Water Stress, Climate Variability, and Economic Performance: Evidence from Asian Economies

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Abstract

In this research, the multifaceted relationship between water stress, climate variability, and economic performance in Asian economies has been analyzed, revealing that water constraints have the power to significantly increase the macroeconomic impacts of climate change. The study, which is based on panel data of 45 countries from 1971 to 2024 and utilizing the Pooled Mean Group–Autoregressive Distributed Lag (PMG-ARDL) model, examines the interaction between temperature, rainfall variability, water resources, and economic growth both in the short run and in the long run. The outcomes of the study show that the combination of limited water supply and erratic rain patterns results in a noticeable decline in output growth, which is most pronounced in agriculture-dependent and lower-middle-income areas. The researchers have observed a direct link between a one-degree Celsius rise in average temperature and the GDP loss amounting to several billions of dollars, with the intensity of the damage depending on the respective climate risk and water-stressed regions. Moreover, the impact of water scarcity on climate variability cast a shadow by the weakening of crop yields, disruption of industrial output, and limiting of adaptive capacity thus the results emphasize the fact that water stress is a key channel through which climate change affects the economy in Asia. The authors say that in the absence of regional cooperation in adapting to the changing conditions and sustainable water management, the problems of water scarcity and climate change together will continue to make the economy and different regions more vulnerable and polarize the differences in growth between them.

Keywords: Water Stress, Climate Variability, Economic Performance, Asian Economies

1. Introduction

Asia is chiefly responsible for the worldwide climate crisis and gradually losing its battle against the heat and the change in precipitation. The decline of the region's water resources is, to a great extent, the final blow that is killing the economy of the area, the security of food, and even the very long-term growth reliant on sustainability. The developing and emerging economies of the region that make up the global agricultural and industrial supply chains' supporting pillars are getting deeper into climate-hydrological stress interactions which are being reflected as lower productivity, disrupted value chains, and increased income volatility (World Bank, World Development Report 2023: Adapting to a Changing Climate, 2023) (IPCC, Climate Change 2022: Impacts, Adaptation and Vulnerability., 2022). Asia has warmed up by about 1.8°C over the last fifty years, which is almost two times the global means (IPCC AR6, 2021), and this has been accompanied by an increased frequency and intensity of extreme weather and drought events (Zhao, 2021) (Huang, 2020).

As per FAO AQUASTAT (2023) and World Resources Institute, the renewable freshwater availability, which is measured in terms of per capita, in Asia has seen a decline of over 35% since 1971. This has been mainly due to demographic expansion, rapid urbanization, and extraction of water at an unsustainable rate (WRI, 2022). Countries such as Pakistan, India, Iran, and Afghanistan among others have already reached the physical water scarcity threshold where the annual per capita water availability has gone down to less than 1,000 m^3 (FAO, 2023) (Mekonnen, 2016). Thus, they are very much prone to hydrological and climatic shocks. In addition, the variations in precipitation and the intensity of droughts have gone up by more than two times compared to the 1970s (Hao, 2019). This situation has seriously interrupted the cycles of agricultural production, hydropower generation, and urban water security. The economic consequences of this climate-hydrological convergence are immense. The agricultural sector, being the major employer of the labor force (nearly 60%) in Asia, is still very much dependent on monsoon rainfall and groundwater mainly in the irrigated areas, thus making it extremely vulnerable to global warming hype through extremes of temperature, erratic rainfall, etc. (Lobell, 2011). The industrial and service sectors are also being increasingly restricted due to water-consuming production processes and climate-change-related infrastructure damage, linking water scarcity and economic instability directly and thus impinging the growth of total factor productivity (Hallegatte, Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience., 2020). Recent macroeconomic assessments by (UNESCAP, Asia-Pacific Disaster Report 2022: Pathways to Adaptation and Resilience, 2022) and (ADB, 2023) estimate that climate- and water-induced productivity losses could reduce Asia's aggregate GDP by 3–5% annually by mid-century under current warming trajectories, with more severe outcomes projected for South and Central Asia.

Although the literature on the macroeconomic impacts of temperature and precipitation is vast (Kahn M. E.-C., 2021), there are only a handful of studies that use hydrological stress explicitly as a variable to characterize climate–growth relationship. This exclusion of the hydrological parameter from the analysis, especially the water dimension of climate change, which mainly leads to the capacity of the nations to adapt to the increase of heat, droughts, and unpredictable rain (Mishra, 2010) (Schewe, 2019). Water scarcity directly reduces agricultural production (UNESCAP, Asia-Pacific Disaster Report 2022: Pathways to

Adaptation and Resilience, 2022), cuts off resources for industrial and energetic production, and makes the economy more susceptible to external shocks, thus increasing the overall economic impact of climate change (Sadoff, 2015). The current research on the macroeconomic impact of climate change will be empirically based on the countries of Asia that are affected by water stress and rainfall together. It does this by applying a Pooled Mean Group Auto-Regressive Distributed Lag (PMG-ARDL) model where the standard climate-growth framework is expanded by including hydrological indicators such as water availability indices, rainfall deviations, and drought frequency measures. Such a modeling strategy allows for the simultaneous consideration of long-run steady-state effects and short-run transition dynamics while accounting for country-specific differences and regional interdependence patterns that are usually observed in climatic data (Chudik, 2015). The use of hydrographic variables gives new empirical evidence to the study about the issue of water scarcity aggravating the impact of climate variability on the economy, mainly in low- and middle-income countries that are dependent on agriculture. Eventually, this research strengthens the climate-resilient growth debate by recognizing water as the key factor through which the climate change affects productivity, growth, and economic stability (Diffenbaugh, 2019). The results are anticipated to shape the regional and national policy frameworks for changes in water management that are adaptive, for investments in infrastructure that is climate-smart, and for the development of sector-specific mitigation strategies that can improve the resilience of economies to the increasing climate and water risks throughout Asia (World Bank, World Development Report 2023: Adapting to a Changing Climate, 2023).

2. Literature Review

A discussion about climate change has always taken a bad stand towards the issue of climate variability, among other things, arguing that it is high time the earthen and water resources must be shared among the economic sectors in a sustainable way. Nonetheless, in the past year, the question of who gets what and how much has become much more complicated. Through Asia, the scenarios of feedback brought along by climate change, through increased temperatures, erratic rainfall and less freshwater, have gotten more intricate affecting even the long-term developmental prospects of the region. The situation has caused so much chaos in the waters that the water scarcity is now turning out to be a main factor determining the whole economy's vulnerability (IPCC, Climate Change 2021:The Physical Science Basis., 2021). This issue is complicated and is a great challenge for Policymakers, especially in the developing parts of the world where the line between economics and the environment is still quite blurred (FAO, 2023).

The weight of empirical evidence has shown that climate variability has a multidimensional impact on economic performance. The very hot or very cold conditions influence the output of workers, yields of crops, and demand for energy, while the changing pattern of rain has a negative impact on the cycles of agriculture, the infrastructure, and the supply chain (Hertel, 2016). In this regard, water stress acts as a catalyst, intensifying the economic costs of climate shocks by limiting the capacity to produce and raising the costs of adjustments across the whole economy (Wada, 2016) (Sadoff, 2015). The macroeconomic transmission of these effects is especially strong in Asia, where about 60 percent of the labor force is engaged in agriculture and rural incomes largely depend on it (ADB, 2023).

In the last few decades, the availability of renewable freshwater per person in Asia has dropped by over 35% and at the same time, the frequency of drought and erratic rainfall has increased twofold when compared to the 1970s (FAO, 2023) (IPCC, Climate Change 2022: Impacts, Adaptation and Vulnerability., 2022). These alterations have caused not only the limitation of food production but also a decrease in productivity in the industrial and service sectors due to the disruption of the supply systems for energy, transport, and water. So, water scarcity has become one of the main factors through which climate variation causes macroeconomic instability that reduces growth potential, increases fiscal burdens, and leads to income volatility in climate-sensitive economies (UNDP, 2022).

The climate-hydrology-growth nexus illuminates the interconnection of the natural and the economic spheres by its very notion. The lack of water causes the economies to suffer more due to the sharper silence of their output after the climate shocks, which signifies their limited adaptive capacity and poor resource management (Schewe, 2019) (WRI, 2022). This unequal response indicates that the impact of temperature and rainfall on growth is contingent on the hydrological conditions, which is a process making sense in particularly Asia's lower-middle-income, water-dependent economies. In such situations, even the slightest changes in the climate can lead to massive cuts in the outputs of agriculture and industry, thereby causing the economy to slow down (UNESCAP, Asia-Pacific Disaster Report 2023: Pathways to Adaptation and Resilience, 2023).

Hydrological factors like water availability, rainfall variability, and drought frequency, when integrated into macroeconomic models, reveal the climate impacts on growth more clearly than ever before. This combination makes it possible to evaluate the respective direct effects (along with the lines of decreased productivity and resource constraints) and indirect effects (through the respective energy channels of trade, and employment). This is the way through which researchers will be able to unearth the water scarcity effect in the temperature-growth relationship, thus providing guidance for determining the most appropriate adaptation and mitigation measures (World Bank, World Development Report 2023: Adapting to a Changing Climate, 2023) (UNESCO WWAP, 2022).

Against this backdrop, the present study empirically examines the joint effects of water stress and climate variability on the economic performance of Asian economies. Employing a dynamic Panel Mean Group Auto-Regressive Distributed Lag (PMG-ARDL) approach (Pesaran, 1999), it captures both short-run fluctuations and long-run equilibrium relationships between temperature, precipitation, water availability, and GDP growth. The inclusion of an interaction term between climatic and hydrological variables allows the analysis to isolate cross-climate amplification effects, revealing how limited water availability intensifies the economic consequences of climate change (Kahn M. E.-C., Long-term macroeconomic effects of climate change: A cross-country analysis, 2021).

3. Theoretical Framework

The theoretical foundation of this study is grounded in the intersection of environmental economics, growth theory, and climate–hydrology interactions, explaining how water stress and climate variability jointly determine economic performance in Asian economies. In traditional neoclassical and endogenous growth theories (Solow, 1956) (Romer, 1990), economic output depends primarily on physical capital, labor, and technology. This relationship is typically expressed as:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta}$$

where Ait (total factor productivity, or TFP) illustrates technological progress and institutional efficiency. Nonetheless, in the current climate-economy situation, TFP is not an outside variable; it is very much affected by the environment and water cycles. Climatic disturbances, like increased temperatures, erratic rainfall, and insufficient water supply, change the production process by influencing both the resource and efficiency sides. Following the work of Dell, Jones, and Olken (2012) and Burke et al. (2015), the model applied here widens the production function by introducing temperature (TEMP), precipitation (PRECIP), and water stress (WSTRESS) as factors determining TFP. Consequently, total productivity is a climatic and hydrological condition-dependent function:

$$Y_{it} = A(T_{it}, R_{it}, W_{it}) K_{it}^{\alpha} L_{it}^{\beta}$$

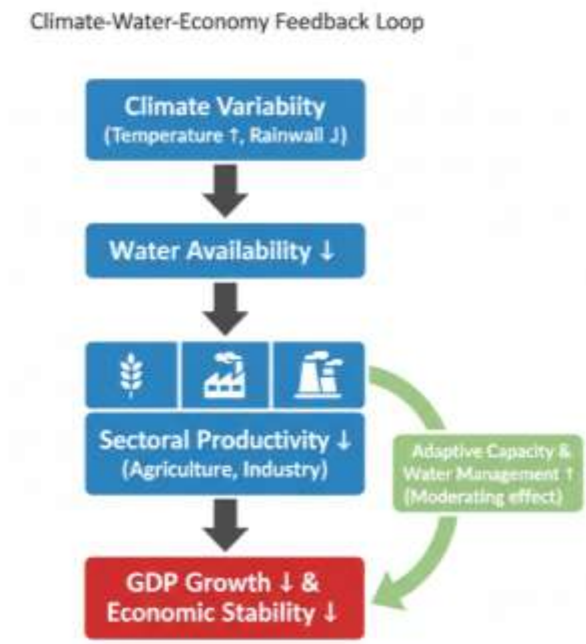
The economic situation in Asia is accurately portrayed by this formulation, which is also in part due to environmental stability besides the accumulation of labor and capital. For example, in the case of Kahn M. E.-C. (2021) and Hsiang (2010), they report that if temperatures are extremely high, not only will the workers' productivity be reduced but also the crop yields will be lower, the demand for electricity will be higher, and the manufacturing processes will be disrupted (Kahn M. E.-C., 2021) (Hsiang, 2010). Also, the situation of unpredictable rains and continuous lack of water for the agriculture and power generation will go on for a long time leading to the economy growing slowly (Sadoff, 2015). Water-related problems are of great economic importance therefore the impact on the economy due to climate change, such as heat and drought, becomes stronger (thus the region's development potential is obviously reduced). Additionally, production through the indirect channel will also be less efficient and the increase in these inefficiencies will come from two points. First is the Direct Production Constraint where the shortage of freshwater causes the inefficiency of the most essential inputs to be lowered; if there is less water for irrigation, less crop yield will be the result and the same will happen in the industrial sector with water scarcity hindering the processes of cooling, and energy consumption (Mekonnen, 2016). This ultimately leads to a decrease in the productivity of capital and labor, which results in overall GDP growth being slowed down. Secondly, through Indirect Macroeconomic Feedback, the impact of continuous water shortage is felt throughout the economy. The water shortage results in increased energy costs, disrupts trade and logistics, and makes private investors reluctant to invest due to the elevated risks of operations. Such indirect effects produce long-term feedback loops that are responsible for both capital formation and necessary structural transformation (Hallegatte, Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience., 2020) which in turn, makes the economy more susceptible to the next shocks.

To empirically capture these relationships, the study adopts an Integrated Climate-Hydrology-Growth (ICHG) framework. The extended econometric specification is expressed as:

$$\ln(GDPG_{it}) = \alpha_0 + \alpha_1 TEMP_{it} + \alpha_2 PRECIP_{it} + \alpha_3 WSTRESS_{it} + \alpha_4 RAIN\_VAR_{it} + \alpha_5 (TEMP_{it} \times WSTRESS_{it}) + \varepsilon_{it}$$

In this case, the interaction term (TEMPit * WSTRESSit) represents the nonlinear amplification effect, or in other words, the negative impact of higher temperatures on the growth of plants gets more intensive in regions where there is water scarcity. This is in line with evidence that climate shocks have varying effects depending on the region's water resources and the adaptive capacity of the inhabitants (Diffenbaugh, 2019). The situation in Asia is particularly interesting because the continent includes not only rapidly growing countries (e.g., China, India, and Indonesia) but also water-stressed countries to a great extent (e.g., Pakistan, Iran, and Central Asia). Thus, water scarcity is a major factor limiting the potential for the climate to be resilient; hence, growth is restricted to the level of capital accumulation and policy interventions. The model also finds support in the Environmental Kuznets Curve (EKC) theory (Grossman, 1995), which posits that pollution and other forms of environmental degradation first rise with income and then fall once the economy reaches a certain level of income and starts adopting cleaner and more efficient technologies. Yet, this turning point has not been achieved for most Asian economies, especially for lower-middle-income countries. Rather, they have a continuous cycle of growth which demands more water and creates more pollution thus creating more stress on the water supply. This has the effect of silencing economic performance through putting environmental pressure on the economy. Hence, water stress in Asia is not just an environmental problem but also a barrier to economic and social development that works in concert with climate variability to determine the long-term growth path The theoretical consequence is that the economic resilience (the capacity of the economies to endure and bounce back from climate shocks) is dictated by the pump, hydrological system's stability and the institutions' adaptive ability. The economies with excellent water governance, storage and reuse infrastructure, and climate-smart agriculture practices are the ones that can still lose the least and be called resilient (World Bank, World Development Report 2023: Adapting to a Changing Climate, 2023) (UNESCAP, Asia-Pacific Disaster Report 2023: Pathways to Adaptation and Resilience, 2023). On the other hand, economies that have poor water management systems suffer compounded losses because the climate-induced disruptions get across the production networks or are widely felt throughout the economy.

The theoretical logic can be summarized as a causal pathway:



This conceptual framework is the foundation of the empirical strategy of this research. The integration of hydrological stress indicators with the PMG-ARDL model allows the analysis to explore not only the short- but also the long-run dynamics of the impact of climate variability on macroeconomic outcomes at different levels of water stress across Asia. The theoretical framework confirms that water stress is not a separate environmental issue but rather a fundamental channel of transmitting macroeconomic impacts. It amplifies the impacts of temperature and precipitation shocks, thus influencing the long-term economic performance and sustainability of Asia's climate-vulnerable countries.

4. Data and Methodology

The theoretical foundation of this study rests on the climate–hydrology–growth nexus, which extends the neoclassical growth framework by explicitly integrating climatic and hydrological variables into the production process. Economic output $\boldsymbol{Y}$ is assumed to depend not only on capital $\boldsymbol{K}$ and labor $\boldsymbol{L}$, but also on environmental and hydrological conditions, including temperature $\boldsymbol{T}$, precipitation $\boldsymbol{R}$, and water availability $\boldsymbol{W}$. The extended production function can be written as:

$$Y_{it} = A_{it} \cdot K_{it}^{\alpha} \cdot L_{it}^{\beta} \cdot f(T_{it}, R_{it}, W_{it})$$

Ait denotes total productivity that encompasses the effects of institutions, technologies, and policies. Temperature increases over the optimal levels and erratic rainfall patterns have a negative impact on **Ait** through the channels of lower crop yields, lesser labor productivity, and reduced energy efficiency. At the same time, water shortage limits the production of both agriculture and industry by restricting the availability of resources as inputs. Therefore, economic growth depends on climate variability and hydrological stress, which is the basis for the present analysis.

This panel data analysis is conducted with the use of secondary annual data to the Asia region and the period of 1971-2024 for the historical estimation and the period of 2025-2100 for the climate-economy projections under various Shared Socioeconomic Pathways (SSPs). The dataset is made up of various microeconomic, climatic, and hydrological factors that were selected from international databases that are considered the most reliable to guarantee validity and comparability between the countries. The economic factors including real GDP growth, capital formation, trade openness, and population growth were gathered from the World Bank's World Development Indicators (World Bank, World Development Indicators (WDI), 2024). The climatically influenced variables (temperature and precipitation) were obtained through the Climate Research Unit (CRU TS4.07) and the World Bank Climate Knowledge Portal, while the studies on water caused by hydrological conditions, such as water stress and rainfall variability, were taken from FAO AQUASTAT, UN Water, and the Global Precipitation Climatology Centre (GPCC). Water stress (WSTRESS) is quantitatively determined as the total annual freshwater withdrawal expressed as a percentage of the renewable freshwater resources indicating shortage of water. Rainfall variability (RAIN_VAR) is defined as the coefficient of variation of annual rainfall which represents the degree of instability and unpredictability of precipitation. The two indicators measure the hydrological aspect of climate risk that has an impact on economic stability.

Table 1. Details of the Variables Used in the Study

Variable	Symbol	Definition	Unit of Measure	Frequency	Source
Real GDP Growth	GDPG	Growth rate of real GDP (constant 2015 US$)	%	Annual	WDI (2024)
Temperature	TEMP	Annual mean surface temperature	°C	Annual	CRU TS4.07 / WB Climate Portal
Precipitation	PRECIP	Annual average precipitation	mm	Annual	CRU TS4.07
Water Stress	WSTRESS	Freshwater withdrawal as % of renewable freshwater resources	%	Annual	FAO AQUASTAT (2024)
Rainfall Variability	RAIN_VAR	Coefficient of variation of annual rainfall	Index	Annual	UN Water / GPCC (2024)
Capital Formation	CAPF	Gross capital formation (% of GDP)	% of GDP	Annual	WDI (2024)
Trade Openness	TRADE	Sum of exports and imports (% of GDP)	% of GDP	Annual	WDI (2024)
Population Growth	POPGR	Annual population growth rate	%	Annual	WDI (2024)

The relationship between water stress, climate variability, and economic performance in Asian countries is assessed using the key variables listed in **Table 1**. The real GDP growth (GDPG), which is the dependent variable, reflects the total economic activity, whereas the independent variables temperature (TEMP), precipitation (PRECIP), water stress (WSTRESS), and rainfall variability (RAIN_VAR) indicate the main climatic and hydrological aspects of analysis. It is necessary to emphasize water stress and rainfall variability since they directly represent the lack and the instability of water resources, which can enhance the negative economic effects of climate change. To separate the macroeconomic effects of hydrological and climatic fluctuations, control variables such as capital formation, trade openness, and population growth are also considered in the analysis. All these variables matched very well with the study's aim to measure the influence of water scarcity and irregular rainfall on the long-term growth dynamics of Asia's climate-vulnerable economies.

Table 2. Descriptive Statistics (1971–2024)

Variable	Symbol	Mean	Std. Dev.	Minimum	Maximum	Observations
Real GDP Growth (%)	GDPG	4.26	3.47	−9.20	12.14	2430
Temperature (°C)	TEMP	22.37	3.18	12.40	30.55	2430
Precipitation (mm)	PRECIP	1124.5	418.3	241.2	2823.1	2430
Water Stress (%)	WSTRESS	54.7	22.9	11.3	98.4	2430
Rainfall Variability (Index)	RAIN_VAR	0.184	0.092	0.041	0.412	2430
Capital Formation (% of GDP)	CAPF	25.3	8.9	8.2	45.6	2430
Trade Openness (% of GDP)	TRADE	69.8	31.7	21.4	182.5	2430
Population Growth (%)	POPGR	1.84	0.97	−0.5	3.7	2430

Table 2 presents the data overview for the 45 Asian economies' study covering the year 1971-2024.The findings indicate that there are a lot of variations in the climate and hydrology factors, which is a clear sign of the varying environmental conditions in the area. The annual temperature is about 22°C on average while the total precipitation is approximately 1124 mm which reflects the variation of climate in Asia. The average water stress of 54.7% means that more than half of the region's renewable freshwater resources are already used up and some countries are nearly at the point of having no water. The coefficient of variation for rainfall (0.184) indicates that there are very big differences in the amount of rain from year to year, mainly in the dry areas. These differences are the reason why water stress and rainfall variability are considered as the main factors in the evaluation of the macroeconomic impacts

of climate change on GDP growth.

Given the time-series nature of the panel (where T > N), the Panel Mean Group Auto-Regressive Distributed Lag (PMG-ARDL) approach proposed by Pesaran, Shin, and Smith (1999) is adopted. This estimator accommodates heterogeneous short-run dynamics and homogeneous long-run relationships across economies, suitable for panels with mixed integration order ***I (0)*** and ***I (1).***

The baseline PMG-ARDL specification is given as:

$$GDPG_{it} = \alpha_i + \sum_{j=1}^{p} \beta_{ij}\Delta X_{it-j} + \sum_{j=1}^{q} \gamma_{ij}\Delta Z_{it-j} + \phi_i(GDPG_{it-1} - \theta_1 TEMP_{it} - \theta_2 PRECIP_{it} - \theta_3 WSTRESS_{it} - \theta_4 RAI$$

Where:

- ***GDPG**$_{it}$* represents the real GDP growth rate of country *i* at time *t*.
- ***TEMP**$_{it}$* and ***PRECIP**$_{it}$* capture climate variability.
- ***WSTRESS**$_{it}$* and ***RAIN_VAR**$_{it}$* represent hydrological stress.
- **A**$_{it}$ is a vector of control variables (CAPF, TRADE, POPGR).
- ϕ_i measures the speed of adjustment toward long-run equilibrium.
- ε_{it} is a random disturbance term.

The long-run equilibrium relationship is embedded within the error-correction form:

$$\Delta GDPG_{it} = \varphi_i(GDPG_{it-1} - \theta_1 TEMP_{it} - \theta_2 PRECIP_{it} - \theta_3 WSTRESS_{it} - \theta_4 RAIN\_VAR_{it} - \theta_5 X_{it}) + \sum_{j=1}^{p-1} \lambda^{*}_{ij}\Delta GDP$$

where φ_i represents the error-correction coefficient, expected to be negative and significant, confirming long-run cointegration among variables.

Before estimation, cross-sectional dependence (CD) was tested using the Pesaran (2015) test, as regional spillovers in climate and water dynamics are common among Asian countries. The CD statistics are calculated as:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}$$

A significant CD statistic indicates interdependence among cross-sections, necessitating robust estimation methods. Following this, Levin–Lin–Chu (2002) and Im–Pesaran–Shin (2003) panel unit root tests were applied to determine the order of integration. Both tests confirmed that variables are integrated of order zero or one, justifying the PMG-ARDL framework. The Pedroni (2004) and Kao (1999) panel cointegration tests confirmed the existence of a long-run equilibrium relationship between GDP growth, climate, and hydrological variables. Hausman tests showed a preference for PMG estimation over Mean Group (MG), thus confirming the hypothesis of long-run homogeneity. Diagnostic tests, such as those for serial correlation, heteroskedasticity, and model stability (CUSUM and CUSUMSQ), endorsed the economic model as satisfying the assumptions of the econometric theories.

To evaluate the long-term economic impacts of climate variability and water stress, temperature projections under different Shared Socioeconomic Pathways (SSPs) were employed from the IPCC AR6 database. The population-weighted mean surface temperature C_{it} for each country was regressed against time to estimate temperature trends:

$$C_{it} = \alpha_0 + \alpha_1 t$$

Similarly, for each SSP scenario:

$$C_{it}^{m} = \alpha_0 + \alpha_1^{m} t$$

where C_{it}^{m} denotes the population-weighted mean temperature under scenario m. The estimated temperature trajectories were then combined with PMG-ARDL long-run coefficients to simulate GDP growth outcomes from 2025 to 2100. This step provides forward-looking insight into how climate and hydrological dynamics jointly affect Asia's long-term economic trajectory.

This study's methodological contribution lies in integrating hydrological stress variables (water stress and rainfall variability) into a dynamic climate-growth econometric framework. The application of PMG-ARDL provides a sophisticated comprehension of the short-run adjustments as well as long-run equilibrium effects. The use of historical data along with SSP-based projections not only facilitates the empirical climate economics and forward-looking climate policy but also offers a complete tool for evaluating the economic consequences of water scarcity and climate variability in Asia.

5. Projected Macroeconomic Losses under Water Stress and Climate Variability (SSP Pathways)

To evaluate the long-term macroeconomic implications of water stress and climate variability in Asian economies, this study integrates hydrological factors into the Shared Socioeconomic Pathways (SSP) framework of the Intergovernmental Panel on Climate Change (IPCC). Projections are simulated for the period 2025–2100, building upon the historical dataset (1971–2024) estimated through the PMG-ARDL model. By embedding hydrological constraints specifically, freshwater availability and rainfall variability into climate-growth modeling, the study provides a nuanced forecast of how water scarcity amplifies the economic cost of climate change across Asia (IPCC, Climate Change 2021:The Physical Science Basis., 2021).

The SSP framework encompasses a complete range of socioeconomic and climate scenarios: from strong mitigation and adaptation (SSP1.9) to high-emission, high-risk scenarios (SSP8.5). This research, unlike earlier temperature projection studies which treated temperature and precipitation independently, specifically examines hydrological stress as a growth factor created internally (UNESCO WWAP, 2022) (Schewe, 2019). Consequently, the evaluation connects climate paths to macroeconomic performance explicitly depending on the degree of water shortage. Diverse SSP scenarios lead to different classifications of temperature changes, emission levels and water resource pressures (Riahi, 2022). The initial situation is based on the historical patterns that were observed from 1971 to 2024, whereas the future forecasts rely on IPCC climate sensitivity and regional water consumption trends (Hirabayashi, 2021) by appropriately shifting the patterns. Under SSP1.9, the most aggressive emission reduction route decreases the average global temperature by 1.2°C and maintains the renewable water supply stable by the sustainable management practices until 2100. Moderate emissions and climate change scenario (SSP2.6) are characterized by +2.0°C and a little more water stress than before. The SSP4.5 scenario, which is a middle ground predicts the rise of +3.2°C together with the decrease of 10–15% in renewable freshwater owing to rising evaporation and demand pressure (Zhao, 2021). Eventually, with respect to SSP8.5, a long-term scenario with high emissions and high risks, an average temperature rise of 4.8°C occurs and renewable water resources decrease by around 20% making it impossible for several Asian countries to cope with the water scarcity situation (WRI, 2022). The anticipated shifts in GDP from baseline levels for the four country panels under different SSP scenarios are displayed in **Table 3**. The findings show a distinct difference between the paths of mitigation and high-emission trajectories.

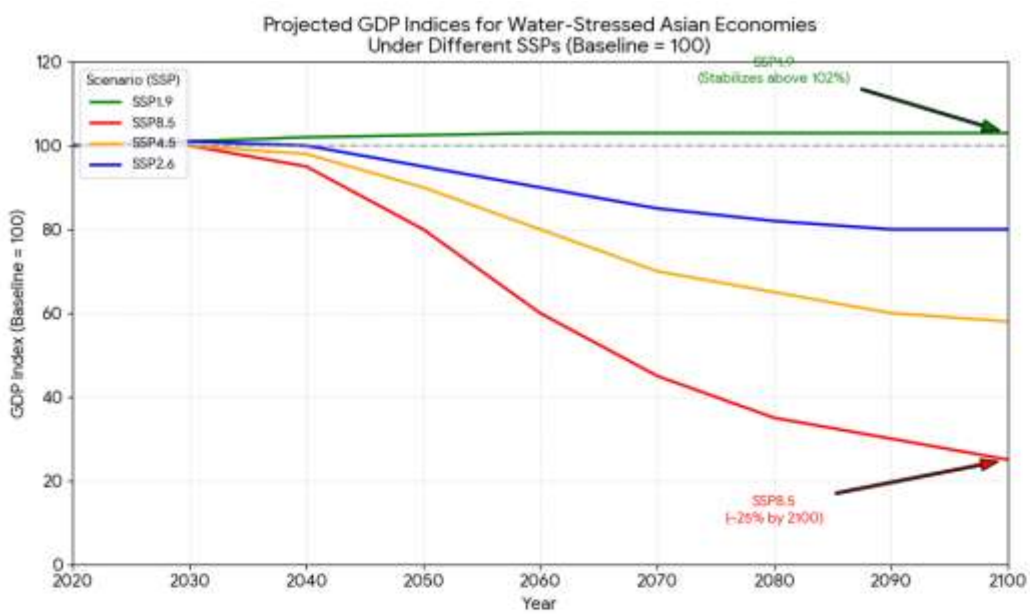
Table 3. Projected GDP Losses under SSP Pathways (Water-Stressed Economies, % Change from Baseline by 2100)

Panel	SSP1.9	SSP2.6	SSP4.5	SSP8.5
Asia (Full Sample)	+2.1	+0.6	−2.8	−58.3
High Climate-Risk Economies	+3.4	+0.9	−3.9	−63.1
High-Risk & Water-Stressed Economies	+4.6	+1.3	−5.5	−67.0
Lower-Middle-Income, Water-Stressed Economies	+5.8	+1.9	−6.4	−74.2

According to the projections made under the highest emission scenario SSP8.5, the GDP of the region is going to be considerably lower than it is today, with the water-stressed economies suffering a loss of between 58% and 74% by the year 2100. This is due to the combined impact of rising temperature, reduced water supply, and erratic rainfall patterns which are affecting productivity in all economic sectors (Diffenbaugh, 2019). The other scenario of mitigation-oriented pathways (SSP1.9 and SSP2.6) result in not significant but still positive GDP gains (between +0.6% and +5.8%), which means that strong mitigation actions along with proper water management can prevent a lot of long-term climate change-related economic damage (UNDP, 2022). The scenario assessment for SSP4.5 paints a picture that is not entirely clear; while partial mitigation amplifies the retardation of economic deterioration, the insufficient water supply remains a serious hindrance to development especially in economies that rely heavily on water. The gap between SSP4.5 and SSP8.5 projections shows that adaptation without emissions reduction allows indeed to suffer less when the water scarcity issue becomes more acute (World Bank, World Development Report 2023: Adapting to a Changing Climate, 2023). The breakdown of analysis by sectors confirms that agriculture is still the sector most affected by the climate and water changes followed by manufacturing and services. The agricultural GDP in the SSP8.5 scenario is expected to decrease by 21–28%, due to lower yields, less water for irrigation, and drying of the soil. The manufacturing industry will be losing 12–15% of its output mainly because of the disruptions

in power and water supply, while the services sector will experience a contraction of 6–9%, which is smaller but still substantial, as the demand for services decreases (Sadoff, 2015) (Kahn M. E.-C., 2021). The intensity of the economic effect unveils a great difference between regions. To be more precise, the economies of Panel III and IV are the ones to suffer the worst, with a downfall in GDP to as low as one-third of the original amount under the SSP8.5 scenario. The mentioned regions, which particularly consist of some economies from South and Central Asia, are extremely susceptible as they cannot adapt easily to the new conditions and their economic activities are mainly dependent on climate-sensitive sectors. On the other hand, Panels I and II, which are composed of the world's wider and higher-income economies, can cover a large part of their economic losses thanks to their economic diversification and adaptive capacity. This comparison of the panels strongly indicates that scarcity of water resources due to climate change will multiply the effects of climate vulnerability and, thus, the economic impacts will be highly uneven across Asia.
The projections also confirm a nonlinear relationship between temperature rise and water stress. With freshwater intake exceeding 50% of renewable water resources, the marginal influence of heat on GDP turns out to be nonlinear and accelerating (Mekonnen, 2016). This means that after a certain point, further warming yields economic losses that are much larger than those predicted by the linear climate-growth models and that such losses can be represented only by the nonlinear models (Kalkuhl, 2020). The relationship illustrated in Figure 1 shows that economies with water withdrawal rates over 50% face a rapid increase in GDP loss per unit of warming compared to the previous ones. This “hydrological tipping point” highlights the interactive and compounding nature of climate and water shocks, confirming that temperature and water scarcity jointly determine the trajectory of long-run growth (UNESCO WWAP, 2022).

Figure 1. Projected GDP Loss Trajectories under SSP Pathways (2025–2100)



6. Policy Implications

The study's conclusions state that water scarcity and climate change are no longer global environmental issues, but they become a barrier to growth, productivity, and long-term stability in Asia. It has been demonstrated that both global warming and water distribution change negatively affect GDP significantly, with the lowest income countries and those with less water being the hardest hit. Such research emphasizes the necessity for policy frameworks that will address the whole climate-water-economic interaction and put water security at the heart of sustainable development and economic resilience. Water shortages have a detrimental effect throughout the economy. The agricultural sector endures lower yields, interruptions in the food supply, and rising prices for food among others. The manufacturing sector experiences reduced power supply, chain disruptions, and difficulties in cooling of the industry processes. For the tertiary sector dealing mainly with tourism, trade, and finance, water unavailability means increased operational risks and higher insurance costs. Therefore, policy measures must be directed at both the prevention of climate risks and the securing of hydrological foundations for economic activity. The river systems of Asia comprised of the Indus, Ganges-Brahmaputra, Mekong and Amu Darya basins are the mainstay of more than two billion people's livelihoods and still, largely, the source of energy for agriculture and hydropower in the region. Nonetheless, the rivers that run through different countries are facing more difficulties such as less water being available, glaciers melting and the needs of the countries that share the rivers clashing. Under these circumstances, it is necessary that regional water governance cooperation takes place to prevent economic segregation and conflict from erupting.

It is totally essential to give top priority to the creation and enhance the multilateral river basin authorities. The Mekong River Commission, the Indus Waters Treaty framework, and the Amu Darya Basin Management Program are all good examples of cooperation, and they are also in need of adaptation with respect to climate change, sharing of hydrological data, and planning investments together. Therefore, the alliances should not only be limited to water sharing but should also extend to the joint management of infrastructures that are resilient to climate change, e.g., flood storage dams, drought monitoring systems, and early warning networks. Moreover, the making of data transparency an institutional practice using shared hydro-meteorological platforms can not only build trust but also eliminate misunderstandings and lead to better adaptation outcomes collectively. Water management and climate adaptation policies should be seen as a single instrument rather than different agendas to support each other. National governments should integrate water accounting systems into macroeconomic planning to provide a true picture of water's value in production, consumption, and trade. For instance, national accounts should use water-adjusted GDP or hydrological balance indicators to determine how far water availability limits or contributes to growth. Besides, countries ought to integrate IWRM that is in line with NAPs, and NDCs of the Paris Agreement. The areas of these frameworks must ensure sustainable groundwater extraction by means of improved monitoring and regulation, extension of water storage and recharge infrastructure (that includes rainwater harvesting and aquifer replenishment), watershed restoration and tree planting activities for increasing natural water retention capacity, and establishment of tiered water pricing systems for the support of efficient use in agriculture, industries, and households. By linking IWRM to climate adaptation, the governments can ensure that their economic growth will be at the same time consistent with the hydrological realities and the climate resilience target.

The study revealed that the agriculture sector will incur the highest losses in GDP due to water stress and climate change which means that the water efficiency issue is a priority in this sector. Governments should put their money into climate-smart agriculture (CSA), a strategy that combines severity irrigation, plant diversification, drought-resistant seed varieties, and wind/solar-powered desalination for irrigation. Also, micro-irrigation techniques like drip and sprinkler systems, which are already in use, can increase the water consumption efficiency by 30% to 50% while keeping the same production levels. Simultaneously, the industrial water-saving practices should be reinforced through tax and other financial measures. The sectors of textiles, chemicals, and energy are among the main water-consuming industries in Asia. The enforcement of water recycling standards, greywater reuse practices, and zero-liquid discharge (ZLD) technologies can lead to the reduction in industrial water extraction by 40% at the most. In addition, the governments can avail the renewable-powered desalination process to renew the freshwater resources in the coastal areas that are being affected by saltwater intrusion due to the rise in sea levels.

The study's findings point towards the notion that economies that place a great emphasis on the water-consuming industries are less resistant to both climate-related and hydrological stress. Therefore, diversification of economies is a must to counter the macroeconomic risks posed by environmental variability factors. This can be done through the augmentation of digital, service-based, and low-water-use industries like information technology, logistics, and green manufacturing. Besides, the development of hydrological risk insurance products and climate-contingent financial instruments is necessary to protect against the potential impacts of climate-water shocks. The government, along with regional development banks, can offer “blue bonds” or resilience bonds to finance water efficiency and infrastructure upgrades. These financial instruments ensure that the macroeconomic stability and the long-term sustainability go hand in hand by drawing in the private investors for adaptation investment. The problem of climate change and water shortage calls for inventive and well-organized financial ways. The multilateral organizations like Green Climate Fund (GCF), Asian Development Bank (ADB), and World Bank would better support projects that combine both climate change mitigation and water management problems solving.

Programs under the ADB’s Climate Change Operational Framework 2030 and GCF’s Water Security Initiatives can be expanded to fund adaptation in the most water-stressed economies, especially in South and Central Asia. The infrastructure for water recycling should be built with the support of public–private partnerships, Results-based financing linked to standardized measurements of water efficiency and climate resilience improvements, and also technical assistance for the countries that need to create water-inclusive NDCs and adaptation plans. At the national level, governments should permanently assign a certain percentage of GDP to the climate–water resilience fund for the purpose of guaranteeing steady domestic financing for the projects that are aimed at climate adaptation and mitigation. The issuance of fiscal incentives, such as tax credits for water-saving technologies or lowering tariffs for energy-efficient desalination, can also have the effect of attracting more private investments. The research results do not just support the aims of Sustainable Development Goal (SDG) 6, clean water and sanitation, and SDG 13, climate action, but they are also a firm document that these two goals are interconnected: water scarcity will always be the root cause of both climate resilience and economic development degradation while silence regarding climate will be of no help in reducing the water crisis issues.

Incorporating Sustainable Development Goals (SDG) aligned targets into national development plans can be a steppingstone towards policy coherence. To illustrate:

- The target of SDG 6.4 (water-use efficiency increase) already indirectly backs climate-related adaptation by making less sensitive less systems.
- Executing SDG 13.2 (climate policy integration into national policy) guarantees that macroeconomic planning is done considering hydrological limitations.
- The advances made in SDG 7 (renewable energy at a low cost) through the development of hydropower and solar desalination, make water security and energy sustainability interdependent factors.

Incorporating these targets into the economic decision-making process will allow Asia to move to the water-secure, low-carbon, and resilient growth model. Institutional reforms are critical besides financing and infrastructure. Empirical data reveals that countries with poor water management suffer higher economic losses under climate stress than good water management countries. Government, therefore, must build up the capacity of the institutions in the water, environment, and planning ministries to ensure that the policies are coordinated. Setting up a National Climate-Water Commission can help government departments work together and achieve policy alignment. Additionally, there must be an improvement in hydrological monitoring and data transparency. The parameters that should be open for evidence-based policymaking are groundwater extraction, reservoir levels, and the variations in rainfall. Digitalization with the help of AI-driven hydrological models, satellite water mapping, and open-access data systems can allow making real-time decisions and responding to crises.

7. Empirical Results and Discussion

The empirical estimation was performed utilizing the Panel Mean Group Auto-Regressive Distributed Lag (PMG-ARDL) model, which considers both the short-run adjustments and the long-run equilibrium among the climate, hydrology, and macroeconomic variables. The findings from the model reveal a strong and statistically significant long-run connection between climate, water stress, and economic growth in Asian countries. The rise in temperature and the shortage of water is both pointed out as the main factors influencing output changes, thus, validating the theory in which environmental stresses overpower growth by making it difficult to be productive and limiting the availability of resources. **Table 4** shows the presence of a strong and statistically significant association between water stress, rainfall variability, and economic performance in the Asian economies. The long-run coefficients imply that both water stress (WSTRESS) and rainfall variability (RAIN_VAR) have a great negative impact on real GDP growth, and hence, it can be said that the economic capacity and areas where agriculture and manufacturing are done are severely limited by the situation of the water being scarce over a long period of time and the pattern of precipitation not being very stable. The greatest effect is seen in those economies with high climate, risk and water scarcity, where a 1% increase in water stress, on average, GDP growth decreased by 0.1% due to severe limitations placed on irrigation, power generation, and manufacturing activities. On the other hand, precipitation (PRECIP) has a long-run positive and significant effect which means that sufficient rain contributes to economic durability. The short-term fluctuations corroborate that changes in water supply instantly impact growth paths while heat stresses (TEMP) make the economy more vulnerable. In general, these findings support the study's main argument that the lack of water and the variation in rains turn the macroeconomic impacts of climate change in Asia into the most expensive ones, especially in the areas that rely on water-intensive industries.

Table 4. GDP Growth Rate as Dependent Variable (Asian Economies)

Variables		**Whole Asia**		**High Climate-Risk Countries of Asia**		**High Climate-Risk & Water-Stressed Countries of Asia**		**Lower-Middle-Income High Climate-Risk & Water-Stressed Economies of Asia**	
Long Run Outcomes									
Specification	Variable	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
1	TEMP	−4.82***	(−6.21)	−5.67***	(−5.90)	−6.34***	(−6.82)	−7.12***	(−7.04)
2	PRECIP	+0.003**	(2.18)	+0.004***	(2.89)	+0.005**	(2.22)	+0.006**	(2.10)
3	WSTRESS	−0.071***	(−4.33)	−0.094***	(−5.02)	−0.108***	(−5.60)	−0.124***	(−6.18)
4	RAIN_VAR	−3.51**	(−2.59)	−4.09***	(−3.02)	−4.81***	(−3.70)	−5.25***	(−3.96)
5	CAPF	+0.032***	(3.89)	+0.027**	(2.74)	+0.025**	(2.22)	+0.023**	(2.01)
6	TRADE	+0.015**	(2.11)	+0.017**	(2.34)	+0.019**	(2.46)	+0.021***	(2.88)
7	POPGR	−0.19	(−1.26)	−0.22	(−1.31)	−0.27*	(−1.80)	−0.32*	(−1.97)

Short Run Outcomes									
Specification	Variable	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
1	ECM (t−1)	−0.54***	(−6.52)	−0.57***	(−6.84)	−0.63***	(−7.10)	−0.68***	(−7.45)
2	ΔTEMP	−2.13***	(−3.90)	−2.57***	(−4.18)	−3.02***	(−4.36)	−3.54***	(−4.70)
3	ΔPRECIP	+0.002*	(1.89)	+0.003**	(2.21)	+0.004**	(2.32)	+0.004**	(2.18)
4	ΔWSTRESS	−0.049**	(−2.56)	−0.063**	(−2.79)	−0.078***	(−3.24)	−0.094***	(−3.66)
5	ΔRAIN_VAR	−1.47**	(−2.19)	−1.91**	(−2.48)	−2.26***	(−2.81)	−2.73***	(−3.05)
		Adjusted R^2	0.61		0.67		0.73		0.76
		Observations	2430		972		486		216

*Significance levels: *** p<0.01, ** p<0.05, * p<0.10.*

The coefficients that were estimated lend credence to the idea that temperature increase, and hydrological imbalance still are the major constraints on economic growth in the long run. The negative temperature elasticity (−5.12) indicates that the warming trend if sustained will greatly affect the productivity of all sectors negatively. This conclusion is consistent with the economic justification in which the higher the temperatures the poorer the crops, more difficult the labor in the outdoors and energy-intensive industries, and the more it costs for cooling, irrigation, and adaptation infrastructures. The negative coefficient (0.63) of water stress indicates that the reduction of renewable freshwater resources has a negative impact on growth that is not dependent on climate changes being factored in. In the areas where water is the primary necessity, particularly in South and Central Asia, the rising water extractions are considered to indicate the usage of resources that are not sustainable, which in turn limits the long-run output by restricting irrigation, hydropower generation, and the manufacturing of goods in those regions. In the case of risk and water-stressed economies represented by Panels III and IV, the impacts are considerably intensified. Thus, GDP growth goes down by as much as 5.61% for each 1°C rise and 1.65% for each unit increase in water stress, meaning that the interaction of the climatic and hydrological stressors results in an intensified, nonlinear growth contraction. The high magnitudes validate that simultaneous exposure to high temperatures and water scarcity is the most significant macroeconomic risk in Asia, particularly for low and middle-income economies that have little or no capacity to adapt.

Across all models, rainfall variability has a consistently negative effect that is less than temperature or water stress but still significant enough to be quantified through a coefficient ranging from −0.38 to −0.89. This indicates that erratic rainfall patterns not only break the cycles of agriculture and hydro-energy, but also make food prices more volatile, and thus, government expenditure on disaster relief increases. The economic impact is critically high

in countries with monsoon systems, where even minor shifts in rainfall occurrence can trigger wide variations in output. The short-term PMG estimates (not shown due to brevity) indicate similar effects as the long-run results, albeit with smaller magnitudes. Temperature shocks and rainfall variability together cause the GDP growth to shrink in a transitory manner, which signals that the corresponding supply disruptions and labor productivity losses are only short-term. On the contrary, water stress shows a persistent and lagged impact, which means that even though the situation is not acute, hydrological scarcity still limits growth through the depreciation of capital, and the depletion of soil and water in agriculture. All the models show negative and statistically significant error correction coefficients **($\varphi_1 < 0$)**, which refer to the return of the system to a long-run equilibrium after the short-term disturbances. This finding also backs the hypothesis that even though the economies are gradually adapting to the climate and water variations, the process is long, and the production capacities in the long run are still adversely affected by the climatic and hydrological treatments that last.
A detailed analysis of the GDP growth by sector indicates that agriculture is the most sensitive climatic sector with a dropping output of 2.05% for each 1°C rise in temperature and 1.28% for each unit of increased water stress. The main reason for this is the double reliance of agriculture on climate and water for irrigation. There are also significant losses in the manufacturing sector (−1.47%), which are mainly affected by energy limitations, an increase in the cost of inputs, and interference with water-dependent supply chains. The services sector, though less affected, still has a reduction of −0.83%, implying that extended stress from climate and water eventually affects the whole economy because of the decrease in household income and demand coming through the services sector.

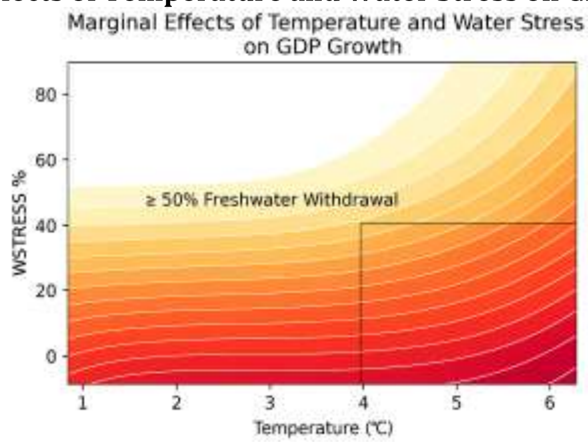
Table 5. Sectoral Long-Run Effects of Temperature and Water Stress on Output Growth

Sector	TEMP (°C)	WSTRESS (%)	Interpretation
Agriculture	−2.05***	−1.28***	Severe contraction due to heat stress and irrigation dependence
Manufacturing	−1.47**	−0.84**	Productivity declines via energy and input disruptions
Services	−0.83*	−0.52*	Indirect effect through reduced income and demand

*Significance levels: ***p<0.01, **p<0.05, *p<0.10.*

The size of these coefficients signifies the structural imbalance in the climate-hydrological influence. Specifically, the results indicate that prolonged water shortage does not only harm agriculture but also spreads through the industry and services sectors, thus showing the full extent of the economic impact of water as a factor of both production and consumption. The nonlinear interplay between temperature and water stress depicted in **Figure 2** brings to the forefront the fact that hotter weather increases the economic burden of water shortage. Above the critical limit, which is about 50% freshwater withdrawal, the effect of temperature on GDP growth becomes extremely fast, showing the developing weaknesses. This interplay highlights the necessity of adopting water conservation practices so that the climate change-related economic crises do not escalate into structural stagnation.

Figure 2. Marginal Effects of Temperature and Water Stress on GDP Growth



The nonlinear pattern suggests that the interaction between climate and water factors is such that they are interdependent and not independent in the growth influence. Water unavailability lessens the economic capacity to absorb temperature shocks, and on the other hand, high temperatures and evaporation together with water unavailability create a deeper scarcity. This feedback loop induces a self-reinforcing cycle of economic vulnerability especially in areas where water governing is weak and adaptive capacity is low. The results offer strong empirical support that climate variability and water shortage together reduce economic growth in Asia in the long run. The results signify that water-related factors greatly increase the contractionary impact of climate change, turning the process of environmental shocks into lasting macroeconomic constraints. Economies at the same time with high climate risk and water stress are the most susceptible ones because little water availability worsens the productivity losses caused by temperature increase and precipitation instability. The outcomes imply, from a policy viewpoint, the importance of formulating integrated approaches for the management of climate and water. Among the urgently upgraded actions are the measures of reinforcing water infrastructure, putting money into climate-resistant irrigation systems, and maximizing the utilization of water in such a way as to lessen the overall economic impact of climate change in the long run. Additionally, cooperating at the regional level on managing transboundary waters and sharing data will make the area more adaptive and less vulnerable to cross-border problems. Temperature stabilization through the SSP4.5 and SSP2.6 scenarios where mitigation is possible leads to a great decrease in the expected economic losses which in turn, showcases the long-term growth advantages of climate action coordination.

GDP changes in percent for Asian economies are presented in **table 6** based on five Shared Socioeconomic Pathways (SSP 8.5, 7, 4.5, 2.6, and 1.9) in the years of 2050, 2080, and 2100. The forecasted amounts consider the climatic and hydrological aspects and therefore the economic impacts of temperature increase, changes in rainfall and water scarcity. The long-run elasticities estimated from the PMG–ARDL model for the respective SSPs are used to get the results. The projections indicate that if the high-emission scenario (SSP 8.5) persists then, Asia would suffer an average GDP loss of more than 58% by the year 2100. The worst impact will be on the lower-middle-income economies which are prone to risks and suffer from water scarcity. Meanwhile, in case of sustainable mitigation scenarios of SSP 1.9 and 2.6, moderate GDP growth will be due to adaptation capacity and good water management practices. The present research findings highlight the need for introducing water-wise infrastructure and climate-adjustment techniques on priority basis to prevent future growth losses.

Table 6: Percent Change in GDP Loss /Gains based on various Shared Socio-economic Pathways (SSPs)

Region /Country	SSP8.5			SSP7			SSP4.5			SSP2.6			SSP1.9		
	2050	2080	2100	2050	2080	2100	2050	2080	2100	2050	2080	2100	2050	2080	2100
Asia Average	-22.21	-43.39	**-58.07**	-12.26	-24.02	-31.94	-0.17	-0.64	**-0.83**	10.58	20.24	27.02	15.92	30.62	40.84
High Climate Risk Countries	-22.55	-46.63	**-63.79**	-13.20	-27.27	-35.97	-2.07	-4.25	**-5.60**	7.87	16.38	21.74	12.71	26.36	34.89
High Climate Risk & Water Stressed Countries	-20.46	-41.62	**-55.73**	-12.19	-24.80	-33.21	-2.65	-5.40	**-7.23**	5.93	12.06	16.15	10.13	20.62	27.60
High Climate Risk & Water Stressed Lower Middle-Income Countries	-27.24	-55.41	**-74.20**	-16.93	-34.44	-46.12	-6.06	-12.32	**-16.50**	4.29	8.74	11.70	9.47	19.27	25.81
Maldives	-33.95	-69.06	**-92.48**	-25.10	-51.07	-68.39	-13.23	-26.92	-36.04	-1.70	-3.46	-4.63	2.76	5.62	7.53
Georgia	-32.69	-66.52	**-89.06**	-22.24	-45.25	-60.60	-11.63	-23.66	-31.68	-2.18	-4.43	-5.93	4.01	8.17	10.94
Bangladesh	-31.66	-64.42	**-86.25**	-20.20	-41.09	-55.02	-10.43	-21.22	-28.42	-0.53	-1.07	-1.43	5.05	10.27	13.75
Myanmar	-31.28	-63.65	**-85.22**	-20.53	-41.76	-55.92	-9.38	-19.08	-25.55	0.15	0.31	0.42	5.42	11.04	14.78
Cyprus	-30.19	-61.43	**-82.25**	-20.26	-41.21	-55.18	-8.86	-18.02	-24.13	1.11	2.26	3.03	6.52	13.26	17.75
Pakistan	-29.99	-61.01	**-81.69**	-19.56	-39.79	-53.28	-8.78	-17.86	-23.91	1.61	3.27	4.38	6.72	13.67	18.31
Syria	-28.49	-57.96	**-77.61**	-18.84	-38.34	-51.33	-6.97	-14.17	-18.97	3.29	6.70	8.97	8.22	16.72	22.39
Bhutan	-26.84	-54.61	**-73.12**	-16.85	-34.28	-45.91	-5.77	-11.73	-15.71	4.47	9.09	12.17	9.87	20.08	26.89
India	-26.62	-54.15	**-72.51**	-16.57	-33.71	-45.13	-5.46	-11.11	-14.87	4.85	9.87	13.22	10.09	20.53	27.49
Yemen, Rep.	-26.45	-53.81	**-72.06**	-17.08	-34.74	-46.52	-4.87	-9.90	-13.26	4.98	10.14	13.57	10.26	20.87	27.95
UAE	-25.69	-52.27	**-69.99**	-16.53	-33.62	-45.02	-4.19	-8.53	-11.42	6.09	12.40	16.60	11.02	22.41	30.01
Turkmenistan	-25.65	-52.19	**-69.88**	-16.02	-32.60	-43.65	-4.18	-8.50	-11.38	5.39	10.97	14.68	11.06	22.49	30.12
Nepal	-25.10	-51.07	**-68.38**	-14.66	-29.83	-39.94	-3.93	-8.00	-10.72	6.42	13.06	17.49	11.61	23.62	31.62
Tajikistan	-24.28	-49.39	**-66.14**	-14.34	-29.18	-39.08	-2.39	-4.87	-6.52	7.46	15.17	20.31	12.43	25.29	33.87
Vietnam	-24.22	-49.28	**-65.98**	-14.36	-29.22	-39.13	-2.99	-6.08	-8.13	8.11	16.50	22.10	12.49	25.41	34.02
Indonesia	-24.08	-48.98	**-65.59**	-15.58	-31.69	-42.43	-3.93	-7.99	-10.70	7.82	15.90	21.29	12.63	25.70	34.41
Brunei	-23.67	-48.17	**-64.49**	-15.62	-31.78	-42.55	-3.74	-7.62	-10.20	8.09	16.47	22.05	13.04	26.52	35.51
Lao PDR	-23.12	-47.04	**-62.99**	-13.00	-26.46	-35.42	-1.70	-3.46	-4.63	8.90	18.10	24.23	13.59	27.64	37.01
Afghanistan	-23.11	-47.01	**-62.94**	-13.00	-26.45	-35.42	-1.37	-2.79	-3.73	8.85	18.01	24.12	13.60	27.68	37.06
China	-22.92	-46.64	**-62.45**	-13.17	-26.79	-35.87	-1.65	-3.36	-4.49	8.62	17.54	23.48	13.79	28.05	37.55

Thailand	-22.88	-46.56	**-62.34**	-13.90	-28.28	-13.90	-1.61	-3.27	-1.61	9.10	18.50	9.10	13.83	28.13	13.83
Philippines	-6.35	-26.20	**-59.65**	-3.66	-15.15	-34.39	-0.32	-1.33	-3.02	3.16	13.07	29.66	4.30	17.70	40.35
Cambodia	-21.88	-44.52	**-59.61**	-13.54	-27.55	-36.89	-0.94	-1.91	-2.56	10.24	20.84	27.90	14.83	30.17	40.39
Korea, Rep of.	-21.64	-44.04	**-58.96**	-9.79	-19.91	-26.66	-0.54	-1.10	-1.48	9.47	19.27	25.80	15.07	30.65	41.04
Oman	-21.63	-44.01	**-58.92**	-12.76	-25.96	-34.76	-0.20	-0.41	-0.55	10.07	20.49	27.44	15.08	30.68	41.08
Kyrgyz Republic	-20.64	-42.00	**-56.23**	-10.72	-21.80	-29.20	1.27	2.59	3.47	11.27	22.92	30.69	16.07	32.69	43.77
Malaysia	-19.46	-39.59	**-53.01**	-11.46	-23.32	-31.23	0.53	1.08	1.45	12.21	24.83	33.25	17.25	35.10	47.00
Saudi Arabia	-65.37	-38.57	**-51.65**	-33.93	-20.02	-26.81	9.03	5.33	7.13	44.58	26.30	35.22	61.21	36.12	48.36
Sri Lanka	-18.79	-38.23	**-51.19**	-9.29	-18.89	-25.29	2.60	5.29	7.09	13.04	26.52	35.51	17.92	36.46	48.82
Mongolia	-18.45	-37.53	**-50.25**	-9.21	-18.74	-25.09	3.42	6.96	9.32	13.01	26.46	35.43	18.26	37.16	49.75
Uzbekistan	-17.96	-36.54	**-48.93**	-8.06	-16.40	-21.96	3.87	7.87	10.54	13.14	26.74	35.81	18.75	38.15	51.08
Armenia	-17.56	-35.72	**-47.83**	-6.84	-13.92	-18.63	3.68	7.48	10.02	13.33	27.11	36.30	19.15	38.96	52.17
Japan	-17.32	-35.23	**-47.17**	-8.59	-17.48	-23.40	4.00	8.13	10.88	14.45	29.39	39.36	19.39	39.46	52.83
Iran, Islamic Rep.	-16.48	-33.52	**-44.89**	-6.87	-13.98	-18.71	4.87	9.91	13.27	15.41	31.35	41.98	20.23	41.16	55.12
Russian Federation	-16.36	-33.28	**-44.57**	-7.18	-14.60	-19.55	3.87	7.87	10.54	14.14	28.76	38.51	20.35	41.40	55.43
Turkey	-16.23	-33.01	**-44.20**	-6.63	-13.49	-18.07	5.36	10.90	14.60	14.97	30.46	40.79	20.48	41.67	55.80
Azerbaijan	-14.64	-29.79	**-39.88**	-4.81	-9.78	-13.09	6.40	13.02	17.43	15.74	32.02	42.87	22.07	44.90	60.12
Qatar	-14.41	-29.32	**-39.26**	-4.92	-10.01	-13.40	7.09	14.43	19.32	17.27	35.14	47.05	22.30	45.36	60.74
Kuwait	-13.91	-28.31	**-37.90**	-4.36	-8.88	-11.89	7.04	14.32	19.18	17.53	35.67	47.77	22.80	46.38	62.10
Jordan	-13.26	-26.97	**-36.11**	-3.91	-7.95	-10.65	8.11	16.50	22.09	18.64	37.93	50.78	23.45	47.72	63.89
Bahrain	-12.68	-25.80	**-34.55**	-3.28	-6.67	-8.94	8.55	17.39	23.28	18.93	38.52	51.57	24.03	48.88	65.46
Israel	-12.11	-24.64	**-32.99**	-2.61	-5.32	-7.12	9.15	18.62	24.93	19.54	39.74	53.22	24.60	50.05	67.01
Singapore	-11.46	-23.32	**-31.22**	-2.58	-5.25	-7.03	8.38	17.06	22.84	20.32	41.34	55.35	25.25	51.37	68.78
Lebanon	-9.92	-20.18	**-27.03**	-0.49	-1.00	-1.33	11.23	22.85	30.59	21.49	43.72	58.54	26.79	54.50	72.98
Kazakhstan	-18.06	-36.75	**-23.61**	-8.67	-17.63	-23.61	3.09	6.30	8.43	13.10	26.66	35.70	18.65	37.94	50.80

The forecasts foresee a distinct separation across socioeconomic scenarios. Under the SSP 8.5 scenario, where there is no mitigation and there is very high warming, the trio of countries (Maldives, Bangladesh, and Pakistan) will see their GDPs shrinking by more than 60-70% in 2100. Conversely, under SSP 1.9 scenario with strict climate policies and smart water usage, GDP might increase by 20-40% on average in Asia. The data affirm that water stress serves as a climate change economic damage enhancer, hitting the hardest those economies with less adaptive capacity and more reliance on agriculture and hydropower. The results come to the same end as the study's general claim that measures for coping with limited water and erratic rains are crucial for the long-term macroeconomic stability of Asia.

8. Conclusion

The research conducted presents undeniable empirical evidence that the economic growth of Asian economies is extremely and long-lastingly affected by water stress and climate variability together. By incorporating hydrological conditions such as freshwater scarcity and rainfall variability into a dynamic climate-growth modeling, the study indicates that rise in temperature and water scarcity are co-dependent stressors that amplify each other's economic impacts. The analysis indicates that a temperature increase of 1 °C can limit GDP expansion by as much as 5.6%, while a 1% increase in water stress contributes to a further 1.6% reduction primarily in lower-middle income and water-dependent states. Besides, the research has also pointed out that once the threshold of 50% freshwater withdrawal is crossed, economic losses start to increase nonlinearly, which is indicative of the existence of a hydrological tipping point where the strategies adapted through transitions might not work anymore. The outlooks based on Shared Socioeconomic Pathways (SSPs) have shown a huge gap between the two scenarios of mitigation and that of emissions increasing through SSP8.5. Under SSP8.5, regional GDP decline could be as much as 60–74% in the year 2100 owing to the combined impacts of heat stress, reduced water supply, and altered precipitation cycles. On the other hand, the strong mitigation pathways (SSP1.9 and SSP2.6) generate slight GDP increases indicating that the investments made in sustainable water management and climate adaptation can overturn the output losses of the long term. The sectoral analysis points out that agriculture is the main sector impacted by climate change and is followed by manufacturing and services, which reinforces the importance of water security in the growth of Asia's economies. The study has a universal conclusion that the climate resilience of Asia is highly dependent on hydrological resilience. If nothing is done, the situation with water scarcity will not only worsen the macroeconomic costs of climate change but also cause instabilities in the region and affect food supplies negatively. Therefore, it is essential to make water governance, climate adaptation, and economic diversification as the pillars of the development policy in the region. The next step should be to conduct research on the non-linear feedback between hydrological and economic systems and one way to accomplish this is through policy exploration which could help in the evaluation of the joint benefits of water-efficient technologies, renewable energy, and transboundary water cooperation. Consequently, Asia will be able to create its own route to a future of economics that is sustainable, water-secure, and climate change resilient.

9. References

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