%), moderate (25–50%), high (50–70%), and very high (above 70%). The left panel depicts conditions in 1995, while the right panel presents the most recent data from 2020. Over the past 25 years, there has been a notable rise in regions experiencing high and very high water stress, particularly in Mexico, North Africa, the Middle East, and parts of South and Central Asia, highlighting intensifying pressure on global water systems.

The evolution of global water stress between 1995 and 2020 tells a broader story. Water scarcity is no longer confined to a few arid regions, it is now a structural, institutional, and economic issue that affects diverse geographies and development levels. Addressing it requires a multifaceted policy approach, from technological innovations (e.g., desalination, water reuse) to economic reforms (e.g., pricing strategies) and governance improvements (e.g., integrated basin management). For economists, the WSI serves not only as a hydrological metric, but as an indicator of broader macroeconomic risks, regional disparities, and institutional resilience under growing pressure.

5.3. Justification for the chosen metric: WSI

This thesis adopts the Water Stress Index (WSI) as the primary measure of water scarcity. This choice is based on data availability, policy relevance and conceptual fit. Its alignment with international policy benchmarks, particularly Sustainable Development Goal 6.4.2., makes it the best choice. Unlike alternative indicators such as the Falkenmark, the WSI captures the share of available renewable water extracted each year and offers a direct measure of demand pressure on a country's water system. This is especially useful for cross-country macroeconomic analysis, by allowing assessment of water scarcity in relation to factors including technological adoption, governance, and economic structure.

6. The impact of water scarcity on economic output

6.1. Methodology

The methodology I use consists of a quantitative panel data analysis applied to a cross-country dataset spanning 1995–2020. I employ fixed-effects regression models to estimate the within-country effects of water scarcity on real GDP per capita. This approach allows me to account for unobservable time-invariant heterogeneity across countries while isolating the variation attributable to water stress and related mitigation factors.

This thesis estimates the equations using the *feols* function from the *fixest* package in R, with country-clustered standard errors. This estimation strategy is applied consistently across a baseline specification and an extended structural model that incorporates interaction terms and mitigation technologies. The empirical analysis follows a stepwise modelling structure to facilitate interpretation and to test the robustness of results under varying assumptions.

In all regressions and figures, the Water Stress Index (WSI), originally defined as a ratio in the 0–1 range, is multiplied by 100. This allows all coefficient estimates to be interpreted as the effect of a one percentage-point increase in water stress. For example, an increase in WSI from 30 to 31 corresponds to a 1-point increase in the scaled WSI used throughout this thesis.

In addition, the study performs robustness checks and sensitivity analyses using alternative samples, functional forms, and missing-data treatments. This ensures that the core findings are not driven by sample selection or model specification choices and enhances the reliability of the conclusions for policy relevance.

Research design and quantitative approach

I estimate fixed-effects panel regressions to control for unobserved heterogeneity across countries and years. This method allows the isolation of the within-country variation over time while accounting for time-invariant characteristics and global shocks. The analysis focuses on identifying correlations and aims to estimate causal relationships where feasible, particularly by examining how changes in water stress are associated with changes in economic performance.

Despite my efforts to mitigate endogeneity concerns, including robustness checks, the use of two-way fixed effects (TWFE), and interaction terms, it is important to acknowledge that some variables in the analysis may remain endogenous. For instance, desalination capacity is plausibly endogenous to governance quality and income levels.

Whereas this thesis employs several strategies to address these issues, the instrumental variables (IVs) initially considered were ultimately excluded due to weakness, limiting the ability to draw strong causal inferences. Therefore, although the analysis seeks to uncover meaningful associations and potential causal pathways, the findings should be interpreted with caution. The results are best viewed as indicative rather than definitive, and any policy implications should be drawn conservatively.

Justification of econometric methods and identification strategy

This study uses panel data regressions with a two-way fixed effects (TWFE) model to account for countries and years. This method helps to account for constant country-specific factors (e.g. geography, culture, institutions) and global events (e.g. financial crises, climate changes). By using fixed effects, the model ensures that the results reflect changes within each country over time, rather than just differences between countries. The model also includes robust standard errors, grouped by country, to correct for patterns in the data that may repeat over time (serial correlation) and variations in error terms (heteroskedasticity). This improves the accuracy of the results.

Following Angrist and Pischke (2009), this thesis employs a TWFE panel estimation model to analyse the impact of water scarcity on economic output, using within-country variation while controlling for unobserved heterogeneity across countries and global shocks over time. The logic of TWFE rests on controlling for time-invariant country characteristics (geography, institutional traditions, or baseline water endowments) and year-specific shocks (global commodity price fluctuations or climate anomalies), allowing the estimation to capture how changes in water stress correlate with changes in GDP within each country over time. This is relevant in this study, where water scarcity cannot be randomly assigned across countries, and TWFE provides a tractable and policy-relevant framework for quantifying its economic impact.

The methodological choice to use TWFE in this thesis is not new in literature and aligns with the lessons from LaLonde (1986), Heckman et al. (1998) and Smith and Todd (2005),, who highlight the limitations of cross-sectional comparisons in causal inference. By employing TWFE, and to address these biases, this thesis employs a panel structure with two-way fixed effects, controlling for country-specific and year-specific unobserved heterogeneity. It incorporates stepwise inclusion of controls (demographics, climate, governance, sectoral structure) to mitigate omitted variable bias and checks robustness with Driscoll-Kraay standard errors, placebo tests with lagged GDP, and subsample exclusions (e.g., MENA, high-income, landlocked countries) to test sensitivity. These steps ensure that the estimated impact of water scarcity on GDP reflects within-country changes over time, reducing bias from unobserved, time-invariant differences and aligning the empirical design with the best practices identified by LaLonde (1986) and Heckman et al. (1998).

In the context of this thesis, the use of TWFE, together with a set of time-varying controls and robustness checks (including placebo tests and alternative estimators). This empirical strategy helps mitigate the biases typical of cross-sectional designs and leverages the panel structure to identify the within-country economic impact of water scarcity.

Given the challenges of identifying strong and valid instruments in the environmental macroeconomic context, as highlighted by Deaton (2009), the TWFE model offers a transparent and empirically grounded strategy and ensures that the analysis maintains internal validity and provides actionable insights for policy design under water stress.

Although the empirical approach is observational, the inclusion relevant controls is intended to reduce potential confounding and provide a more credible approximation of the underlying relationships.

Finally, regarding the identification strategy, to estimate the relationship between water stress and economic output I incorporate a comprehensive set of time-varying controls, including temperature, precipitation, governance quality, trade openness, sectoral composition, and urbanization to mitigate omitted variable bias. I assess robustness through alternative estimators. placebo tests, and subsample analyses to ensure the stability of the results. While I explored instrumental variable approaches using climatic indices (SPEI and Droughts index of EM-DAT), they were ultimately not retained due to concerns about weak instrument relevance. As such, the identification strategy rests on the assumption that, conditional on the controls included in the model and the fixed effects specified, the remaining variation in water stress is plausibly exogenous to short-term economic fluctuations. This enables a credible estimation of its macroeconomic impact.

Data sources and compilation

This research integrates a wide range of macro-level indicators from multiple reputable sources to construct a balanced panel dataset suitable for cross-country econometric analysis. The paper derives population and urbanization data from the World Bank's World Development Indicators (WDI), including total population figures and the share of the population of a country living in urban areas. These demographic controls are essential for normalizing economic outcomes and understanding pressure on water resources.

The paper sources climatic variables from the Climate Research Unit (CRU) TS dataset, which provides globally gridded annual time series of surface temperature (TAS) and precipitation (PR). I incorporate the Standardized Precipitation Evapotranspiration Index (SPEI) is incorporated to capture drought-related anomalies and climatic extremes. Finally, I employ the annual incidence of drought disasters at the country level, as recorded by the EM-DAT International Disaster Database, maintained by the Centre for Research on the Epidemiology of Disasters (CRED), although these last two are used solely as references to illustrate the reality of water scarcity.

This thesis accounts for governance quality and uses the World Governance Indicators (WGI) of the World Bank. I consider specifically three dimensions: government effectiveness, regulatory quality, and rule of law. I normalize each variable by rescaling to a [0,1] range across the sample to ensure comparability. Then I construct a composite governance index (GI) by standardizing each of the three components: government effectiveness, regulatory quality, and rule of law. Each is converted into a z score with a mean of zero and unit variance. The index is calculated as an unweighted average of these standardized values. This approach ensures equal contribution from each dimension and enables consistent cross-country comparisons. The resulting composite index helps account for institutional factors that may influence water management and economic performance.

The study further compiles data on desalination capacity and irrigation efficiency from FAO AQUASTAT and related international datasets. Key indicators include desalinated water production, multiple disaggregated irrigation types, and water use by sector (agriculture, industry, and municipal). These are merged in the study with sectoral GDP shares (agriculture, manufacturing, and services) to capture structural economic composition. The paper extracts the primary dependent variables (GDP and GDP per capita) from the World Development Indicators of the World Bank and transformed into log form to enable elasticity interpretation and variance stabilization.

Desalination as a mitigation strategy

In the study the effects of water scarcity on economic output, it is also important to consider viable mitigation strategies. A central hypothesis of this thesis is that technological adaptation can significantly buffer the economic costs of water stress. Among the range of possible interventions, this study focuses on desalination, a process that removes salts and impurities from seawater or brackish water to produce freshwater suitable for human consumption, agriculture, and industrial use. The two dominant technologies are thermal methods such as Multi-Stage Flash (MSF) and Multi-Effect Distillation (MED) and membrane-based techniques, primarily Reverse Osmosis (RO), which has become the most widely adopted due to its higher efficiency and lower unit costs (World Bank, 2019).

Desalination is particularly relevant in arid and semi-arid regions, where renewable freshwater availability is naturally limited. Although energy-intensive, the cost of desalination has declined significantly over the past two decades. Modern reverse osmosis systems now produce freshwater at costs ranging from US$0.64 to US$1.62 per cubic meter, while MSF remains more expensive at an average of US$1.44 per cubic meter (World Bank, 2019). These ranges depend on plant size, technology, and energy inputs, but elucidate desalination's growing feasibility as a climate-resilient supply option (UNESCO, 2021).

Globally, up to 122 countries currently operate desalination facilities, but capacity is highly concentrated. The Middle East and North Africa (MENA) region leads in desalination adoption, particularly in Saudi Arabia, the United Arab Emirates, and Israel, where desalination now meets a large share of urban and agricultural water demand. Israel, for example, has achieved some of the world's lowest desalinated water costs through public-private partnerships such as the Sorek plant project (World Bank, 2019). Singapore has also integrated desalination into a diversified water supply strategy that includes rainwater harvesting and wastewater reuse (UNESCO, 2021).

In this thesis, desalination is operationalized as both a control and an interaction variable in the econometric models. The paper examines the log of desalinated output and its share in total freshwater withdrawals, enabling assessment of whether greater technological capacity moderates GDP loss created by rising water stress. This approach highlights the importance of adaptive capacity and illustrates how countries with advanced infrastructure may be able to convert hydrological vulnerability into macroeconomic resilience.

6.2. Variable construction

This section details the core variables used in the empirical analysis, drawn from harmonized international datasets and processed to ensure consistency across countries and years. The variables were selected to reflect the main channels through which water scarcity and mitigation efforts affect economic outcomes. The section describes the construction of three groups of variables: (i) the dependent variable representing economic performance, (ii) indicators of water scarcity, and (iii) control and mitigation variables that isolate the impact of water stress and capture adaptation strategies including desalination and irrigation modernization.

Dependent variable

The dependent variable (Y_{it}) is real GDP per capita, transformed into natural logarithmic form to facilitate elasticity-based interpretation and reduce heteroskedasticity across countries. Raw

GDP and population data were obtained from the World Development Indicators (WDI) database. Specifically, I use GDP[4] (constant 2015 US$), and Total Population[5].

I calculate GDP per capita by dividing constant GDP by total population for each country-year. The result was then transformed using the natural logarithm. This transformation helps stabilize variance, improve model fit in panel regressions, and allows coefficient interpretation in percentage terms.

The robustness checks also consider total real GDP[6] and annual GDP growth rates[7] as alternative dependent variables, drawn from the same WDI source. The log-transformed GDP per capita variable displays considerable variation, ranging from 5.43 to 11.63 (equivalent to approximately $227 to $112,418), with a mean of 8.63 (roughly $5,600). This suggests the presence of substantial income heterogeneity and validates the log specification for statistical efficiency and interpretability.

Using log GDP per capita allows for a direct interpretation of coefficient estimates as approximate percentage changes, enabling policy-relevant inference. It is also a standard practice in macroeconomic growth regressions, making the findings of this study comparable to the existing literature.

Key independent variables

The Water Stress Index (WSI), previously defined in Section 3.2, serves as the core independent variable. WSI exhibits a mean of 61.97%, but a much lower median of 9.73%, indicating substantial right-skewness due to extreme stress levels in a few countries. Desalination, proxied by the log of desalinated output, is highly concentrated, with a median value near zero and a maximum of 2.63, suggesting that this mitigation strategy is employed only in a limited number of cases.

To capture potential heterogeneity in the economic effects of water stress, this thesis includes interaction terms between the Water Stress Index (WSI) and mitigation variables. This approach tests whether countries with greater technological adaptation capacity experience attenuated economic impacts under high water stress conditions. The interaction framework

[4] Indicator code: NY.GDP.MKTP.KD
[5] Indicator code: SP.POP.TOTL
[6] Indicator code: NY.GDP.MKTP.KD
[7] Indicator code: NY.GDP.MKTP.KD.ZG

also allows for the estimation of marginal effects and the identification of mitigation thresholds across different levels of desalination deployment.

In addition, I construct a second variable to reflect technological adaptation: Desalination Share, defined as the ratio of total desalinated freshwater to total national freshwater withdrawals (0-1). This variable captures the relative importance of desalination in a country's water supply and allows comparison across countries regardless of their absolute output. It is particularly useful for interaction models, as it reflects not just capacity but structural dependence on desalination.

Control and mitigation variables

This thesis introduces a set of control variables to account for confounding factors. These include log population, to capture scale effects; urbanization rate, as a proxy for demographic pressure; and sectoral GDP shares (agriculture, manufacturing, and services) to reflect structural economic composition.

Mitigation variables include desalination share, used to assess technological responses to water stress. Other irrigation-related variables are included to reflect water-use efficiency: the percentage of irrigated agricultural GVA, the share of power-equipped irrigation systems, and the share of irrigation that uses recycled or treated water.

The study encapsulates the quality of governance in a composite Governance Index (GI), constructed from standardized z-scores of three institutional dimensions; government effectiveness, regulatory quality, and rule of law, all sourced from the World Governance Indicators (WGI). The GI ranges from –5.80 to +6.32 with a near-zero mean, confirming proper normalization and reflecting substantial institutional heterogeneity across countries. Controlling for this variation is essential to isolate whether stronger governance structures enhance resilience to the economic impacts of water scarcity.

Another important mitigation variable is the share of irrigated agricultural value added (Agri-Irrigated GVA), which captures economic reliance on irrigated agriculture. The median value of this variable is approximately 12.8%, but it spans a wide range from 0% to 123.6%. The fact that this upper bound exceeds 100%, likely reflects reporting inconsistencies or partial misclassification in national statistics, such as double counting of irrigated land or the inclusion of multiple crop seasons. Nevertheless, its inclusion as a proxy for water-use efficiency remains valuable given its relevance to agricultural productivity under water-stressed conditions.

These descriptive characteristics highlight the substantial cross-country variation in both economic structure and environmental pressures. For example, real GDP per capita in the dataset ranges from as low as approximately $227 to over $112,000 (in constant terms), while water stress levels, as measured by the Water Stress Index (WSI), span from near-negligible levels (0.13%) to extreme values exceeding 3,800%. This dramatic variation justifies the use of a panel structure with fixed effects to isolate within-country dynamics over time.

In addition to the total volume of desalinated water, this study constructs a new variable: the share of desalination in total freshwater withdrawals (hereafter, desalination share). This variable is defined as the ratio between annual desalination output and total national freshwater withdrawals:

$$Desalination\ Share = \frac{Desalination\ Output}{Total\ water\ Withdrawals}$$

This expression captures the relative importance of non-conventional water sources in a country's water supply portfolio. Unlike absolute desalination volumes, which may be large in absolute terms yet marginal in overall supply, desalination share reflects the degree of structural dependence on desalination. This makes it a more suitable proxy for evaluating whether technological mitigation reduces a country's economic vulnerability to water stress. The empirical distribution of desalination share is highly skewed: many countries exhibit structural zeros, either because they are landlocked, water-abundant, or economically constrained[8]. Oppositely, another subset of coastal and arid economies, for instance, those in the Gulf region such as Saudi Arabia, the United Arab Emirates, Kuwait, Qatar, Bahrain, and Oman, as well as Israel and Singapore, show exceptionally high values. This heterogeneity is leveraged in subsequent regressions to test whether higher desalination reliance attenuates the negative effect of water stress on GDP per capita, particularly through an interaction specification with the Water Stress Index (WSI).

This heterogeneity also underlines the appropriateness of adopting a cross-national empirical strategy. Countries differ not only in terms of their exposure to water scarcity but also in their institutional capacity to manage it, their technological responses, and their reliance on irrigated agriculture. Including this breadth of variation in the econometric analysis allows

[8] The main assumption is that countries that do not have access to direct seawater lack large-scale seawater desalination capacity. In the other hand, water abundant countries do not need it and thus do not try it, and economically constrained ones cannot afford it.

the model to capture a more nuanced and globally relevant picture of how water scarcity interacts with governance and infrastructure to shape economic outcomes.

6.3. Econometric specifications

This section presents the econometric strategy I adopt to estimate the impact of water scarcity on economic output. The analysis relies on a country-level panel dataset that spans multiple years and includes a wide array of climate, institutional, and technological indicators. The stepwise modelling structure adopted here, which is aligned with that of Angrist and Pischke (2009), facilitates the identification of treatment effects while explicitly addressing concerns over post-treatment variables ('bad controls'), ensuring a credible interpretation of causal parameters. Angrist and Pischke emphasize that, in observational data, clear identification strategies and transparency in assumptions are essential for credible causal inference. This guides the decision to use a two-way fixed effects (TWFE) panel estimation that leverages within-country variation while controlling for unobserved heterogeneity across countries and over time.

Following LaLonde (1986), who demonstrated the limitations of non-experimental estimators against randomized benchmarks, and Heckman et al. (1998), who advanced methods to address selection on unobservables in program evaluation, this approach situates itself within the broader literature seeking credible causal estimates when randomization is infeasible. However, this approach is not limited to program evaluation and remains a reasonable approach for studying the economic impact of climate variables or water scarcity in many contexts. This method allows for controlling both time-invariant characteristics unique to each entity (like states or countries) and common shocks across time, which can help to isolate the effect of the variable of interest. Two-way fixed effects models are particularly useful when dealing with panel data, where observations are available for the same entities across multiple time periods. For example, they have been used to analyse the impact of climate change on agricultural yield and the broader economic implications of climate change on sectors such as agriculture, forestry, and energy (Emediegwu et al., 2022; Butt et al., 2005).

Nonetheless, while the two-way fixed effects model is a strong methodological choice, it is essential to ensure that the assumptions underlying its application are met. This includes having a balanced panel and sufficient time variation in the climate variables of interest. It is also beneficial to the model to explore additional econometric techniques, and to perform robustness checks to confirm findings, given the complexity and potential non-linearities of climate impacts (Neumann, 1999). These have been implemented in several different categories in this thesis.

Moreover, the choices taken here also align with insights from the design-based literature (Imbens, 2009), which clarifies that while instrumental variables and local average treatment effects address endogeneity and heterogeneity, well-executed fixed effects models remain a powerful tool for capturing within-unit causal variation when instruments are weak or unavailable, provided assumptions about parallel trends hold. This methodological path is validated by leading economists precisely because it reflects an explicit commitment to credible identification in non-experimental contexts, balancing internal validity with feasibility while learning from the limitations of alternative approaches documented in the program evaluation literature.

6.3.1. Model and empirical strategy

I employ country and year fixed effects to account for unobserved, time-invariant differences between countries and to mitigate the impact of global shocks or trends that might skew the estimated links between water stress and economic performance. Although there are valid arguments for using time series in this context, I am convinced that my approach is justified for several reasons. Firstly, data limitations are a significant factor: many countries, particularly in the Middle East and North Africa, lack reliable data due to ongoing political and societal instability, which complicates studies on water scarcity, economic output, and desalination. Secondly, the primary aim of this thesis is to explore the impact of water scarcity on GDP across different institutional and climatic settings, a task that is more challenging to achieve with time series data. I am confident that the issues associated with employing a panel data approach in this context are adequately resolved through various robustness checks that include considerations for climate, quality of governance, economic, structural, and sectoral factors to mitigate the risk of omitted variable bias.

In line with Angrist and Pischke’s (2009) guidance on causal inference, I acknowledge that several control variables in my analysis such as desalination, irrigated agricultural output, and urbanization share may constitute post-treatment variables with respect to water stress. Including them directly in a single regression risks biasing the estimated impact downward, as these “bad controls” may partially absorb the treatment effect by intervening in the relationship between water scarcity and economic output.

Thus, I take a stepwise approach following Angrist and Pischke's (2009) guidance on handling potential post-treatment variables ('bad controls') by presenting a sequence of models that incrementally include these variables, illustrating how estimates evolve and bounding the plausible causal effect of water stress.

To navigate this trade-off between controlling for confounders and preserving the causal structure, I adopt a stepwise modelling approach that incrementally introduces sets of covariates. This strategy serves two purposes, first: It helps diagnose how sensitive the estimated coefficient on the Water Stress Index (WSI) is to the inclusion of potential mediators or adaptations. Second: it transparently bounds the total versus the direct effects, following best practices in applied econometrics.

I interpret the baseline fixed effects model (with WSI only) as an upper-bound estimate, reflecting the total effect of water scarcity, including through adaptations. The fully saturated model, by contrast, offers a lower-bound, net-direct effect, adjusting for governance quality, adaptation infrastructure, and sectoral shifts.

6.3.2. Theoretical mechanisms linking water scarcity to economic output

A relevant question regarding identification is whether and how water scarcity affects economic variables, and if so, through what channels does water scarcity affect income and development.

Water scarcity affects the economy through multiple interrelated channels, both direct and indirect. At a global level, it constrains development and income by disrupting the hydrological cycles that sustain food systems, energy production, and public health, which are foundational for economic growth. As Rockström et al. (2023) argue, water is not merely a local resource but a global common good that underpins societal well-being, with anthropogenic pressures and climate change destabilizing precipitation patterns and reducing the reliability of water supplies. This instability affects economic systems by increasing the frequency of droughts and floods, which in turn damage infrastructure, depress agricultural productivity, and strain public health systems; factors that reduce labour productivity and household incomes.

At the most basic level, inadequate water supply affects public health by increasing the prevalence of waterborne diseases and reducing hygiene, which in turn lowers labour productivity and human capital accumulation (Jeuland & Whittington, 2014; WHO, 2019). Chronic water scarcity also affects nutrition by undermining agricultural yields and food availability, particularly in regions that are dependent on rain-fed or irrigated agriculture (Falkenmark & Rockström, 2006).

Agriculture is a significant component of the economy in many developing regions, often contributing substantially to GDP and employing a large segment of the labour force. From a production standpoint, water is a crucial input not only for agriculture, but also for manufacturing and energy generation. In the agricultural sector, decreased yields caused by water scarcity can reduce rural incomes, which in turn slow GDP growth. In Africa, for example, agriculture accounts for 37% of GDP and over 76% of employment (Langyintuo, 2020). Decreases in agricultural yields can directly impact the income of rural populations, which rely heavily on farming for their livelihoods. When yields fall, particularly in regions where agriculture is rainfed and susceptible to climate variability, incomes drop, impoverishing rural communities (Msowoya et al., 2016).

Agricultural growth has a disproportionately positive impact on GDP and poverty reduction, particularly in developing economies. Some authors claim that GDP growth originating in agriculture is about three times more effective in raising incomes of the poorest 40% than growth in other sectors However, the effectiveness can be conditional on various regional factors including water availability (Janvry and Sadoulet, 2009). Additionally, in countries like China, rapid economic growth exacerbated income inequality, which can slow down poverty reduction despite higher GDP (Yao, 1999).

It is also increasingly true that water scarcity can fuel conflicts, drive up public spending and divert funds from other critical investments. As climate change and population growth worsen water shortages, managing limited resources becomes a major economic and social challenge (Damania, 2020). This situation frequently leads to higher public expenditure on the development and implementation of water management solutions, such as desalination plants and advanced irrigation systems, which often involve significant financial costs. (Al-Addous et al., 2024).

In addition, water shortages can disrupt industrial output, raise input costs, and reduce competitiveness, especially in water-intensive sectors. Empirical microeconomic studies show that firms facing water supply interruptions often reduce hiring, delay investment, or substitute toward less water-intensive activities (Damania et al., 2017). At the household level, time spent collecting water, especially among women and children, translates into lower educational attainment and foregone labour income (UNICEF & WHO, 2021).

Since Pigou's work in the late 1940s, economists have acknowledged that environmental problems, like water scarcity, create externalities and inefficiencies that require institutional responses (Atkinson & Stern, 1974; Pigou, 1947). Recent behavioural economics and medicine studies reinforce this view by showing that stress related to water scarcity impairs decision-making, reduces risk tolerance, and increases vulnerability to income shocks, thereby mirroring how environmental constraints can produce micro-level frictions that accumulate into macroeconomic consequences (Haushofer & Fehr, 2014).

These behavioural responses, such as increased risk aversion and time discounting tend to reduce investment in education, technology adoption, and health, undermining long-term development. These micro-level mechanisms, aligned with Pigouvian principles of externality correction, justify policy interventions to mitigate the economic costs of water scarcity and improve social welfare.

6.3.3. Empirical model specification: From baseline to the full model

The primary model estimated throughout this thesis is a two-way fixed effects (TWFE) panel regression, which accounts for time-invariant country characteristics and global temporal shocks. The general form is:

$$\log(GDPpc_{it}) = \alpha_i + \delta_t + \beta_1 WSI_{it} + X_{it}^{'}\beta + \varepsilon_{it}$$

Where:

- $\log(GDPpc_{it})$: Real GDP per capita (log-transformed) for country *i* in year *t*
- α_i : Country fixed effects
- δ_t : Year fixed effects
- WSI_{it} : Water Stress Index (scaled between 0 and 1)
- $X_{it}^{'}$: Vector of time-varying controls (introduced in stages)
- ε_{it} : Error term

Following Angrist and Pischke (2009), the covariates in $X_{it}^{'}$ are introduced sequentially or step-by-step as described below:

First, the **baseline** specification includes only WSI and fixed effects:

$$\log(GDPpc_{it}) = \alpha_i + \delta_t + \beta_1 \times WSI_{it} + \varepsilon_{it}$$

The dependent variable is specified in logarithmic form to reduce skewness, stabilize variance across countries with different income levels, and allow for the interpretation of coefficients as approximate percentage changes in GDP per capita associated with a unit change in the independent variables. This transformation is standard in cross-country growth regressions and improves model fit and interpretability (see Silva & Tenreyro, 2006, for a discussion on functional form choices in economic growth modelling).

The Water Scarcity Index (WSI) measures the ratio of total annual freshwater withdrawals to total renewable freshwater resources, expressed as a percentage. It reflects the degree of pressure a country's economy places on its available water supply, with higher values indicating greater stress. I scaled WSI to 0–1 to allow interpretation of the estimated coefficient as the percentage change in log GDP per capita associated with a 1 percentage point increase in water stress, *ceteris paribus*.

I estimate the regressions using a two-way fixed effects specification, controlling for both country and year effects, and implement the *feols* estimator with heteroskedasticity-robust standard errors. Prior to estimation, I assess the panel to confirm sufficient within-country and within-year variation to support fixed effects identification.

Second, I add **demographic control** including population size:

$$+ \beta_2 \times \log(Population_{it})$$

Population is included in logarithmic form to adjust for scale differences across countries and to stabilize variance in the panel. This transformation normalizes the distribution, allowing coefficients to be interpreted as elasticities and ensuring comparability across economies. Including log population helps isolate the effect of water scarcity on GDP per capita while accounting for the influence of demographic scale.

Third, I incorporate **climate controls**, to incorporate mean annual temperature and precipitation:

$$+ \beta_3 \times Temperature_{it} + \beta_4 \times Precipitation_{it}$$

I incorporate temperature and precipitation as annual country-level averages, capturing climate variability that can influence economic output through multiple channels. Temperature, measured in degrees Celsius, reflects heat exposure that can affect agricultural productivity, labour efficiency, and energy demand, while precipitation, measured in millimeters, proxies water availability relevant for agriculture and hydrological stability. Including these variables in the regression framework controls for the direct effects of climate on GDP per capita and helps isolate the specific impact of water scarcity. By accounting for temperature and precipitation, the empirical strategy reduces omitted variable bias that could arise if climate variability correlates with water stress and economic outcomes.

Fourth, I include **institutional quality**, mainly represented by the composite governance index (GI):

$$+\beta_5 \times GI_{it}$$

To address institutional factors that are relevant to Water Scarcity, I construct a Governance Index (GI) as the sum of standardized z-scores of three key governance dimensions from the World Bank World Governance Index dataset: *government effectiveness*, *regulatory quality*, and *rule of law*, as follows:

$$WGI_{it} = \sum_{j=1}^{3} \frac{x_{it}^{j} - \bar{x}^{j}}{\sigma^{j}}$$

Each component is normalized to have a mean of zero and unit variance prior to aggregation. The benefits of this approach are that it equalizes scale and variance, improves comparability, and helps deal with heteroscedasticity across countries and governance components

Fifth, I sum **Mitigation and Adaptation Variables**, these include desalination and irrigated agricultural production:

$$+\beta_6 \times \log(Desalination\ share) + \beta_7 \times \%\ AgirrigatedGVA_{it}$$

Where **the percentage of agricultural Gross Value Added that comes from irrigated agriculture (%Ag IrrigatedGVA)**, captures the share of the total agricultural economic output that depends on irrigation systems. This is a proxy for water-use efficiency.

To capture a country's technological capacity to mitigate water scarcity, I include the as an explanatory variable the desalination share of countries which can be defined as:

$$Desalination\_share_{it} = \frac{Desalination\ Water}{Total\ freshwater\ withdrawals}$$

This variable reflects the structural importance of desalination in a country’s water supply system. Unlike log-transformed desalination volumes, this share-based measure avoids issues with zero values, enhances cross-country comparability, and directly represents the role of technology in mitigating water scarcity.

Sixth, I include **structural controls**, which add sectoral GDP composition and urbanization:

$$+ \beta_8 \times AgricShare_{it} + \beta_9 \times ManufShare_{it} + \beta_{10} \times ServiceShare_{it} + \beta_{11} \times UrbanRate_{it}$$

Including the shares of agriculture, manufacturing, and services in GDP helps isolate the specific effect of water scarcity from sectoral structures, recognizing that water intensity and vulnerability vary across sectors.

The urbanization rate is particularly relevant, as water accessibility is not determined solely by a country's natural water endowments but also by the infrastructure required to withdraw, transport, and distribute water to where it is needed. Similar to the role of transmission infrastructure in the energy sector, aqueducts and canalization are essential for making water available for productive and household uses. Urbanization inherently implies greater canalization and centralized water management, making it a proxy for water infrastructure. Including these structural controls ensures that the estimated relationship between water scarcity and economic output is not confounded by differences in sectoral composition and urban infrastructure across countries.

Finally, I introduce macroeconomic structure controls to account for economic scale, openness, and vulnerability to environmental shocks:

$$+\beta_{12} \times \log(Capital\ Formation)_{it} + \beta_{13} \times \log\ (Trade\ Openness)_{it}$$

I use log capital formation (as % of GDP) is indicative of long-term investment in productive assets and infrastructure, which can buffer economies against environmental stress and foster adaptation to water scarcity. Trade openness, also measured as a share of GDP and included in log form, captures economic integration and access to external goods and capital, factors that may alleviate domestic resource constraints or amplify exposure to global shocks. Including these variables helps isolate the economic effects of water scarcity from broader macro-structural characteristics that could confound the estimates if omitted.

6.4. Empirical results and interpretation

Descriptive statistics

This section provides an overview of the key variables used in the empirical analysis. Table 1 summarizes the central tendencies and dispersion measures of the dataset.

The dependent variable, real GDP per capita (in natural logarithms), exhibits a mean value of 8.63 and a standard deviation of 1.42, indicating substantial variation in economic performance across countries and over time. The observed range extends from 5.43 to 11.63, which approximately corresponds to a real income distribution from USD 227 to USD 112,418 per capita. These figures suggest a wide spectrum of development levels in the sample, ranging from low-income to high-income economies.

Table 1: Descriptive Statistics of Main Variables

Variable	**Non missing Obs.**	**Missing (%)**	**Mean**	**SD**	**Min**	**Median**	**Max**
Log GDP per Capita (Real)	2845	0	8.627	1.423	5.426	8.633	11.630
Water Stress Index (%)	1944	0	61.967	274.971	0.132	9.726	3850.5
Desalination Share	1711	73.2	0.0005	0.003	0.000	0.000	0.022
Log Desalination Output	512	0	0.046	0.181	0.000	0.005	2.625
Governance Index	2845	0	0.124	2.819	-5.804	-0.353	6.325
Irrigated GVA share	1524	11	25.729	29.943	0.000	12.838	123.59
Temperature (°C)	1549	2	19.104	8.181	-4.860	22.000	29.750
Precipitation (mm)	2759	2	1133.212	781.418	26.450	982.46	4105
Log Population	2844	0	15.909	1.762	11.121	16.020	21.068
% GDP from Agriculture	2845	0	10.609	10.693	0.030	6.621	79.042
% GDP from Manufacturing	2845	0	13.018	6.918	0.233	12.591	48.443
% GDP from Services	2845	0	53.511	11.602	10.859	54.194	87.421
Log capital	404	86	3.298	0.266	2.245	3.274	3.966
Log trade	404	86	4.337	0.529	3.132	4.210	6.083
Urban Share	2759	0	58.250	22.645	7.412	59.152	100.000

The main explanatory variable, the Water Stress Index (WSI), also displays pronounced heterogeneity. Values range from 0.13% to over 3,800%, with a median close to 9.73%, highlighting the unequal distribution of freshwater availability. This broad dispersion validates the use of a cross-country panel design to capture differences in exposure to water scarcity.

Control variables reflect further structural and institutional diversity. The governance index (GI), a standardized z-score indicator, ranges from −5.8 to +6.3, with a mean close to zero, confirming the normalization process. Desalination capacity, expressed in logarithmic terms, has a low median value and high skewness, consistent with its concentration in a few water-scarce and high-income countries. The share of irrigated agricultural gross value added varies widely, from negligible levels, up to 124% of agricultural GDP, which may be attributed to data reporting inconsistencies or cross-sectoral overlaps.

In sum, the summary statistics reveal considerable variability in both economic outcomes and exposure to water-related challenges. This heterogeneity reinforces the relevance of using country and year fixed effects to isolate the within-country variation of interest.

Trends in water scarcity and economic indicators

Trends in water scarcity over the 1995–2020 period reveal a clear pattern of increasing stress, particularly among middle-income and rapidly industrializing nations. Based on WSI dynamics, countries like India, Mexico, and Turkey have seen sharp rises in water withdrawals relative to renewable resources, signalling the cumulative pressure from urbanization, agricultural intensification, and weak regulatory regimes.

Figure 3.2 from Section 3 illustrates how countries categorized as "Very High-Water Stress" (>70%) expanded geographically between 1995 and 2020 and shifted from predominantly arid regions (Middle East and North Africa, South Asia) to include parts of Sub-Saharan Africa and Latin America. This global spread of water stress suggests that economic transformation, rather than natural aridity alone, has become a key driver of scarcity. Simultaneously, real GDP per capita rose across most of the sample, but not uniformly. Water-stressed economies tend to exhibit more volatile growth, especially when mitigation technologies and governance systems are lacking. By contrast, countries with stable or low[9] WSI values (e.g., Canada, Germany) generally enjoy smoother economic trajectories.

These trends in water stress and income highlight the central hypothesis of this thesis: water scarcity imposes a structural constraint on growth, but this constraint is mediated by policy, technology, and institutional factors. As confirmed in the econometric results (Section 4.5), the effect of WSI on GDP per capita is persistent and robust to multiple model

[9] WSI values below 25 (i.e., 25% of renewable resources used) are considered low stress.

specifications, and this reinforces the significance of incorporating scarcity dynamics into macroeconomic planning.

6.5. Regression findings

The robust negative effect of water stress on GDP across specifications aligns with expectations under TWFE as described by Angrist and Pischke (2009), confirming that leveraging within-country variation while controlling for fixed effects yields credible estimates in non-experimental settings. As noted by Deaton (2009), Heckman et al. (2009), and Imbens (2009), this approach ensures transparency and empirical grounding, though it does not capture the broader general equilibrium effects that CGE models can simulate. Thus, while TWFE provides a clear and policy-relevant estimate of the direct economic impact of water scarcity, it should be seen as a conservative measure that complements structural models for understanding the full economic consequences of environmental stress.

6.5.1. The impact of water scarcity in the economy: Interpretation of coefficients

The estimated coefficient for the rescaled Water Stress Index is consistently negative and statistically significant across all model specifications, confirming the adverse impact of increasing water scarcity on economic output.

WSI is rescaled by multiplying the original 0–1 ratio by 100 to facilitate interpretation. Thus, a one-point increase in WSI corresponds to a one percentage-point increase in water stress. Table 2 shows that, in the baseline model, a one-point increase in WSI is associated with a 5.9% reduction in real GDP per capita. This effect gradually declines to 2% in the fully controlled specification, after demographic, climatic, institutional and sectoral factors are accounted for. Additionally, the governance index (GI) exerts a positive and significant influence on GDP per capita, suggesting that stronger institutions may buffer the negative effects of environmental constraints. While mitigation variables such as desalination and irrigated agricultural value added are included in later models, their estimated effects remain statistically weak, implying limited effectiveness at current scales. These results support the hypothesis that water scarcity imposes measurable economic penalties and demonstrate the importance of institutional resilience in mitigating such challenges.

Table 2: Stepwise Estimates of the Impact of Water Scarcity on GDP per capita Across Model Specifications

	Baseline	Add Pop	Climate	Governance	Mitigation	Urban	Economic	Full Model
Water Stress Index (x100)	-0.059***	-0.042***	-0.041***	-0.035***	-0.041***	-0.030**	-0.020***	-0.020***
	(0.010)	(0.007)	(0.007)	(0.008)	(0.011)	(0.010)	(0.006)	(0.006)
Log Population		-0.348***	-0.369***	-0.313***	-0.259***	-0.290***	-0.843***	-0.845***
		(0.038)	(0.039)	(0.038)	(0.044)	(0.041)	(0.062)	(0.062)
Temperature			0.006	0.003	0.004	0.004	-0.030+	-0.029+
			(0.007)	(0.006)	(0.006)	(0.006)	(0.016)	(0.016)
Precipitation			0.000	0.000	0.000	0.000	0.000*	0.000*
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Governance Index				0.104***	0.106***	0.091***	0.057***	0.058***
				(0.006)	(0.007)	(0.006)	(0.015)	(0.015)
Desalination Share					0.042	0.050 *	0.041 **	0.039 *
					(0.026)	(0.022)	(0.016)	(0.016)
Irrigated GVA Share					0.000	0.001	0.002	0.002
					(0.001)	(0.001)	(0.002)	(0.002)
Agriculture Share						-0.017***	-0.051***	-0.050***
						(0.002)	(0.009)	(0.009)
Manufacturing Share						-0.004**	0.001	0.001
						(0.001)	(0.002)	(0.002)
Services Share						-0.006***	-0.010***	-0.010***
						(0.001)	(0.001)	(0.001)
Urbanization rate						0.005***	0.011***	0.011***
						(0.001)	(0.003)	(0.003)
Log capital formation							0.303***	0.302***
							(0.037)	(0.037)
Log trade openness							-0.219***	-0.218***
							(0.039)	(0.039)
Observations	2845	2845	2785	2785	2471	2471	366	366
R^2	0.992	0.992	0.992	0.994	0.994	0.995	0.995	0.996

R^2 Adj.	0.992	0.992	0.992	0.993	0.994	0.995	0.995	0.995
R^2 Within	0.017	0.067	0.074	0.227	0.218	0.329	0.714	0.715
R^2 Within Adj.	0.016	0.066	0.073	0.226	0.216	0.326	0.702	0.702
AIC	-3335.9	-3481.7	-3402.7	-3905.1	-3607.5	-3977.1	-774.9	-773.5
BIC	-2329.8	-2469.6	-2400.2	-2896.7	-2631.0	-2977.3	-564.1	-558.8
RMSE	0.13	0.12	0.12	0.11	0.11	0.10	0.07	0.07
FE: country	X	X	X	X	X	X	X	X
FE: year	X	X	X	X	X	X	X	X

Note: All models include country and year fixed effects. Standard errors clustered by country. Significance codes: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The negative impact of water stress on economic performance is statistically significant and consistent across all model specifications. In the baseline model, a 100% increase in the Water Stress Index (WSI) is associated with a 5.9% reduction in real GDP per capita.[10] As additional covariates are sequentially introduced, including climate, governance, mitigation efforts, sectoral composition, urbanization, and macroeconomic controls, the estimated effect attenuates but remains statistically significant, stabilizing at around 2% in the fully saturated model. This range shows the robustness of the WSI–GDP relationship and highlights the persistent economic vulnerability imposed by increasing water stress, even after accounting for a broad set of structural and policy-related variables.

The full model thus accounts not only for climatic and institutional variation but also for sectoral structure, technological adaptation, urban infrastructure, and macroeconomic context. This stepwise modelling strategy ensures a transparent identification process, aligning with Angrist and Pischke (2009), while mitigating omitted variable bias through progressive inclusion of theoretically relevant controls. The rich specification permits robust inference about the independent impact of water scarcity on economic performance across a diverse set of countries and over time.

Compared to estimates from international organizations using Computable General Equilibrium (CGE) models — such as those by the World Bank — which simulate economy-wide interactions under environmental stressors and project a global GDP reduction of 6% to 18% due to water scarcity by the year 2050, the results of this study are of similar magnitude, though derived using a different methodology: panel econometric techniques with fixed effects and robustness checks (Böhringer & Rutherford, 2008; Sue Wing, 2004). Additionally, the *Economics of Water* report of 2023 places potential GDP losses at a median of 8% for high-income countries and between 10%–15% for lower-income countries under a business-as-usual scenario, emphasizing the scale of macroeconomic risks linked to worsening water stress (UNESCO, 2023). This comparison situates the present study within broader macroeconomic risk assessments and validates its empirical findings against established modelling approaches. Unlike CGE models, which rely on structural assumptions and calibrated parameters, the panel econometric approach leverages observed country-level variation over time, providing an empirical estimate grounded in historical data. This reinforces the robustness of the present study's estimates and suggest that, if anything, they likely represent a conservative lower bound

[10] By "Real" GDP per capita refers to GDP per capita that has been adjusted for inflation to reflect the true purchasing power of income in a given year

on the broader economic impacts of increasing water scarcity, highlighting the urgency of integrating water management and technological adaptation within macroeconomic policy frameworks.

6.5.2. Desalination as an economic buffer: Interaction effects

To explore whether desalination mitigates the adverse economic consequences of water scarcity, this section estimates interaction models that allow the marginal effect of water stress on GDP to vary with the intensity of desalination deployment. The central hypothesis is that desalination not only supplements water supply, but also improves economic resilience under conditions of environmental stress, a view supported by several other scholars (Gleick, 2018; Gude, 2017).

For this section, all landlocked countries were excluded from the desalination analysis, as these countries do not have direct access to seawater and, in practice, lack large-scale seawater desalination infrastructure.[11] This ensures that the analysis of desalination as a mitigation strategy for water scarcity reflects only contexts where the technology is feasible and policy relevant.

I specify the following two-way fixed effects panel regression model:

$$\log(GDP_{it}) = \beta_0 + \beta_1 WSI_{it} + \beta_2 D_{it} + \beta_3 (WSI_{it} \times D_{it}) + \boldsymbol{X}_{\boldsymbol{it}}^{'}\boldsymbol{\gamma} + \alpha_i + \delta_t + \varepsilon_{it}$$

Where $\log(GDP_{it})$ denotes the logarithm of real GDP per capita for country i in year t; WSI_{it} is the scaled Water Stress Index; D_{it} is the desalination proxy; $\boldsymbol{X}_{\boldsymbol{it}}$ is a vector of controls including log population, governance quality (GI), temperature (tas), precipitation (pr), the share of agriculture under irrigation, and sectoral GDP shares; and α_i and δ_t denote country and year fixed effects, respectively. The coefficient of interest, β_3 captures the extent to which desalination buffers the economic effects of water scarcity.

In this specification, D_{it} is operationalized as the share of total freshwater withdrawals met by desalinated water (*desalination share*). This metric is merged with the panel using

[11] The following 44 landlocked countries were excluded from the desalination analysis: Afghanistan, Andorra, Armenia, Austria, Azerbaijan, Bhutan, Bolivia, Botswana, Burkina Faso, Burundi, Central African Republic, Chad, Czechia, Eswatini, Ethiopia, Hungary, Kazakhstan, Kyrgyzstan, Lao People's Democratic Republic, Lesotho, Liechtenstein, Luxembourg, Malawi, Mali, Moldova, Mongolia, Nepal, Niger, North Macedonia, Paraguay, Rwanda, San Marino, Serbia, Slovakia, South Sudan, Switzerland, Tajikistan, Turkmenistan, Uganda, Uzbekistan, Vatican City, Zambia, Zimbabwe.

AQUASTAT and desalination capacity datasets, with missing values imputed where appropriate or retained as missing to avoid biasing the interaction effects.

I perform estimations using two-way fixed effects with standard errors clustered at the country level to account for within-country serial correlation and heteroskedasticity. The Water Stress Index is scaled between 0 and 1 to facilitate interpretation of interaction terms and comparability across specifications.

The model uses the interaction between the Water Stress Index and desalination share (WSI x desalination share). It is important to highlight that, because of the way WSI is computed, this interaction captures the current share of desalination in total water withdrawals, reflecting a flow perspective on water management. This measure is highly sensitive to water withdrawal patterns across countries and years, making it particularly reflective of reactive desalination use in water-scarce, lower-income contexts. For instance, countries may increase their use of desalinated water as water scarcity intensifies, but without substantial long-term investment in desalination infrastructure, resulting in fluctuations in the share of desalination in response to immediate water stress (World Bank, 2019; Bacha et al., 2003). In this context, the interaction term in the regression can be interpreted as capturing ***how the share of desalination modulates the economic impact of water scarcity*** in real time, illustrating how even modest reliance on desalination can influence the relationship between water stress and GDP per capita.

Table 3: Desalination Share Interaction Regression

Dependent Variable: Log GDP per capita
Fixed Effects: Country and Year
Standard Errors: Clustered by Country
Observations: 1,969
Countries: 122
Years: 1995-2020

Variable	Estimate	Std. Error	t-value	p-value	Significance
Water Stress Index (x100)	-0.0204	0.0110	-1.86	0.0656	.
Desalination Share	-0.00031	0.00014	-2.05	0.0411	*
Log Population	-0.1742	0.1021	-1.71	0.0909	.
Governance Index	0.0847	0.0124	6.81	5.71e-10	***
Irrigated GVA Share	-0.00028	0.00162	-0.17	0.8645	
Temperature(°C)	0.00744	0.00901	0.83	0.4107	
Precipitation(mm)	-0.0000062	0.000013	-0.47	0.6359	
% GDP from Agriculture	-0.01356	0.00395	-3.44	0.00084	***
% GDP from Manufacturing	-0.00428	0.00362	-1.18	0.2396	
% GDP from Services	-0.00456	0.00180	-2.53	0.0127	*
Interaction (WSI x Desal. Share)	-0.00013	0.000026	-4.94	2.91e-06	***

Adjusted R^2: 0.9946. R^2 including fixed effects.
Within R^2: 0.3559. R^2 explained by covariates after demeaning out fixed effects.
RMSE: 0.0910
Significance Codes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.1$

The results presented in table 3 provide evidence of how desalination interacts with water scarcity to influence economic performance, measured by log GDP per capita, across countries and over time. The Water Stress Index, scaled between 0 and 1, shows a negative but marginally significant association with GDP per capita, indicating that higher water stress tends to reduce economic output, though with modest statistical strength in this specification. Importantly, the interaction term between WSI and desalination share is negative and highly significant, suggesting that the adverse economic impacts of water scarcity are mitigated in countries that have a higher proportion of their water supply sourced from desalination. This finding aligns with the hypothesis that desalination, as a technological adaptation, entails economic resilience in the face of environmental stress.

Overall, these results confirm that desalination can function as a technological adaptation that can mitigate the economic vulnerability associated with water scarcity. The significant interaction terms in both models demonstrate that desalination capacity, whether measured by current share in water withdrawals or as installed capacity, reduces the marginal negative impact of water scarcity on economic output. The results further suggest that investments in desalination infrastructure can not only augment water supply, but also support sustained economic growth under increasing water stress conditions, highlighting desalination as a viable strategy for enhancing climate-resilient economic development.

Up to this moment the question is: Can this buffing effect be quantified? If so, what is the percentage of mitigation power of desalination on GDP losses from water stress? To address this question, I calculate the mitigation effect as:

$$\%Mitigation = \frac{Marginal\ Effect\ at\ zerodesal - Marginal\ Effect\ at\ high\ desal}{Marginal\ Effect\ at\ zero\ desal}$$

This formula calculates the percentage by which desalination reduces the economic damage of water scarcity on GDP per capita. It does this by comparing the marginal negative effect of water scarcity when there is no desalination with the marginal effect when desalination capacity is high, showing how much the impact is reduced. By dividing the reduction by the initial damage and multiplying by 100, the formula expresses how effectively desalination mitigates the economic penalties of water stress as a clear percentage. However, these estimates should be interpreted with the understanding that the marginal economic benefit of desalination may differ across countries depending on local governance and energy conditions.

Using the interaction model, the results indicate that desalination's buffering effect on the economic impacts of water scarcity varies significantly across contexts. In countries with low to moderate desalination capacity, mitigation remains modest, with GDP losses being reduced by only 2–4.5%. In contrast, in high desalination capacity contexts, mitigation of GDP losses from water scarcity ranges from ~80% on average across advanced desalination economies, to over 130% in the highest-capacity extreme cases. Desalination provides small economic protection from water scarcity in most countries, but in highly water-stressed, technologically advanced economies, it can fully neutralize the economic burden of water scarcity, reflecting how technological scale and institutional quality transform adaptation effectiveness. This demonstrates that while desalination holds potential as a climate adaptation strategy, its effectiveness in buffering economic losses is highly contingent upon the scale of technological deployment, emphasizing the need for targeted investment and capacity expansion in water-stressed regions (See Appendix 3 for the full decile mitigation breakdown and country listings).

6.5.3. Functional form robustness

a) Poisson pseudo maximum likelihood (PPML)

To assess the robustness of the log-linear functional form typically employed in estimating the impact of water stress on economic performance, I apply the Poisson Pseudo Maximum Likelihood (PPML) estimator. While originally developed for count data, PPML is widely used in empirical economics for continuous, strictly positive dependent variables due to its desirable properties under heteroskedasticity (Silva & Tenreyro, 2006). PPML estimates the conditional expectation of the dependent variable in levels while preserving multiplicative effects of regressors in a semi-logarithmic setup. Specifically, the model assumes

$$E[Y_{it}|\boldsymbol{X_{it}}] = \exp\left(\boldsymbol{X_{it}}\beta\right)$$

Where Y_{it} denotes GDP per capita for country i, in year t, and $\boldsymbol{X_{it}}$ includes water stress, climate controls, and governance indicators

Table 6: PPML Estimates for GDP per Capita

Estimator: PPML (Robust SEs clustered by country)
Observations: 1,436
Countries: 122
Years: 1995-2020

Variable	Estimate	Std. Error	t value	p value
WSI (x 100)	-0.036	0.021	-1.748	0.081 †
Governance Index (GI)	0.055	0.018	3.024	0.002 **
Log Population	-0.405	0.143	-2.841	0.005 **
Temperature (°C)	0.002	0.006	0.382	0.702
Precipitation (mm)	-0.000013	0.000018	-0.730	0.465
% GDP from Agriculture	-0.035	0.005	-6.441	1.185e-10 ***
% GDP from Services	-0.004	0.002	-2.351	0.019 *
% GDP from Manufacturing	0.002	0.007	0.308	0.758
Desalination share	-0.0001	0.0002	-0.591	0.554
Pseudo-R^2: 0.721				

Note: PPML estimation accounts for heteroskedasticity and is robust to zero or extreme values in the dependent variable. Significance codes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, · $p < 0.1$.

The coefficient on WSI (scaled) is negative and statistically significant (–0.036, $p = 0.081$), that suggests a potential inverse relationship between water stress and GDP per capita. While the direction of the effect is consistent with expectations, the magnitude remains modest, and results should be interpreted with caution. Governance quality (GI) remains positively associated with GDP per capita (0.055, $p = 0.002$), while the share of GDP in agriculture is again negatively correlated with income levels (–0.035, $p < 0.001$), consistent with structural dependency concerns in water-scarce contexts. Other controls behave as expected, with temperature and precipitation showing no significant direct effects in this specification.

b) Driscoll-Kraay robust standard errors

I apply Driscoll-Kraay standard errors to account for cross-sectional dependence and serial correlation in the panel data, which are common in macroeconomic panels in which countries are exposed to shared shocks (e.g., commodity prices, global financial cycles) and persistent unobserved factors. This method provides robust inference even when standard errors would otherwise be biased, ensuring that my findings on the economic impact of water scarcity remain valid under more realistic error structures.

While the baseline model uses log-transformed GDP per capita, it is important to justify this functional form. Logarithmic transformation helps to normalize the distribution of GDP, reduces heteroskedasticity, and allows for elasticities to be estimated directly from the coefficients. The Box-Cox test further suggests that the log specification ($\lambda = 0$) is optimal, supporting my baseline choice.

Table 7: Driscoll-Kraay Robust Standard Errors (Two-Way Fixed Effects)

Dependent variable: log(GDP per capita, real terms).
Fixed effects for country and year included.
Observations: 2,236
Countries: 113
Years: 1995-2016

Variable	Estimate	Std. Error	t value	p value	Sign.
WSI (x 100)	-0.0319	0.0099	-3.24	0.0012	***
Log Population	-0.2607	0.0319	-8.17	<0.001	***
Governance Index	+0.0787	0.0045	17.47	<0.001	***
Temperature	+0.0039	0.0064	0.61	0.542	
Precipitation	0.000007	0.000017	-0.44	0.690	
% GDP from Agriculture	-0.0139	0.0035	-3.95	<0.001	***
% GDP from Services	-0.0043	0.0012	-3.51	0.0005	***
% GDP from manufacturing	-0.0045	0.0011	-3.92	<0.001	***
Irrigated GVA Share	-0.00021	0.00038	-0.54	0.587	
Desalination share	-0.00060	-0.00005	-12.72	<0.001	***

Standard errors are Driscoll-Kraay robust.
Significance levels: † p < .10, * p < .05, ** p < .01, *** p < .001.

Using two-way fixed effects with country and year dummies, I find that the Water Stress Index remains negatively associated with real GDP per capita, with an estimated coefficient of -0.032 and significant at the 1% level (p = 0.0012). This supports the core thesis that higher water stress is linked to lower economic output (See Table 7).

Other covariates retain expected signs and significance. Population size continues to display a negative association with per capita income, while governance quality (GI) remains positively and strongly correlated with economic performance. Sectoral structure matters: the shares of GDP from agriculture, services, and manufacturing are all significantly negative. The effect of the % GDP from Agriculture suggests that economies with heavier reliance on this sector face income vulnerabilities under water stress. Meanwhile, temperature and precipitation do not exhibit significant direct effects in this specification, and neither does the irrigated GVA share. Notably, desalination share enters as negative and significant (–0.00060, p < 0.001), potentially reflecting the high costs or structural dependence associated with desalination-driven water supply.

c) Box-Cox transformation

I apply the Box-Cox transformation to assess whether the main finding, that water scarcity reduces economic output is sensitive to the functional form of the dependent variable. This transformation systematically tests different power transformations of GDP per capita to identify the specification that best fits the data while addressing potential non-linearity and heteroskedasticity in the residuals.

The Box-Cox procedure generalizes the log-linear and linear-in-levels specifications by allowing the data to inform the appropriate power transformation. Additionally, I estimate a **Box-Cox transformation** of the GDP outcome:

$$y_{it}^{(\lambda)} = \begin{cases} \frac{y_{it}^{\lambda}}{\lambda}, & \lambda \neq 0 \\ \log(y_{it}), & \lambda = 0 \end{cases}$$

Where λ is estimated from the data. This method nests both the level and log specifications and can help formally assess the most appropriate transformation of the outcome variable. The test identified an optimal lambda of 0, which corresponds to a natural logarithm transformation, confirming that my use of log GDP per capita in the main analysis is appropriate.

6.5.4. Measurement robustness

a) Pesaran cross-sectional dependence test

I conduct the Pesaran Cross-Sectional Dependence (CD) test on the residuals of the two-way fixed effects panel regression, following Pesaran (2015). The test strongly rejects the null hypothesis of cross-sectional independence ($z = -3.94$, $p < 0.001$), suggesting that country-level GDP per capita is influenced by unobserved common shocks or spillover effects that are not fully captured by the covariates or fixed effects.

b) Clustered standard errors

To address potential downward bias in standard errors due to within-country correlation over time, I implement cluster-robust standard errors at the country level, allowing for arbitrary autocorrelation and heteroskedasticity within each country. This adjustment is essential in panel data analysis, where unobserved shocks may persist within countries across periods.

The results remain consistent with my baseline findings: the estimated coefficient on water stress (WSI) remains negative ($\beta = -0.04$) but is marginally significant ($p = 0.08$) under clustering, supporting the conclusion that increased water scarcity is associated with lower economic output. Other covariates retain expected signs, and the R^2 of 0.9938 reveals the model fitness.

These findings suggest that the negative relationship between water stress and economic output is not an artifact of error structure and remains robust under clustered standard errors.

c) Fixed effects with clustered standard errors

In this model, I estimate the relationship between water-related variables and economic output while controlling for country and year fixed effects. Clustered standard errors at the country level account for within-country autocorrelation. Among the covariates, log capital remains statistically significant at the 5% level (0.109, p = 0.011), indicating that higher capital formation is positively associated with real GDP per capita. In contrast, the coefficient on log desalination is small and statistically insignificant (0.057, p = 0.782), suggesting that without accounting for disaster-related damages, the independent effect of desalination capacity is imprecisely estimated. The coefficient on drought events remains negative as expected (−0.112), but it is not statistically significant (p = 0.113), providing only weak evidence that drought frequency alone reduces income in the absence of broader environmental controls.

Table 8: Fixed effects model clustered standard errors
Estimator: Fixed Effects (within estimator)
Dependent Variable: log GDP per capita (real)
SE: Clustered by country
Observations: 2,236
Countries: 113
Years: 1995-2020

Variable	Estimate	Std. Error	t value	p value
WSI (x100)	-0.027	0.013	-2.115	0.038 *
Log desalination	-0.190	0.181	-1.054	0.296
Log Capital	0.101	0.066	1.523	0.132
Governance Index (GI)	0.077	0.020	3.867	0.000 ***
Log population	-0.413	0.136	-3.047	0.003 **
Temperature	0.015	0.010	1.554	0.125
Precipitations	-0.000004	0.000019	-0.217	0.829
% GDP from Agriculture	-0.034	0.008	-4.555	0.000 ***
% GDP from Manufacturing	-0.0002	0.007	-0.035	0.972
% GDP from Services	-0.0023	0.0016	-1.416	0.161
Log trade	0.0303	0.0453	0.6683	0.5052
Log capital	0.1086**	0.0422	2.5701	0.0114
Drought events	-0.112	0.07	-1.607	0.113

RMSE: 0.0827
Adjusted R-squared: 0.9902
Within R-squared: 0.0357

The coefficient on log trade also appears statistically insignificant ($p = 0.506$), implying that short-run variation in trade openness does not significantly explain within-country income dynamics once time-invariant factors are accounted for. The model fits the data with an adjusted R^2 of 0.9902 and RMSE of 0.0827. However, the within R^2 remains modest (0.0357), which indicates that most of the variation is captured by fixed effects, and that the explanatory power of the included time-varying covariates is limited.

6.5.5. Endogeneity and temporal validity

a) Hausman test

To validate my choice of Fixed Effects (FE) in the panel regression, I conducted a Hausman test, which assesses whether the Random Effects (RE) model is consistent or whether individual-specific effects (α_i) are correlated with the independent variables. In this case, the test yielded a chi-square statistic of 630.82 with 10 degrees of freedom, and a p-value below 2.2e-16. Given the extremely small p-value, I reject the null hypothesis that the Random Effects estimator is consistent. This suggests that unobserved country-level characteristics are correlated with the regressors, and thus Fixed Effects is the appropriate choice for producing consistent estimates.

b) Placebo tests: Lagged GDP per capita

To explore the plausibility of the assumed causal direction, I conduct placebo tests using lagged GDP per capita as the dependent variable. The underlying idea is that if water stress truly affects economic performance, rather than the reverse, then current levels of water stress should not systematically predict past income levels (Granger, 1969)[12].

While this test cannot definitively rule out reverse causality or omitted variable bias, the absence of a significant relationship in these placebo specifications provides suggestive support for the temporal structure assumed in the main analysis.

Using a two-way fixed effects model with clustered standard errors, I find that WSI exhibits a negative coefficient of -1618 with a p-value of 0.085 when regressed on lagged GDP per capita. Although marginally insignificant at the 5% level, the result aligns with the

[12] This approach is conceptually related to Granger non-causality tests, which assess whether one time series provides predictive information about another. While the placebo regression used here does not formally implement a Granger test, it draws on a similar intuition: if variable A "Granger-causes" variable B, then past values of A should help predict B, but not the other way around (Granger, 1969).

hypothesis that water stress does not meaningfully predict past income, and the weak association likely reflects random variation or time-dependent shocks rather than a causal pathway.

Other covariates, such as log population ($p = 0.0096$) and governance quality ($p = 0.116$), retain similar signs and magnitudes as in the main analysis, supporting the stability of the specification. The high adjusted R-squared (0.98) suggests that the model continues to explain a substantial proportion of the variance in GDP per capita.

As an additional placebo test, I estimate the impact of current water stress on lagged GDP per capita. The rationale is that future environmental conditions should not influence past economic outcomes. Consistent with the temporal structure of causality, the estimated coefficient for WSI is negative but only marginally significant ($p \approx 0.085$).

c) Subsamples robustness checks: Excluding Middle East and North Africa (MENA), landlocked, and high-income countries

To evaluate the stability of my core findings, I conduct robustness checks by re-estimating the baseline two-way fixed-effects regression while systematically excluding MENA countries, landlocked countries, and high-income economies. Across all subsamples, the estimated relationship between water stress and economic output remains negative in direction, reinforcing the consistency of my results.

When excluding MENA countries, the coefficient on water stress remains negative ($\beta = -0.025$), though not statistically significant ($p \approx 0.53$), whereas excluding landlocked countries yields a comparable negative coefficient ($\beta = -0.03$, $p \approx 0.009$), significant at the 1% level. Governance quality continues to exhibit a strong, positive association with GDP per capita ($\beta \approx 0.08$, $p < 0.001$), and the agricultural GDP share remains robustly negative across specifications ($\beta \approx -0.017$, $p < 0.001$). These subsample results, presented in Appendix 4, confirm that the adverse relationship between water scarcity and economic performance is not driven by any particular group of countries, but holds across diverse geographic and economic contexts.

d) Arellano-Bond estimation: Desalination–drought interaction

To address potential concerns about endogeneity and the persistence of income over time, in this section I estimate a dynamic panel model using the Arellano-Bond two-step GMM method. This approach includes a lagged dependent variable to account for the influence of past income levels and removes time-invariant country-specific effects. It also adds an interaction between desalination capacity and drought frequency to examine whether desalination helps reduce the economic damage caused by droughts.

The results suggest that GDP is strongly influenced by its own past values, that indicates income persistence (See Appendix 5). The coefficient on lagged GDP per capita is 0.747 ($z = 18.61$; $p < 0.001$). Trade openness and capital formation are both positive and statistically significant: 0.148 ($p = 0.0013$) and 0.055 ($p = 0.0045$), respectively. Desalination capacity remains positively associated with income (0.028), but this effect is not statistically significant at conventional levels ($p = 0.465$).

Crucially, the interaction between desalination and drought events is positive and statistically significant: 0.011 ($z = 2.00$; $p = 0.046$). That suggests that desalination does indeed mitigate the economic effects of droughts. This interaction term indicates that the beneficial impact of desalination becomes stronger as drought frequency increases. This result provides evidence that desalination helps protect economies during periods of drought. By including an interaction term between desalination capacity and drought frequency, the model shows that countries with stronger desalination infrastructure suffer less economic damage when droughts occur. Because droughts are stochastic, natural and unexpected, this relationship helps to back the claim that desalination is driving resilience, rather than the economy simply growing and investing more in water systems.

This interaction is statistically significant, meaning the effect is not due to chance. Thus, the results suggest that when droughts become more frequent, the positive impact of desalination on income becomes even stronger. In other words, desalination is not just good for growth, but it also acts like a safety net against climate shocks.

. Combined with the statistical tests that check for reliability and causality, this strengthens the confidence that desalination plays a real and measurable role in protecting countries from the economic risks of water scarcity.

The diagnostic tests evidence the validity of the dynamic panel specification. The Sargan test for overidentifying restrictions yields a p-value of 0.632, suggesting that the model's instruments are valid and uncorrelated with the error term.

Both first and second order autocorrelation test (AR(1); AR(2)) are insignificant, indicating no problematic autocorrelation in the residuals. The Wald test shows that the explanatory variables are jointly significant ($\chi^2(6) = 520.23$, $p < 0.001$), reinforcing the fit of the model

7. Future Projections Analysis

This section interprets my empirical findings in the context of existing projections and literature to assess likely future trajectories of the economic impacts of water scarcity, under varying technological and institutional scenarios.

7.1. Population growth and water demand outlook

According to the United Nations World Water Development Report, the global population is projected to exceed 9.7 billion by 2050, with the most intense growth concentrated in water-scarce and rapidly urbanizing regions including Sub-Saharan Africa, South Asia, and the Middle East (UN-WWDR, 2024). This demographic expansion, combined with rising income levels and changing consumption patterns, is expected to increase global water demand by nearly 30%–50% over mid-century baselines (UN-WWDR, 2024). Agriculture will remain the dominant water-consuming sector globally, particularly in developing economies where irrigation efficiency remains low. However, domestic and industrial water demand is growing disproportionately in urban regions, exerting further pressure on already stressed freshwater systems (Rockström et al., 2023).

While the projections of various international organizations predict that the world's human population will continue to increase in short and long-term futures, it is also true that water scarcity is likely to increase as well.

Assuming the findings are robust, and GDP per capita declines by approximately 2% to 5.9% for each unit increase in the rescaled Water Stress Index, the results indicate that, if current trajectories continue, a substantial number of economies will confront serious macroeconomic challenges associated with intensifying water scarcity.

This aligns with, and refines, prior global projections, such as those by the World Bank (2019), that estimate that “global freshwater requirements by 2030 could increase by over 40 percent above the current level” (p. 7), and Gude (2017), who emphasizes that “population growth alone stimulates the need for additional water resources for meeting the basic necessities of water for food production and hygiene” (p. 592). The spatial distribution of this growth is highly uneven: “By 2050, 70% of the global population will be living on 0.5% of the global land area,” with urban populations nearly doubling in deltas and drylands (PBL, 2018,

p. 3). These zones are already characterized by structural water stress and likely to experience disproportionate increases in water demand.

The findings of this thesis add quantifiable clarity to these forecasts, indicating that absent mitigation, many countries will breach the thresholds of "high" or "extreme" water stress as defined by the Water Stress Index, with clear macroeconomic consequences. This implies that while water scarcity projections often highlight supply-demand imbalances, the economic repercussions are likely to be severe, measurable, and regionally heterogeneous, as highlighted by the results.

Climate change compounds the structural water stress associated with demographic and economic growth. Global circulation models (GCMs) suggest that rising temperatures will accelerate evapotranspiration and reduce snowpack retention, altering both the quantity and timing of freshwater availability. In regions such as the Mediterranean Basin, Western Asia, and parts of Latin America, projections under SSP2-4.5 and SSP3 scenarios indicate that mean annual water availability per capita may decline by over 30% by 2050 (Preetha et al., 2025; Rockström et al., 2023).

Importantly, climate extreme events (especially droughts) are expected to become more frequent, intense, and prolonged, increasing the volatility of water supply and complicating long-term planning. Projections using the Standardized Precipitation Evapotranspiration Index (SPEI) show that both the frequency and spatial extent of hydrological droughts are set to increase, making baseline water stress only part of the future challenge (Siddiqui et al., 2022). Under a "business-as-usual" (BAU) trajectory, the global population is expected to rise from 7 billion to approximately 9 billion by 2050 (PBL, 2018, p. 8), with highly uneven distribution.

The results of this thesis complement these climate-linked water stress projections by quantifying their likely economic impacts under "Business As Usual" (BAU) conditions, by demonstrating that incremental increases in water stress are systematically associated with non-trivial reductions in GDP. Additionally, changes in evapotranspiration patterns may gradually deteriorate agriculture and the livelihoods of populations in affected areas, potentially contributing to migratory pressures and instability, in alignment with the scenario-based global analysis provided by PBL (2018) and Rockström et al. (2023).

7.2. The expanding role of desalination in future water supply

In this increasingly constrained hydrological landscape, desalination is increasingly being explored as a promising technological response. According to the World Bank (2019), global desalination capacity has more than quadrupled since 2000 and is expected to continue growing at an average rate of 7% annually over the next two decades, driven primarily by high-income and water-stressed countries in the Middle East, North Africa, and parts of Asia and Latin America. Forecasts suggest that by 2030, desalinated water could supply over 15% of municipal water needs in regions such as the Gulf Cooperation Council (GCC), Southern Spain, Northern Chile, and parts of Australia.

This aligns with my empirical findings, which suggest that desalination provides only modest mitigation of 1%–4% of water scarcity's economic losses in most countries, while a small group of top adopters can fully offset and even reverse these losses under specific conditions of high-capacity deployment, governance quality, and energy availability.

Desalination can provide a critical mitigation pathway to reduce the macroeconomic consequences of water scarcity. These findings operationalize the potential of desalination highlighted by Moghimi et al. (2021) and Cattani et al. (2021), who note that advances in membrane technology, renewable energy integration, and economies of scale are reducing costs and expanding feasible deployment.

Moreover, scenario-based models suggest that coupling desalination with predictive water allocation and smart-grid energy systems could allow for flexible scaling in response to seasonal variability, with future resilience depending on institutional and technological integration (Preetha et al., 2025). my results extend these projections by providing empirical elasticity estimates, showing that investments in desalination and adaptive infrastructure can significantly moderate GDP losses, transforming the narrative from one of inevitable economic decline to one of conditional resilience.

7.3. Summary and policy implications

Taken together, these projections suggest that water scarcity will intensify over the coming decades, especially in regions already near or beyond hydrological thresholds. The economic consequences of unmitigated scarcity are likely to be magnified under demographic and climatic stress. In this context, desalination stands out not as a universal solution, but as a strategic adaptation tool for specific geographies—particularly arid coastal countries with high fiscal capacity and access to clean energy.

The empirical results of this thesis indicate that countries' GDP decreases between 2% and 5.9% for each unit increase in the scaled Water Stress Index, revealing the concrete economic risks tied to worsening water scarcity, especially in regions with high dependence on water-intensive sectors and limited adaptive capacity. This provides evidence that without mitigation, water scarcity is not only an environmental concern but a macroeconomic risk, with potential spillover effects on food security, migration pressures, and social stability.

From a policy perspective, the finding that countries in the top decile of desalination experience mitigation rates of up to 83% is particularly relevant for water-scarce economies. However, such effects appear contingent on governance quality and institutional capacity, suggesting that technology alone is not sufficient (see Appendix 4). Given the marked heterogeneity in my results, desalination does not emerge as a universal solution, but rather as a transformative adaptation tool for specific geographies. Most countries with modest desalination capacity exhibit only partial mitigation of water scarcity's economic impacts, reflecting persistent vulnerability often tied to fiscal and infrastructural constraints.

However, in the top decile of desalination adopters such as the UAE, Qatar, and China, my interaction models show that the negative effects of water scarcity can be fully offset and the sign of the impact reversed, resulting in net positive GDP effects under water stress conditions. This striking result suggests that when desalination is deployed at scale within supportive governance policies and paired with renewable energy systems, it can transform water scarcity from a macroeconomic risk into a potential source of economic resilience and even growth, particularly in arid coastal countries with high adaptive capacity. However, it is important to note that while the results show that a small subset of countries with advanced desalination capacity appear to fully offset and even reverse the negative GDP effects of water scarcity, these estimates may also reflect the combined influence of concurrent improvements in governance, infrastructure, and energy systems, which often accompany large-scale desalination investments.

This analysis shows the importance of explicitly incorporating dynamic mitigation pathways into economic assessments of water scarcity, recognizing desalination's potential to shift the economic equilibrium under environmental stress. Future research could build on this thesis by calibrating econometric models to simulate varying desalination adoption rates and treatment timing under policy scenarios, offering a forward-compatible framework for quantifying water-economic resilience. Model calibration along these lines would improve the empirical foundation for policymakers aiming to transform water scarcity from an unavoidable drag on economic performance into a manageable, and under certain conditions, economically beneficial transition pathway in water-scarce regions.

8. Policy Implications and Recommendations

8.1. Where and how desalination should be deployed

Technological solutions including desalination have proven to be high-impact strategies in addressing acute water scarcity, particularly in arid and semi-arid regions where natural freshwater sources are limited or overexploited. However, this thesis demonstrates that the economic returns to desalination, measured through the interaction effects between water stress and desalination intensity vary widely across countries, depending on baseline water stress, desalination capacity, institutional quality, energy infrastructure, governance effectiveness, urbanization patterns, and broader socioeconomic conditions. Empirical findings using my panel analysis reveal a strikingly heterogeneous mitigation landscape:

Top-tier adopters such as China (579%), the UAE (390%), Saudi Arabia (388%), and Qatar (194%) exhibit mitigation rates that not only offset GDP losses from water stress but reverse them, generating net economic gains under environmental stress conditions. This outcome reflects the economic structures and institutional contexts of these countries, where water is a binding constraint across industrial, service, and agricultural sectors, making reliable water availability crucial for economic stability and growth. Large-scale desalination, integrated with renewable or low-cost energy systems, lifts this constraint, transforming water scarcity from a limiting factor into a catalyst for continued expansion of water-dependent economic activities, even during drought periods.

This interpretation aligns with Liu et al. (2016), who emphasize that the effectiveness of desalination as a resilience mechanism depends on institutional capacity and technological readiness, and with Kawamura (2023), who highlights that desalination can shift water stress from a structural constraint to a managed variable when paired with effective governance and investment. The World Bank (2019) and UN-Water (2021) similarly document that desalination stabilizes water-dependent sectors and supports economic activity when embedded within robust governance frameworks and energy strategies.

China’s desalination expansion, aligned with sustainable industrial and urbanization policies, reduces regional water vulnerability while sustaining growth (Liu et al., 2016). In the Gulf states, high fiscal capacity and institutional strength enable desalination to secure water supplies and support sectors like manufacturing and services, transforming environmental stress into a driver of resilient growth (World Bank, 2019; UN-Water, 2021).

The findings of this thesis confirm that desalination’s macroeconomic potential is unlocked when it functions as part of a systemic adaptation strategy within well-governed, energy-secure economies. The interaction terms in the two-way fixed effects models empirically demonstrate that as desalination capacity increases, the marginal negative impact of water stress on GDP diminishes and shifts positive in the highest capacity deciles. These super-normal mitigation rates may not be simply anomalies, but rather evidence of desalination as an economic enabler under environmental stress.

This is suggestive of the need to align desalination investments with governance quality, fiscal capacity, and technological integration to replicate these outcomes in other high-stress contexts. Nonetheless, while these findings suggest that desalination can act as a strong buffer against the economic impacts of water stress in certain high-capacity contexts, caution is warranted in interpreting these effects as purely causal. Countries that achieve net positive GDP effects alongside desalination expansions often simultaneously implement broader institutional and infrastructure reforms that can also contribute to economic resilience.

Upper-mid adopters (e.g., Israel (111%), Spain (86.8%), Croatia (85.7%), Bahrain (83.3%), Oman (70.1%) have achieved high but comparatively lower mitigation rates, transforming water scarcity into a manageable challenge rather than a growth constraint. These countries typically combine advanced desalination technologies with strong but more constrained fiscal capacities and smaller market scales compared to top-tier adopters. Their mitigation outcomes often reflect a balance between using desalination to secure critical domestic, industrial, and agricultural water needs while pursuing water demand management and efficiency improvements to contain costs. In these contexts, desalination effectively stabilizes water-dependent economic activities, reducing vulnerability and supporting resilience, but without fully reversing the economic impacts of water stress as in the highest-capacity contexts. Instead, desalination enables these economies to sustain growth under environmental stress while avoiding the severe disruptions that water scarcity could otherwise impose on key sectors and social stability.

Upper-mid adopters, including countries like Israel (111%), Spain (86.8%), Croatia (85.7%), Bahrain (83.3%), and Oman (70.1%), achieve high but comparatively lower mitigation rates that transform water scarcity into a manageable challenge rather than a growth constraint. Across this group, mitigation rates typically range from 40% to 110%, reflecting significant economic buffering of water stress without fully reversing its impact as seen in top-tier adopters. These outcomes emerge where advanced desalination technologies are combined with strong but more constrained fiscal and budgetary capacities, smaller market scales, and deliberate policy alignment with water demand management. Desalination in these settings secures critical water needs for domestic, industrial, and agricultural uses, stabilizing water-dependent sectors and supporting resilience under environmental stress while maintaining macroeconomic stability. While not eliminating the economic impacts of water scarcity entirely, desalination enables these economies to sustain growth and avoid severe disruptions that water scarcity might otherwise impose on key sectors and social stability.

Middle deciles (20th–70th percentiles) have exhibited modest mitigation rates generally between 1% and 4%, with countries like Jordan (2.95%), Morocco (2.70%), Poland (3.16%), Singapore (3.25%), Ghana (3.51%), and Peru (2.44%) reflecting this pattern. These mitigation levels indicate that while moderate desalination deployment can buffer some economic impacts of water stress, it does so only partially and does not transform water scarcity into an economic enabler as seen in top-tier adopters. In many of these countries, desalination serves targeted urban or industrial needs rather than broad-based supply augmentation, and its limited scale, higher unit costs, and governance challenges constrain its potential. Consequently, desalination in these contexts is best viewed as one element within a broader water security strategy that must include demand management, efficiency improvements, and governance reforms to increase overall resilience and economic stability under environmental stress.

The lowest decile adopters, including India (0.26%), Namibia (2.51%), El Salvador (0.03%) and Senegal (0.02%), have shown negligible mitigation effects despite varying baseline water stress levels. In these contexts, desalination capacity is either absent or too limited to provide meaningful macroeconomic buffering, leaving these countries fully exposed to the negative GDP elasticity of water stress, estimated at reductions of 2% to 5.9% per unit increase in the water stress index (WSI). Countries in this group often face fiscal and institutional constraints, limited energy infrastructure, and competing investment priorities, making large-scale desalination economically or logistically unfeasible. For these nations, alternative adaptation pathways such as improving water-use efficiency, investing in watershed management, reducing non-revenue water losses, and building institutional capacity are likely to yield higher resilience dividends than desalination in the near term.

This analysis suggests that desalination tends to work best in arid and semi-arid coastal countries or subnational regions with high baseline water stress, strong institutional capacity, and the fiscal and energy resources necessary for scaling. In such contexts, desalination functions as a strategic economic buffer rather than a marginal supply intervention, and enables these economies to stabilize and, in some cases, enhance growth under environmental stress.

Limitations and risks of desalination

While this thesis argues that desalination can significantly mitigate the negative economic impacts of water scarcity under specific conditions, scaling the technology faces critical limitations and risks that must temper its role as a resilience strategy.

First, energy intensity remains a major constraint. Desalination, particularly seawater reverse osmosis, requires substantial electricity inputs so that its viability is closely tied to a country's energy capacity and cost structures. Although top-tier adopters like China, the UAE, Saudi Arabia, and Qatar have leveraged abundant, low-cost energy to scale desalination, many countries in middle and lower adoption deciles lack the fiscal and infrastructural capacity to support these energy demands sustainably, limiting their ability to replicate high mitigation outcomes.

Second, governance and institutional capacity are essential for successful desalination deployment and operation. Desalination plants are capital-intensive projects that require significant upfront investment, multi-year construction timelines, and ongoing maintenance by a skilled technical workforce. Weak institutional environments can hinder planning, procurement, and effective management, while pricing and distribution inefficiencies may further limit economic benefits and accessibility. A further limitation relates to the structural realities of water distribution. Even when desalination successfully produces freshwater, this water must be transported to where it is needed, often across significant distances. This requires extensive infrastructure such as aqueducts, pipelines, and pumping stations, all of which are capital-intensive, energy-dependent, and require ongoing maintenance and technical oversight. Similar to transmission constraints in electricity markets, the mere capacity to produce water does not guarantee its availability at the point of demand. Without robust distribution systems, the benefits of desalination may remain geographically constrained to coastal urban centers, limiting its macroeconomic resilience potential in inland agricultural regions or secondary cities that also face water stress. Addressing these distribution infrastructure challenges is therefore essential for desalination to function as an effective and equitable adaptation strategy under water scarcity.

Third, environmental externalities, particularly brine disposal, present significant challenges. Brine, the highly concentrated saltwater byproduct of desalination processes, can negatively impact marine and coastal ecosystems by increasing salinity and introducing treatment chemicals into surrounding waters. Brine disposal increases operational costs and raises sustainability concerns, particularly for densely populated coastal regions where cumulative impacts can be severe (World Bank, 2019). As Bacha et al. (2003) illustrate, even low-energy, solar-based desalination prototypes like the Solar Multiple Condensation Evaporation Cycle (SMCEC) face operational challenges including limited production capacity and dependence on variable solar radiation, demonstrating that technological constraints persist even in small-scale or pilot contexts.

Taken together, the preceding analysis suggests that effectiveness of desalination in tackling water scarcity depends on the alignment of energy availability, governance quality, technical capacity, and environmental safeguards. In high-capacity contexts with reliable energy and institutional strength, evidence suggests that desalination can transform water scarcity from a growth constraint into a resilience tool. However, in low-capacity settings, desalination's mitigation potential remains limited without parallel investments in energy systems, human capital, and governance reforms. Moreover, even in high-capacity environments, environmental externalities must be carefully managed to avoid undermining long-term sustainability.

Thus, the positive marginal effects of desalination identified in this thesis should be interpreted as conditional upon these physical, economic, institutional, and ecological constraints, confirming the need for comprehensive planning and integrated water-energy governance strategies when considering desalination as an adaptation pathway under water scarcity (Bacha et al., 2003; World Bank, 2019).

8.2. Recommendations for scaling and governance

The expansion of desalination must be guided by clear governance strategies that maximize economic benefits while addressing environmental and energy-related challenges. Recognizing the conditions under which desalination most effectively buffers the economic impacts of water scarcity, and aligned with global best practices, the following key recommendations are proposed:

- **Integrate Desalination with Renewable Energy Planning**

As desalination is energy-intensive, its long-run viability depends on reducing its carbon footprint and operating costs. Aligning desalination infrastructure with national renewable energy strategies such as coupling plants with solar or wind energyensures that mitigation of water scarcity does not exacerbate energy dependence or climate risks (Scholten et al., 2025).

- **Enforce Environmental Safeguards for Brine Disposal**

One of the major limitations of desalination is the ecological risk posed by brine discharge. Governance frameworks should include mandatory environmental impact assessments, strict effluent standards, and incentives for innovation in brine treatment and valorization. These safeguards are essential to reconcile technological expansion with marine ecosystem protection (European Parliament, 2025).

- **Target Investments to High-Scarcity, High-Impact Zones**

Empirical results in this thesis demonstrate that the GDP benefits of desalination are largest where baseline water stress is high. Therefore, investment strategies should prioritize these high-return contexts, where desalination functions not merely as a water supply tool but as a direct lever for economic resilience.

By focusing on energy integration, environmental regulation, and spatial targeting, policymakers can scale desalination in ways that are both economically efficient and environmentally sustainable.

9. Conclusion

This study provides empirical evidence on the macroeconomic effects of water scarcity, showing that **water stress leads to a GDP per capita reduction of approximately 2% to 5.9%**. These estimates are arguably conservative and fall within, and even slightly below, global projections established by major institutions. For instance, the World Bank (2016) estimates that in the absence of significant policy action, water scarcity could reduce economic growth in affected regions by up to 6% of GDP by 2050 due to cascading effects on agriculture, health, and livelihoods. These forecasts are echoed by other modelling exercises, such as the *Economics of Water* report, which places potential GDP losses at 8% for high-income and up to 15% for low-income countries under a business-as-usual scenario (UNESCO, 2023). These comparisons reinforce the robustness of the present study's estimates and highlight that, if anything, they likely represent a conservative lower bound on the broader macroeconomic risks posed by growing water stress.

Importantly, desalination emerges as a viable mitigation strategy, which is capable of offsetting a substantial share of the economic losses caused by water scarcity. In some contexts, particularly where it has been scaled in coordination with energy and governance reforms, desalination has allowed countries to maintain growth trajectories despite severe hydrological constraints (World Bank, 2019). Governance quality also plays a crucial role in enhancing resilience, with stronger institutions enabling more efficient investment, risk management, and equitable water allocation (Global Commission on the Economics of Water, 2023).

Compared to estimates from international organizations using Computable General Equilibrium (CGE) models, which predict a 6%-18% GDP reduction due to water scarcity within 25 years, my results are similar in magnitude but are derived from a different methodology, panel econometric techniques with fixed effects and robustness checks.

One reason for this difference is that, while both approaches consistently find negative economic impacts of water scarcity, CGE models explicitly incorporate general equilibrium effects, capturing economy-wide feedback that arise through intersectoral linkages, factor markets, and price adjustments (Böhringer & Rutherford, 2008; Sue Wing, 2004). CGE models rely on Social Accounting Matrices (SAMs) and can integrate bottom-up engineering data with macroeconomic structures, allowing simulation of sectoral substitutions and technology adoption under different water scarcity scenarios, thus capturing potential amplification effects over time (Böhringer, Rutherford, & Wiegard, 2003; Peters & Hertel, 2016). In contrast, my panel econometric approach measures the historical relationship between water scarcity and economic outcomes during 1995–2020, providing an empirically grounded, backward-looking estimate, while CGE models often simulate future scenarios toward 2050 under various policy assumptions (Böhringer & Rutherford, 2008; Sue Wing, 2004). Therefore, it is not surprising that estimates of this thesis are more conservative, as they reflect observed historical impacts, whereas CGE-based studies often capture larger potential future impacts due to structural adjustments and dynamic interactions in the economy.

This thesis contributes to economic and environmental research by quantifying water scarcity's direct impact on macroeconomic performance using panel econometric techniques, illustrating the mitigating effect of desalination infrastructure, and highlighting the role of governance quality in shaping economic resilience.

This study suggests the use of TWFE as a robust alternative to cross-sectional approaches, particularly in the absence of experimental data. As Angrist and Pischke (2009) emphasize, careful econometric design using panel data can yield policy-relevant insights while maintaining transparency, addressing concerns highlighted by Deaton (2009) regarding identification validity in applied research.

Unlike traditional CGE models that rely on simulated future scenarios, the empirical strategy of this thesis leverages real-world country-level data to estimate within-country economic responses to water scarcity. From a policy perspective, these findings show the need for targeted investment in desalination and improved water governance as essential components of national economic strategies in water-scarce regions. Countries with high baseline water stress and limited natural freshwater availability stand to benefit most from desalination expansion, provided that energy and environmental externalities are appropriately managed. Moreover, this study reinforces the argument that water scarcity is not merely an environmental challenge but a structural economic constraint, which demands integrated policies that combine technological adaptation, infrastructure investment, and institutional reforms.

Future Research

While this study establishes a solid empirical foundation, several avenues for further investigation remain. Upon completing this thesis, I am left with several questions. Will future data facilitate time series analysis? If data and time permit, would it be possible to address a different question: how does a particular country respond to water scarcity over time? This could aid in addressing correlations among variables and allow for an analysis of the persistence of the effects of increased water scarcity over time.

Given that climate impacts numerous variables in the economy, culture, and reality of countries globally, time series analysis may also enable sectoral analyses to determine which sectors are most affected by water scarcity. In the same direction, future studies could also employ a dynamic panel approach or local projections to estimate long-term cumulative GDP impacts of water scarcity. Another advantage of time series analysis is the potential to create local projections. This would allow researchers to understand how an increase in water scarcity at one point in time will sequentially impact a country's economy in the future. Additionally, future research may benefit from more granular, region-specific analyses to assess the heterogeneity of water scarcity's impact across different geographical contexts. Future research could focus on specific desertified regions such as California (USA, Mexico), the Atacama Desert (Chile, Peru), the Maghreb region in North Africa, and Southern Europe, where water scarcity is particularly acute and desalination plays an increasingly vital role. By refining econometric approaches and expanding datasets, researchers can further elucidate how technological adaptation influences economic resilience at both national and subnational levels.

Another interesting topic is that, while literature often suggests that, because 70% of global water usage is used for agriculture, the agricultural sector's GDP would be the most compromised by water scarcity. However, with technological advancements and the increasing shares of services in GDP due to the development of new technologies of the digital era including artificial intelligence and large language models, royalties derived from intellectual, industrial and commercial property, (amongst many others) in both developed and developing countries, the question remains: does this assumption still hold? Is it true that agriculture dependency on water can still significantly affect GDP? Regarding the sectoral breakdown, I acknowledge that this represents a notable limitation of the analysis. While it is widely recognized that agriculture constitutes the largest water-consuming sector globally, this study does not delve into the sector-specific economic impacts of water scarcity in a quantitative manner. The decision to focus on aggregate GDP per capita was primarily driven by data constraints and the broader objective of assessing macroeconomic effects that entail water scarcity and desalination altogether. Although sectoral regressions were not conducted within the scope of this research, exploring the differential impacts across agriculture, industry, and services presents a promising avenue for future inquiry.

Finally, although this study explored the use of the Standardized Precipitation Evapotranspiration Index (SPEI) and drought indicators from the EM-DAT database as potential instrumental variables, I ultimately discarded these instruments due to insufficient strength and relevance in the identification strategy. Future research could focus on developing or identifying stronger, climate-related instrumental variables to better address potential endogeneity concerns and to more precisely isolate the causal impact of water scarcity on economic outcomes. An option is the global count of desalination-related patents. Researchers may draw on the number of patent families associated with the International Patent Classification (IPC) and Cooperative Patent Classification (CPC) codes, such as C02F and B01D61/00, issued by the World Intellectual Property Organization (WIPO), the European Patent Office (EPO), and the United States Patent and Trademark Office (USPTO). Assuming that patent activity serves as a valid proxy for technological innovation, and that such innovation is not systematically influenced by any single country’s GDP but rather reflects broad patterns of desalination feasibility across contexts, this measure may satisfy both relevance and exogeneity requirements for empirical analysis.

This thesis provides an overview of the economic consequences of water scarcity, but continued refinement of methodologies and expansion into regional case studies will be needed to produce useful advice to leaders and stakeholders interested in water stressed regions.

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