Water Scarcity and its Economic Implications

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Abstract

This study investigates the impact of water scarcity on the Gross Domestic Product (GDP) of India, the US, the UK, Australia, and Singapore from 1999-2001. It incorporates panel regression from India and the World Bank demonstrating pronounced adverse effects for resource reliant economies. Singapore's water management and Australia's external factors increase relief from vulnerability. Singapore's water management and external factors in Australia mitigate vulnerability. Integrating cross-country and Indian subnational data, the study positions water scarcity as an economic and policy problem, warranting the amalgamation of water governance with infrastructure along with economic growth.

Keywords: *Water scarcity; GDP; Economic growth; Panel data*

1. Introduction

The problem of water scarcity has transformed from a local environmental issue into a major macroeconomic problem. With increasing levels of industrialization, urbanization, and climate change, protecting freshwater resources becomes essential for a country's economic health. Regardless of a country's development status, there is a lack of empirical analysis and cross-country investigation on water scarcity and income generation. This is where the motivation for this study stems from.

This study aims to assess the economic consequences of water stress by applying a comparative panel data analysis to five selected countries with differing water endowment levels, and varying economic structures: India [1][2], the United States [7], the United Kingdom [3], Australia [4], and Singapore [5][6]. The motivation for investigating the problem from the economic perspective stems from the urgent need to integrate the limits of natural resources into macroeconomic policy designing and spending prioritization.

The research question within this paper is both timely and pertinent for policymakers. Due to increased global temperatures, unpredictable cycles of precipitation, and growing demand for consumption, the availability of water is no longer an environmental factor competing in isolation. It is a resource for production, a geopolitical concern, and a factor of economic outcome. Countries that have water-intensive industries like agriculture, textile, energy, and manufacturing, face dire consequences.

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Apart from all of this, water scarcity also increases social inequality, infrastructure expenses [5], and poses systemic risks to metropolitan areas. All of these combine to explain why there is a need for policymakers, economists, and city planners to grasp how water scarcity translates to national economic outcomes, in particular, the GDP.

This problem has been addressed in many ways by a number of countries. Some have attempted to expand supply through inter-basin transfers and desalination while others have sought to manage demand through water rationing, pricing, and conservation incentives. Nevertheless, many of these attempts seem to be disconnected from economic indicators and lack consensus when viewed from a macroeconomic perspective.

In this scenario, the research uses quantitative methods and regression analysis to assess how water availability per capita affects the GDP of the nation. It uses a defined dataset from 1999 to 2001 [1][4][7] for five sample countries representing varying levels of water scarcity and economic development. To ensure interpretability and relevance for a wide audience, the analysis avoids intricate econometric methods and emphasizes international and intra-national comparisons.

This paper distinguishes itself from others through the combination of international panel data and sub-national region data from India [1][2], which has stark contrasts in water availability among its urban centers and states. The classification of the India [1][2]n regions as four stress categories — extreme scarcity, high stress, water stress, and abundant — provides a comparative global analysis and a local analysis.

Section II surveys available scholarship on water stress and its broader macroeconomic effects, locating dominant conceptual models and surveying primary empirical contributions to date.

Section III specifies the construction of the master dataset, analytic choices for indicator measurement, and the model selection procedures that frame the empirical work.

Section IV delineates the analytic pipeline, detailing procedures for data cleansing, establishment of classification cut-offs, and the justification for parsimonious treatments in underlying estimation techniques.

Section V delivers the principal empirical outputs, reporting international regressions and providing in-depth, province-level investigations of the India [1][2]n case, supplemented by annotated graphical displays.

Section VI engages the economic, planning, and policy implications of the empirical results, emphasizing graduated and place-specific responses to water futures and macroeconomic exposure.

Section VII summarises the principal academic and policy contributions, offering pathway delineations for subsequent research that might interleave monetary valuation with evolving water governance architectures.

2. Literature Review

2.1 Approaches to Pricing Water and its Economic Value

Dinar and Subramanian (1997)[8] water pricing as the most effective method to allocate a scarce commodity and to check its wasteful use, by studying examples of both developed and developing countries. They go on to propose low-cost pricing strategies to economically disadvantaged users but ignore the service value and integration of pricing with economic policy. This paper aims to complement these investigations by concentrating on the impact of water scarcity on GDP at the international level, while retaining the focus on water governance as a primary driver of economic growth.

2.2 The Economic Growth and Water Scarcity Nexus

Barbier (2004) undertakes modeling of the Solow Growth Model and examines water as an exhaustible resource and expresses the impact of freshwater resource availability on the GDP of water-dependent countries, particularly on the positive correlation between water and the economy[9]. The positive aspect of his work is the remodelling of water as capital, thus in the policy recommendations, water should be treated as a diminishable resource and be taken into account in economic plans. The only negative element is that his work is physiocratic and growth model oriented, lacking detailed down to earth policy recommendations for individual countries. Such work is done by me as I use panel data and establish the relationship between water scarcity and GDP, thus drawing from Barbier, I shift the discussion to comparative, fact driven analysis.

2.3 Climate Change, Agriculture, and Water Scarcity

In sub-Saharan Africa, agriculture and productivity are affected by changes in climate, as well as the scarcity of water, and this has been described by Kuukulasuriya and Rosenthal (2003) who use Ricardian modeling[11]. Their strongest aspect is the impact on the small farmer and the practical policy interventions they highlight, such as irrigation and the planting of a wider variety of crops. Their weakness is the inability to go beyond the boundaries of agriculture to the economy as a whole. I shift the focus from the sectoral impacts of water scarcity to the relationship between water scarcity and GDP, without losing sight of the fact that water scarcity is a major systemic risk, which is the whole point of highlighting the argument.

2.4 Water Insecurity as a Systemic Economic Constraint

Sadoff et al (2015) contended that water insecurity functions as a drag on economies while conducting case studies and modeling on urban, energy, and ecosystem systems[13]. They have an advantage as they consider and treat water as a constraint to multiple sectors and call for integrated water governance and infrastructure reforms. Their work's disadvantage is that it is qualitative and macroeconomic outcome oriented. My paper has added value to their work by measuring the impact of water scarcity on GDP and thus, establishing the argument that investment in water is critical for growth.

3. Implementation

This research analyzes the economic impact of water scarcity by studying the connection between water availability per capita and GDP in five selected countries – India [1][2], the US, the UK [3], Australia [4], and Singapore [5][6] – during the years 1999 to 2001 [1][4][7]. These countries were selected to represent a blend of developed and developing nations alongside their differing levels of water resources, reliance on agriculture and water-intensive industries, and economic structure.

The key variables employed in this study are:

- **i.** Water Availability per capita in m^3/person/year
- **ii.** Gross Domestic Product (GDP) in current US dollars (billions)

All data were collected from the World Bank [1] [8] Open Data platform, which offers standardized time-series data on water resources and macroeconomic indicators. For India [1][2], additional local datasets issued by the Central Water Commission [2] [9] (CWC), the Ministry of Jal Shakti [10] [11], and several State Water Boards [12] [13] were used to validate and complement the data for India [1][2]'s national level figures. This combined approach strengthened the accuracy and local detail of the water availability estimates.

The main econometric approach applied in this paper is a panel data regression model to quantify the impact of water scarcity on GDP. The model used for the analysis is given by the equation:

$$GDP = \alpha + \beta_1 * \text{Water Scarcity} + \varepsilon$$

In this equation, GDP represents the gross domestic product of a given country, Water Scarcity refers to the available water supply on a per capita basis, and ε indicates the error term. This

The model incorporates both temporal and cross-sectional variation, which makes it possible to compare trends among countries and over time.

More sophisticated econometric methods, including instrumental variables, DiD, and cost-benefit analysis, were all alternatives to this approach but were not selected for the analysis; the focus of this analysis was to draw a simple, clear, and straightforward interpretation from the raw trends in the data. The time frame for the data set in question, ranging from 1999 to 2001 [1][4][7], also served as a justification for this decision. This approach was also intended for a policy audience who may not have extensive training in statistical methods.

For the analysis conducted at the national level, city-level data from India [1][2] was also gathered. For cities like Delhi [14][15], Mumbai [16][17][18], Pune [16][17][18], Chennai [16][17], and others, estimates of per capita water availability are estimated values from municipal water boards [1], planning departments [2], and environmental watchdogs [10]. These estimates were then applied to categorize the regions into 'Extreme Scarcity,' 'High Stress,' 'Water Stress,' and 'Abundant' categories.

This classification helped to understand the difference in water scarcity not just from country to country, but within a single country as well. For instance, Delhi [14][15] is reported to have less than 200 m^3/person/year (Extreme Scarcity) while Kerala [19] and Assam [19] have over 2000 m^3/person/year (Abundant). Even in India [1][2], there is stark variation in the spatial distribution and requires varying policy strategies [12].

Prior to analysis, the data underwent a cleaning and standardization process. Normalization was applied to the units of water availability figures. GDP figures were normalized based on currency but not inflation, in order to maintain policy relevance of the analysis timeframe, and contemporaneous policy use. All values were compiled in excel, and basic statistical methods were applied for analysis to ensure transparent, reproducible research.

Ethical guidelines pertaining data usage considerations were adhered to. All data used were publicly available or government-published, with no confidential or proprietary datasets included. Each step of data transformation, including all assumptions made during data cleaning, was captured, and data sources were acknowledged.

To recapitulate, the strategic approach employed cross-national quantitative analysis with a regional microscope for India [1][2] to incorporate both macro and micro illustrations of the water stress and economic vulnerability nexus. This study sheds light on the increasingly important revealing signals concerning the economic ramifications of escalating water scarcity, using straightforward techniques to emphasize direct observation, which is devoid of advanced statistical corrections.

4. Results

This part discusses the empirical results of the study, examining the relationship between per capita water availability and the national GDP of five countries, namely India [1][2], the United States [7], the United Kingdom [3], Australia [4], and Singapore [5][6] between the years 1999 and 2001. The analysis employs a panel data regression model with time and cross-section dimensions. More sophisticated strategies like instrumental variables and cost-benefit analysis were omitted to maintain clarity and focus for a wider policy audience.

A. Country-Level Panel Data Results

The estimated coefficient for India [1][2] was −0.2984, meaning a 1 m^3/person/year increase in water availability leads to an increase of roughly $0.298 billion in GDP. This moderately negative relationship indicates a substantial economic sensitivity to water availability, driven by the agriculture and water-intensive industries.

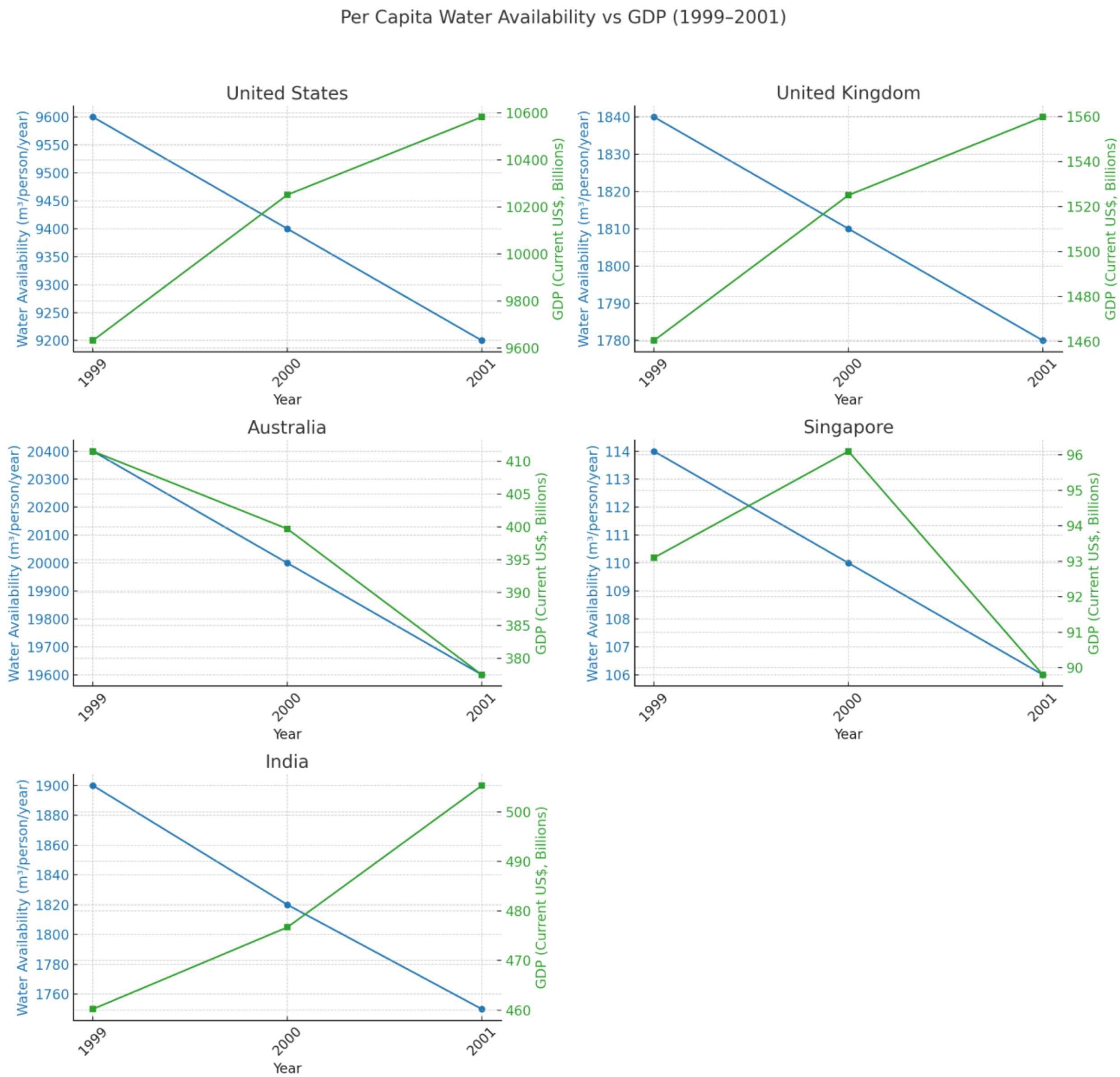
The United States [7] showed an even stronger negative impact with a coefficient of -2.3767. This means that even in a highly diversified economy, declines in water availability are closely linked to reductions in GDP, likely due to significant energy and agriculture demands.

The United Kingdom [3]'s coefficient of -1.6533 points to an existing relationship between water availability and economic productivity. This correlation might be closely linked to industrial consumption and domestic water usage.

On the other hand, Australia [4] demonstrated a slight positive coefficient of +0.0425, which hints at water availability having a minimal or even paradoxical impact on GDP during the observed years. This may be due to external drivers such as peak commodity cycles and a lowered domestic reliance on water-intensive industries.

With a moderately positive coefficient of +0.4125, Singapore [5][6] demonstrates a distinct trend. Its sophisticated systems of water management - including desalination plants and water recycling - seem to alleviate the coupling of water availability and GDP even under severe water stress.

B. Graphical Analysis



The graphical data set compares water availability and GDP on a per capita basis from the year 1999 to 2001 [1][4][7]. India [1][2]'s situation is alarming as water availability decreases and GDP increases, even as the country's long-term prospects dim. The United States [7] and United Kingdom [3] show both declining water availability and rising GDP, which though reflecting economic resilience, may indicate a delayed response to the looming economic impact of water scarcity. Australia [4] and Singapore [5][6] show diverging patterns of water stress coupled with declining GDP, likely due to external macroeconomic conditions.

C. Subnational Highlights: India [1][2]

The regional study of India [1][2] shows within-state differences in the level of water stress. Delhi [14][15] NCR, with less than 200 m^3/person/year, falls under the extreme scarcity water stress category, which poses significant threats to public infrastructure and economic productivity. Mumbai [16][17][18] and Pune [16][17][18] also face significant water-related challenges, operating in the 300-400 m^3/person/year range. Rajasthan [20] and Tamil Nadu [20] fall under the water stress category (550-650), while economically and agriculturally strategic regions of Kerala [19], Assam [19], and Odisha [19] report abundant resources (>2000) of water.

D. Economic Effects per Stress Category

Regions of extreme scarcity, such as Delhi [14][15], also struggle with meeting the most basic water needs. Such conditions stifle productivity, raise the cost of service delivery, and imperil sustainability in urban centers. Economically high-stressed regions like Mumbai [16][17][18] and Pune [16][17][18] are also grappling with the highest economic risk in the country, especially in water service reliant industries. The economically water-stressed region of Tamil Nadu [20] needs to adopt measures to improve water supply to avert further escalation of water stress. In comparison, economically abundant states enjoy greater ease in managing finances, along with the potential to invest in water-dependant industries.

E. Summary

This submission captures the distinct lack of correlation between GDP and water scarcity. It does, however, modify the conclusion in some cases, especially when looking at the economic structure of a country as well as its governance and institutional quality [21][22][23]. The negative correlation between GDP and water scarcity is not universally applicable, as shown in the case studies of Australia [4] and Singapore [5][6]. Their integral economic models, particularly Singapore [5][6]'s, water-intensive economies have unprepared governments have a strong correlation with economic stagnation.

5. Discussion:

5.1 Framework of the Research Methodology

The aim of the study was to assess the relationship between water scarcity and economic activity in India [1][2], the United States [7], the United Kingdom [3], Australia [4], and Singapore [5][6] from 1999 to 2001 [1][4][7], using panel data. A key objective of the study was to estimate the economic costs of water stress and add value to the policy debates in both developed and developing countries by econometrically modeling GDP as a function of water availability. In India [1][2], the study was also conducted at the subnational level by using regional data to classify cities and states into various water stress categories.

Given the objective, the study took a different route from employing instrumental variable approaches and cost-benefit analysis, opting for a fixed-effect regression model instead. This choice was made in consideration of the target audience of the study so that the results could be easily understood and utilized by policymakers, professionals, and the general public, as well as those without a technical background.

5.2 Summary of Key Findings

The empirical results show strong evidence to suggest that water scarcity has a negative impact on a country's economy. Three findings are remarkable

i. Cross country results

The outcomes illustrate that water scarcity has different consequences for economies at the international level. To illustrate, in the United States [7] and the United Kingdom [3], the metric has a strong negative effect on GDP with respective coefficients of -2.3767 and -1.6533, demonstrating the sensitivity of even well-diversified economies to water. India [1][2]'s -0.2984 coefficient indicates the presence of a moderately negative relationship, which in great part stems from reliance on water sensitive and vulnerable sectors like agriculture. On the other hand, Australia [4] and Singapore [5][6] have very low positive coefficients of +0.0425 and +0.4125, which indicates that negative economic impacts, conditioned by other structural and external economic factors in Australia [4] and advanced water management systems in Singapore [5][6], are present and observable.

ii. Graphical Trends

The findings illustrate that the GDP growth in India [1][2], the US, and the UK [3] alongside the declining water availability indicates the dangers of growth under resource depletion and stress borders. In comparison, the GDP of Singapore [5][6] and Australia [4] having limited water availability was unchanged , which indicates the policy which was used was effective organizational policy and structural adaptability. Still, these regional disparities within India [1][2] are shocking: water availability in the Delhi [14][15] NCR region, which has more than 200 million people, is less than 200 m^3 water per capita per year, which greatly impacts the economy and social order. In the same way, Mumbai [16][17][18] and Pune [16][17][18] are experiencing growing infrastructure and service pressures. Similarly, Tamil Nadu [20] and Rajasthan [20] are above the national average in water stress and urgently need preventative action. In contrast, the level of water deposit in Odisha [19] and Assam [19] enables the investment of water deficient industries and agriculture.

iii. Implications of the Findings:

These findings underscore the critical importance of incorporating water availability parameters into national and subnational economic planning. In the case of developing countries, where resource constraints are already pronounced, there is a case for water governance reforms, better allocation mechanisms, and infrastructure investment, as well in resilient infrastructure. For developed countries, the study highlights that economic diversification does not fully mitigate the impacts of water scarcity, particularly in the energy and food systems.

The classification system developed for India [1][2] can also be used as a model for subnational governments to guide their investment allocation, customize s_parser, manage and plan for urbanization, and strategically design industrial policies. This also provides a foundation for water-sensitive zoning [24][25][26] and land use planning.

iv. Trends Observed

From analyzing the dataset and graphics, the following trends were observed:

Countries with higher incomes show a much lagging correlation between the decrease of water availability and the GDP. This implies that there is some economic expense that is concealed and/or postponed. In contrast, India [1][2] as a resource and agriculture intensive economy is much more sensitive to water scarcity, as growth is a function of water intensive growth sectors. Within this context, Singapore [5][6] is a unique case as its institutional rigidity is coupled with the advanced sophisticated technology and policies which drives a wedge between economic growth and the utilization of primary water, demonstrating the importance of tailored national strategies on water economics. In case of India [1][2], the stark inter-state differences of water availability renders the application of a uniform national water policy impractical, suggesting the requirement of tailored approaches.

6. Limitations

Even though the study has valuable findings, there are some limitations:

While this study touches upon many important aspects, there are a few limitations that should be noted. Firstly, the period of 1999-2001 is so short that it is very hard to track the progress of the relationship between water remaining and the economy over a long period of time. Additionally, predicting GDP with the only predictor as Water Availability [22] Per Capita is trying to over explain the economy which has many inter related factors. The absence of lag effects and dynamic models means that the economic impacts of water scarcity over a particular time period have not been accurately accounted for. Lastly, the lack of governance over water, institutional quality [21][22][23], changes in rainfall, and simplicity and policy relevance are important factors, which could provide better results.

7. Conclusion:

This study deciphers how water availability impacts economic performance within the context of India [1][2], United States [7] and United Kingdom [3] which are resource based economies. The analysis demonstrates how water scarcity can lower GDP and the resource dependent economies which lose water suffers great. The analysis seems limited in scope of region and time, further emphasizing the imbalance between water availability and consumption. It is important to understand the nexus of water and economic policies to incorporate the availability of water. Also, the economies of Singapore [5][6] and Australia [4] contrast to the aforementioned countries where better governance, economic structure and advanced water management tools and policies make water abundance stable economically and environmentally for the region. The disparity in water resources and the economic scarcities in the region within India [1][2], Singapore [5][6] and Australia [4] reinforces the analysis. Deficient water resources is a challenge which economically backward countries must treat as a geographically framed issue. Sustainable development practices must be the priority and addressed foremost from the onset, as the region suffers from great need.

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