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Macro-Criticality of Water Resources

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ABSTRACT: This paper examines the macro-criticality of water resources in the context of climate change. It summarizes the past and future trends of water scarcity and droughts and proposes a framework to analyze the macro-criticality and role of public sector engagement in the water sector. The paper maps out channels through which water resources affect the macro-fiscal and balance of payments positions and develops an understanding of macro-fiscal exposure based on empirical evidence. It also synthesizes emerging insights from IMF-supported operations and capacity development activities, thereby clarifying the rationale and scope for IMF engagement in water-related policy reforms.

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WORKING PAPERS

Macro-Criticality of Water Resources

Prepared by Suphachol Suphachalasai, Ximing Dong, Pedro Juarros, Junko Mochizuki, Christine Richmond, and Sylke von Thadden-Kostopoulos[1]

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Contents

BOXES

FIGURES

TABLES

Introduction

Water[1] is a vital source of life and a foundational input to economic activity. It is one of the most critical factors of production, underpinning long-term development and supporting nearly every sector of the economy. From agriculture and industry to energy and transport, water plays a central role in the production of goods and services and the movement of people and commodities. Moreover, access to safe water and sanitation is essential for poverty reduction, human health, and inclusive growth and ensuring availability and sustainable management for all would yield broad-based benefits across these areas. Several key statistics illustrate water's economic and social importance:

- The annual economic value of water and freshwater ecosystems is estimated at US$58 trillion, equivalent to about 60 percent of global gross domestic product (GDP);[2]
- The trade of agricultural products constitutes about 90 percent of the total virtual water,[3] while international trade reduces global water use in agriculture by 5 percent;[4]
- Hydropower accounts for nearly 15 percent of global electricity generation;[5]
- Irrigation is key to improving food security but remains severely underdeveloped, with over 30 nations having less than 1 percent of cultivated land equipped for irrigation;[6]
- Universal access to safe drinking water and sanitation could prevent at least 1.4 million deaths annually, yet one in four people globally still lack access to safe drinking water;[7, 8]
- The lack of access to water places a heavy economic burden on women and girls who spend 200 million hours daily collecting water;[9]
- More than 1,600 water-related conflicts have been identified since 2000 with significant increase over the decades.[10]
- Transboundary water systems account for 60 percent of global freshwater flows and over half of the world's population lives in transboundary river and lake basins;[11] and
- Over 80 percent of global trade by volume is transported by sea.[12]

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[1] See Annex I for key definitions used in this study.

[2] Water crisis threatens $58 trillion in economic value, food security and sustainability | Press Releases | WWF. Direct value (US$7.5 trillion), indirect value (US$50 trillion) includes significant benefits from carbon storage, drought and flood mitigation, and biodiversity support.

[3] Virtual water is water consumed for the production of goods that are subsequently traded on the international market. See, Vallino et al 2021.

[4] WTO: The relation between international trade and freshwater scarcity.

[5] Global Electricity Review 2025 (Ember)

[6] Agricultural Uses of Water - Apure; FAO Aquastat.

[7] Drinking-water; FAO Aquastat.

[8] Burden of disease attributable to unsafe drinking-water, sanitation and hygiene, 2019 update. Geneva: World Health Organization; 2023. iris.who.int/bitstream/handle/10665/370026/9789240075610-eng.pdf?sequence=1

[9] https://www.unicef.org/press-releases/unicef-collecting-water-often-colossal-waste-time-women-and-girls

[10] https://www.worldwater.org/conflict/map/

[11] UN-Water 2021; Jha 2023.

Yet, with growing demands and competition for water, variable resources, deteriorating quality, and the need to expand reliable and safe access, management of water resources presents a multitude of challenges. These challenges are likely to be exacerbated by climate change. Droughts are becoming more frequent and severe, with the global land area affected by drought doubling between 1900 and 2020.[13] Human activities, including increasing water demand, deforestation, urban expansion, and unsustainable agricultural practices, can further worsen water scarcity and drought risk by degrading ecosystems and water resources.

The conceptual foundation for public sector engagement in water governance is rooted in the recognition of water as an economic good, as articulated in the 1992 Dublin Statement on Water and Sustainable Development (ICWE 1992). This characterization reflects the multifaceted nature of water, which provides a wide array of use values—such as for agriculture, industry, and household consumption—as well as non-use values, including ecosystem preservation and cultural significance. Treating water as an economic good underscores the importance of efficient allocation, pricing, and management mechanisms to address scarcity and competing demands. However, the inherent complexity of water's value across different users and sectors necessitates a nuanced policy approach that balances economic efficiency with equity and sustainability considerations, particularly in contexts where market mechanisms alone may fail to ensure universal access or protect environmental integrity.

The ways in which the water sector is managed can have significant macro-fiscal and balance of payments implications. The overall economic and environmental sustainability of a country's water sector is a key determinant of its macroeconomic and fiscal performance. The status of water resources and supply, as well as policies related to the water sector, can have significant consequences for governments' revenues and expenditures. For instance, severe and prolonged water scarcity and drought could hurt economic activities and people's livelihoods and thus create additional spending and investment needs in areas such as infrastructure, health, and social assistance. Moreover, the lack of water and its increasing variability are projected to pose significant risks to macroeconomy. Unfortunately, most countries currently lack public sector capacities to effectively plan for integrated water resources management (UN Water 2024). Water institutions are often fragmented with some countries even lacking the most basic mandate to regulate key activities such as water services provision. In many developing countries, the water sector operates in a vicious cycle of under-investment, infrastructure deterioration, poor service quality, and low revenue collection, all hampering equitable and reliable access.

Against this backdrop, this paper examines the macro-criticality of water resources and considers the macro-fiscal implications. Specifically, this paper (i) maps out channels through which water resources affect the macro-fiscal and balance of payments positions of countries and provides estimates of the relationships between key macro-fiscal and water-related indicators, and (ii) develops an understanding of macro-fiscal exposure to water scarcity and drought risks based on empirical evidence. These two macro dimensions are important considerations for incorporating water resources challenges into macro-fiscal planning and policy decisions. In addition, this paper proposes 'water value chain' as an integrated framework for analyzing the macro-criticality and the role of public sector across the life cycle of water including its total economic value, the varying degrees/types of market failures at different stages of the value chain, and the need for granular and context-specific policy interventions and understanding of their macro-fiscal implications.

[13] OECD (2025)

The rest of the paper is organized as follows: Section 2 discusses some of the recent literature, outlining the rational for public sector intervention. Section 3 establishes some of the recent trends in water and the potential impact of climate change. Sections 4 and 5 present the macro-fiscal criticalities of water, while section 6 concludes by providing some policy implications and areas of future work.

Related Literature

Water is a multifaceted resource studied through diverse disciplinary lenses, each contributing unique insights to its management and sustainability. For example, hydrologists examine the movement, distribution, and quality of water across the Earth's surface and subsurface, focusing on the hydrologic cycle and human impacts on water systems (Jones 1997; Oki and Kanae 2006; Caretta et al. 2022).[14] Scientists, including ecologists and biochemists, investigate water's role in ecosystems and its biochemical properties (Rittmann and McCarty 2001; Millennium Ecosystem Assessment, 2005; Mitsch and Gosselink 2015), while engineers study and design infrastructure for water supply, treatment, and flood control (McCarty and Smith 1986; Winsemius et al. 2016; Blöschl et al. 2019). Public health experts assess waterborne diseases and sanitation, emphasizing access to clean water as a determinant of health (Colwell 1996; Prüss et al. 2002).[15] Development professionals prioritize water access in poverty alleviation and resilience-building, especially in vulnerable regions (Briscoe and Ferranti 1988; Zhang and Borja-Vega. 2024). Meanwhile economists analyze water as an economic good, exploring pricing, allocation, and the cost-benefit of water-related investments and policies (Olmstead 2010; Griffin et al. 2016; Dinar and Tsur 2021). Together, these show the different perspectives and importance of water as both a natural and socio-economic resource.

The United Nations' Sustainable Development Goal 6 (UN SDG 6) reinforces the centrality of water to human development. However, despite progress, most countries are not spending enough (Gaspar et al. 2019), and billions of people still lack safely managed water services, while climate change is exacerbating vulnerabilities, particularly in low-income and fragile contexts. The World Bank's 2023 report on water security in the Middle East and North Africa (MENA) region underscores the macroeconomic risks of water scarcity. It finds that water-related shocks—such as droughts and supply disruptions—can reduce GDP growth, increase fiscal pressures, and heighten social tensions. The report calls for a "water-smart" growth strategy that integrates water considerations into national development planning, supported by institutional reforms and targeted investments (World Bank 2023a). Similarly, the World Bank's 2024 analysis of water resilience in the Sahel region emphasizes the need for adaptive infrastructure, data systems, and cross-border cooperation. It highlights the importance of inclusive governance and community engagement in building resilience to climate-induced water stress (World Bank 2024).[16]

Amidst these developments, the Global Commission on the Economics of Water (GCEW, 2023) called for a fundamental reevaluation of the water cycle as a global common good, emphasizing that current governance and pricing systems are failing to address escalating water stress, inequality, and environmental degradation. It advocates for a new economic framework that integrates water into macroeconomic planning, promotes full-cost pricing with targeted social protections, and mobilizes public and private finance for resilient infrastructure. The GCEW also emphasizes the need for global cooperation,

[14] What is Hydrology? | U.S. Geological Survey
[15] Heal, K., C. Valeo, T. Oki, and S. Hubbard (2020)
[16] World Bank. (2024)

proposing the establishment of a Global Water Panel to coordinate cross-border water governance and align national policies with global sustainability goals.[17]

Fiscal instruments are increasingly seen as essential tools for managing water resources. The majority of investment needs are expected to be provided by the public sector, but with low budget execution, large subsidies, and declining efficiency in the provision of water, there are significant challenges (Joseph et al., 2024; Andres et al., 2019). Young (2015) emphasizes that taxes, tariffs, and subsidies can be designed to internalize environmental costs, promote conservation, and mobilize private finance. However, poorly designed instruments can exacerbate inequality and political resistance while hampering environmental quality, which underscores the need for careful policy design and stakeholder engagement (OECD 1997; OECD 1999; OECD 2003).

To date, the IMF has published one comprehensive paper on water. Kochhar and others (2015) points to growing water challenges—for both advanced and developing countries—and examines the role of economic policy instruments and institutions in managing water challenges. The paper stresses the importance of getting incentives right, notably by reforming water pricing, which will vary by country. Moreover, sound water management requires an integrated and holistic approach going beyond the water sector itself, complementing water pricing reforms with policies that rationalize water use in areas such as agriculture, trade, and energy, while redirecting achieved gains toward protecting the poor. The paper also highlights the macro-fiscal risks of water shocks and the need for integrated, data-driven policy frameworks that align environmental, social, and economic objectives.

While water's macro-fiscal relevance, and the need for the economic management of water, are increasingly recognized, knowledge is still scattered, limiting opportunities for effective policy interventions. Existing studies that capture the interaction between the hydrological system and the economy (e.g. Baker et al 2021; Burek et al 2020; Exposito et al 2020; Kahil et al 2016; Harou et al 2009) highlight priority areas but fall short of offering a comprehensive framework for macroeconomic and fiscal policy interventions across the water value chain. Meanwhile, policy-oriented literature (e.g. Dinar 2000; Rogers et al 2002; Wheeler et al 2023) tends to adopt a sectoral lens, with limited integration into macro-fiscal analysis. Although the relationship between water scarcity, drought, and GDP is relatively well established (Akyapi et al., 2025; Kompas et al 2023; Ortuzar et al. 2023; Zaveri et al 2023; Roson and Damania 2017, among others), other macro-fiscal dimensions—such as fiscal risks, public investment needs, and institutional capacity—remain underexplored. This paper seeks to address these gaps by identifying key channels through which water-related challenges affect macroeconomic stability and fiscal sustainability. Building on the foundational work of Kochhar and others (2015), which underscored the macro-criticality of water scarcity and access, this paper proposes a new framework for an integrated economic assessment of water (water value chain), incorporates recent advances in climate and hydrological science, as well as new empirical and modeling evidence. It also synthesizes emerging insights from IMF-supported operations and capacity development activities, thereby clarifying the rationale and scope for IMF engagement in water-related reforms.

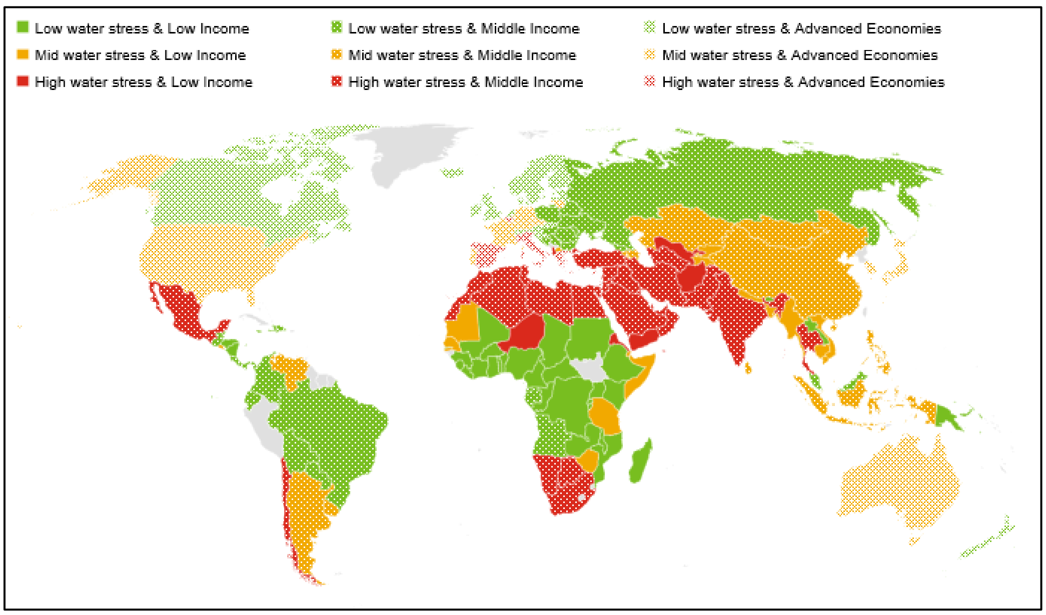
[17] Global Commission on the Economics of Water (2023).

Recent Trends and Climate Change Outlook

Recent Trends

Renewable freshwater resources are highly unevenly distributed across regions. Per capita renewable water availability ranges from approximately 43,500 cubic meters (m^3) per year in Australia and New Zealand to just 1,420 m^3 per year in Northern Africa and Western Asia. In contrast, per capita water withdrawals are not aligned with availability, ranging from 1,020 m^3 per year in Central and Southern Asia to only 69.3 m^3 per year in Oceania.[18] This mismatch between supply and demand has resulted in high levels of water stress in 47 countries, particularly in the MENA, Central Asia, and South Asia (Figure 1). Interestingly, despite notable improvements in water-use efficiency, global water withdrawals have increased by over 25 percent during the past three decades—from 2.4 trillion m^3 in 1990 to nearly 3 trillion m^3 in 2020.

Figure 1. Global Classification of Countries by Water Scarcity and GDP per Capita



Source: IMF Staff Calculations based on the WRI Aqueduct 4.0. [19]
Note: See Annex II for income and water stress classification. The country-level classification as defined by the WRI weights basin-level information on water stress. Low water stress at the country level does not exclude possibilities that a country may face sub-national regional heterogeneity in water stress.

Since the 1980s, droughts have intensified globally as a consequence of rising temperatures, declining humidity, and increased net radiation (sunlight). This has led to a 74 percent expansion in drought-affected land between 2018 and 2022, relative to 1981–2017.[20] Agricultural and ecological droughts have become more frequent and severe across all continents , even in the absence of consistent global trends in meteorological

[18] The use of non-conventional sources of water is still limited globally. Total desalinated water produced and direct use of treated municipal wastewater in 2020 were approximately 22.7 billion m^3 and 20.6 billion m^3 per year respectively, or about 1 percent of global total water withdrawal.

[19] aqueduct-40-technical-note.pdf

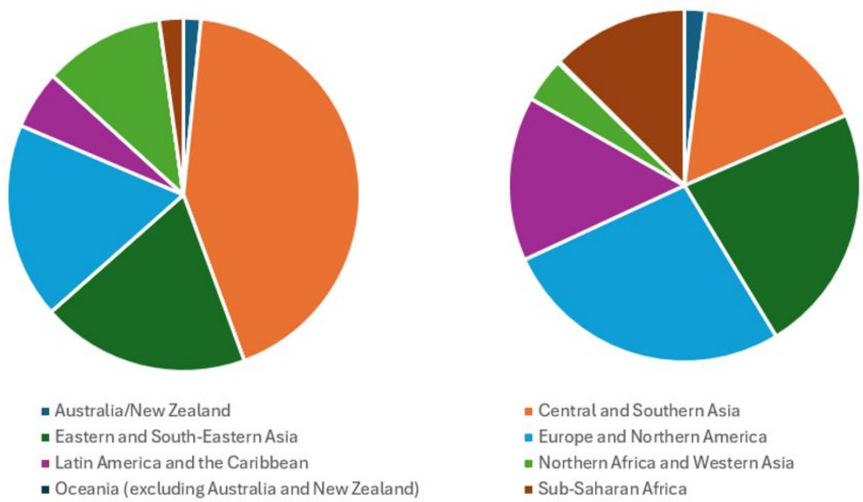
[20] Solomon et al. (2025).

drought.[21] He and Rosa (2023), for example, estimate that approximately 80 percent of rain-fed cropland globally now experiences at least one month of agricultural drought annually. Hydrological droughts—characterized by reduced surface and groundwater flows—have also worsened, particularly in regions such as the Mediterranean, parts of Africa, and Asia. Rivers across the globe have become drier—2023 marked the year with the lowest streamflow levels in 33 years signaling critical changes in water availability.[22]

Globally, blue water consumed by all economic activities is estimated at approximately 980 billion m^3 in 2022. Central and Southern Asia, Eastern and South-Eastern Asia and Europe and Northern America are the largest blue water consuming regions accounting for 43 percent, 19 percent and 18 percent of the global total consumption respectively (Figure 2). The largest consuming countries include India, China, United States and Pakistan, which allocates significant blue water, primarily for agricultural production.

Of the total blue water consumed globally, approximately 570 billion m^3 or 58 percent of total blue water consumption takes place in countries that are currently considered to be under high water scarcity.[23] Among the top consumers of blue water in water scarcity regions includes India, Pakistan, Iran and Egypt. According to the global agricultural models reviewed by the IPCC ARC, irrigation water requirements are projected to increase two- to three-fold towards the end of the 21st century.

Figure 2. Regional Contribution to Blue (left) and Green (right) Water Consumption in 2022



Source: IMF Staff Estimates based on the Eora 26 Database.
Note: See Annex II for regional classification.

Green water is primarily used for rainfed agricultural activities with an estimated total consumption of 6,670 billion m^3 in 2022. The largest green water consuming regions include Europe and North America which consume 27 percent of the global total, followed by Eastern and South-Eastern Asia with 23 percent, Central and Southern Asia at 17 percent, and Latin America and the Caribbean at 15 percent of consumption respectively (Figure 2). The largest amount of green water is consumed for agriculture in countries such as

[21] Seneviratne, S. (2021) https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/

[22] WMO (2023).

[23] IMF Staff estimate based on Eora 26 and the water stress indicator of above 3 as per the World Resources Institute Aqueduct Database.

India, United States, China, Brazil, and Indonesia. Yet, 43 percent of total green water consumption (approximately 2,870 Gm^3) is taking place in countries that are currently considered to be under medium-high and high drought risk (including India, China, Indonesia, Thailand, and Ukraine).[24]

Climate Change

Projections indicate that water scarcity will worsen in approximately 80 percent of countries by the end of the 21st century, primarily due to demographic and economic drivers—namely, population growth and rising per capita water demand.[25] However, climate change adds an additional layer of complexity to existing water challenges (Figure 3).

According to the Intergovernmental Panel on Climate Change's sixth assessment report, there is high confidence that climate change has already altered the global water cycle. This includes observable increases in atmospheric moisture, rainfall intensity, evapotranspiration, and glacial melt.[26, 27, 28] Without substantial changes to greenhouse gas emissions, further disruptions are inevitable: mountain glaciers are projected to retreat across all regions, with small glaciers contributing to reduced downstream water availability and large glaciers increasing flood risks temporarily before eventual mass loss.

Climate change is also already amplifying drought risks. A recent attribution study of the 2023–2024 Amazon Basin drought—marked by 120-year record low river levels—finds that while El Niño contributed to reduced precipitation, climate change was the dominant factor. It increased the likelihood of meteorological drought tenfold and agricultural drought thirtyfold.[29] Similarly, Kimutai et al. (2025) found that the 2022 long-rain season precipitation deficit in the Horn of Africa was made 2–7 times more likely by climate change, with dryness increasing by 8–26 percent.[30]

[24] IMF Staff estimate based on Eora 26 and the drought risk indicator of above 3 as per the World Resources Institute Aqueduct Database.

[25] Graham et al. (2020) evaluate 90 scenarios combining general circulation models, representative concentration pathways, and shared socioeconomic pathways and find that human drivers dominate water scarcity outcomes in 80 percent of areas globally.

[26] Douville et al. (2021).

[27] The global hydrological cycle is a closed system with stable amount of water. There are four natural stores of water (ocean, terrestrial water, terrestrial ice and atmosphere), along with man-made stores including reservoirs and irrigated soils and water flows through them. lows of water among stores occur via processes such as evaporation, transpiration (through plants), precipitation, ice-melting and human water use and technical conversion such as desalination The total volume of water across the globe is estimated approximately 1.4-5 billion km^3 with 97.4 percent stored as ocean, 1.98 percent as ice, 0.6 percent as terrestrial water, and the remaining as atmosphere and man-made stores. Whereas negligible amounts of breakdown or creation of water occur naturally, climate change does not affect the amount of total water in the global cycle, but merely alters the proportion of water held in alternative stores and flows among them (Jones 1997).

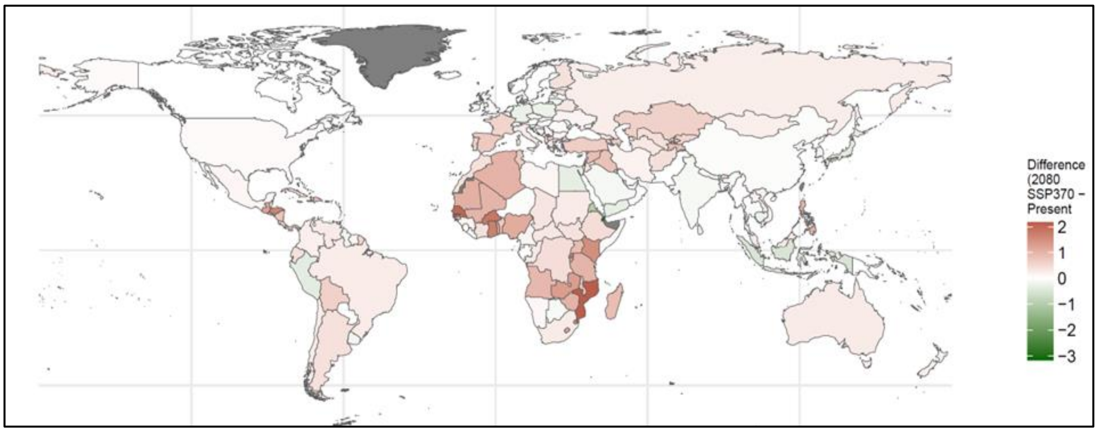
[28] Uncertainly surrounding such water flow projections remain high. Decreased hydrological flows are projected in basins such as the Colorado, Tigris-Euphrates and Amazon under higher emission scenarios. Increased hydrological flows are projected for example Yangtze, Mekong, Ganges-Brahmaputra, Nile, and Zaire basins. Climate change will also affect groundwater. Sea levels rise will cause saline intrusion into aquifers in low-lying coast and small islands. In the tropics and semi-arid regions, increase in precipitation intensification may enhance occasional groundwater recharge but such impact is nullified in the semiarid areas due to over-abstraction. (Caretta et al. 2022).

[29] Climate change, not El Niño, main driver of exceptional drought in highly vulnerable Amazon River Basin – World Weather Attribution

[30] Kimutai, J.(2025) Regionally, drying trends are pronounced in specific areas. Southwestern North America endures a megadrought, likely the worst in 1,200 years, driven by human-induced warming (Williams et al., 2020). The Mediterranean, Southwestern Australia, and Southern Africa see strong increases in agricultural and hydrological droughts, with the Sahel facing up to 25% rainfall reductions by 2100 under high-emissions scenarios (IPCC AR6 WG1 Chapter 11). The Middle East and North Africa (MENA) region experiences megadroughts now three times more likely due to climate change (Kelley et al., 2015), while the record-breaking 2023/2024 Amazon drought highlights the vulnerability of Central and South America (Espinoza et al., 2024).

Looking ahead, even under 2°C of warming (continuation of current trends), more regions are projected to experience intensified agricultural and ecological droughts. The Mediterranean, Southern Africa, South America, and Sub-Saharan Africa are particularly vulnerable. At 4°C of warming, about half of all inhabited regions globally are expected to face increased drought risk. Only a few regions, such as Northeast Africa and South Asia, may experience some relief under these conditions.[31]

Figure 3. Changes in Projected Water Stress Index Under Climate Change by 2080



Source: IMF Staff estimates based on WRI Aqueduct 4.0
Note: The SSP370 scenario, a medium-high emissions scenario, projects a global mean temperature increase of approximately 3.6°C by 2100 relative to pre-industrial levels on average.

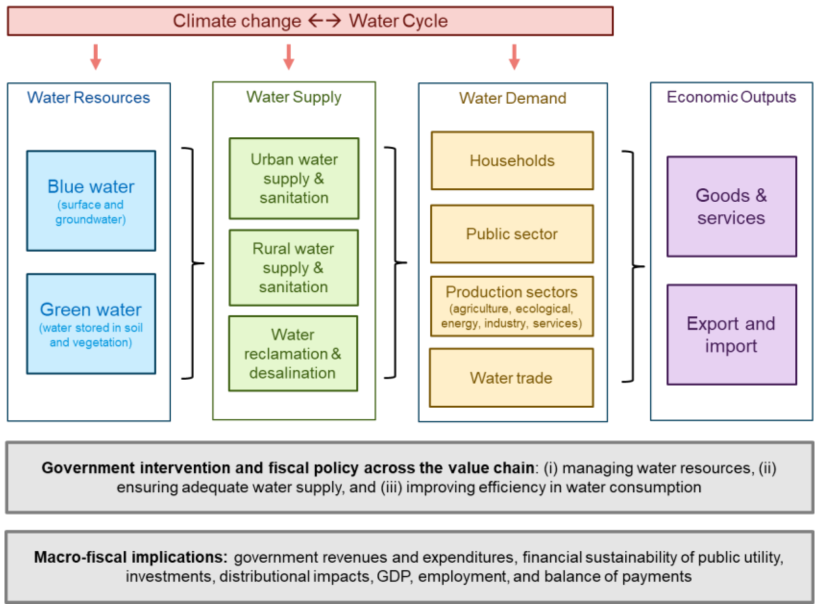
Water Value Chain

The macroeconomic and fiscal implications of water sector challenges under climate change may be conceptualized through what we term 'water value chain' as shown in Figure 4. As will be summarized in section 4, blue and green water underpin macro-critical water consuming sectors including agriculture, energy and water transport and their disruptions significantly hamper macroeconomic outputs. Likewise, illustrated in section 5, the public sector plays a crucial role in ensuring sustainable use of surface and ground water resources, providing adequate supply through public investment and creating an enabling environment for private sector participation, and promoting efficiency improvement in the end-use sectors. The water value chain depicts each stage in which water becomes usable and useful resources in an economy whereby the costs and benefits arise to affect the macroeconomic and fiscal outlooks. Starting from blue and green water as the natural resource base, one could systematically diagnose the state of water, fiscal policy, and

[31] Seneviratne, S et al (2021)

macroeconomy interactions.[32] Water supply-demand imbalances manifest in various forms and to varying degrees in each stage of the value chain (e.g. groundwater depletion and contamination, low flows of transboundary river, aging and inadequate public infrastructure, water pollution and overconsumption). In this context, the water value chain provides a useful framework for determining the economic values of water and specific policy interventions to target market failures and/or externalities that exist along the value chain.[33]

Figure 4. Water Value Chain, Macro-Fiscal Implications, and the Role of Fiscal Policy



Source: IMF staff.

Note: In certain circumstances, water resources are consumed directly at source without the supply sector. Evapotranspiration and precipitation processes of blue and green water are part of water resources.

Macroeconomic Impacts

Water-related risks are increasingly macro-critical, with direct implications for economic performance and external stability. Water scarcity, variability, and water quality degradation can constrain productive

[32] Water resources through the value chain demonstrate different economic characteristics with varying degrees of market failures. Therefore, appropriate management of water involves a complex (and often nested) set of institutions (OECD 2015; Meran et al. 2021). Water as economic goods along two axes namely: (a) Rivalry –the extent that the consumption of goods by one person diminishes the availability of the goods for others and (b) Excludability –the ability to prevent the consumption of goods at a reasonable cost (Easter and Feder 1996; OECD 2015; Meran et al. 2021) Consumptive use of water is characterized by higher rivalry. When the excludability of such consumptive water is also high, such as drinking water consumed by individuals, water may be considered private goods. When the excludability of consumptive water is low, such as irrigation water in a communally owned system, water may instead be considered common pool resources. For non-consumptive use of water, such as recreational use of water bodies, in-stream uses water for navigation, and more broadly, non-use value of water (Grafton et al. 2023), such as a variety of ecosystem functions provided by water/hydrological cycle, rivalry is generally low. For these types of values, when excludability is also high, such as recreational use of water bodies within a private property, water may be considered club goods. When excludability is low, such as the global hydrological cycle sustaining the livelihoods of watersheds worldwide, as well as local hydrological cycles underpinning the local ecosystems, water may be considered public goods. In addition to these classifications, water is also referred to as a merit good whose consumption "has benefit to society beyond that which accrues to the individual (Easter and Feder 1996, p9)."

[33] Multiple complementary policy instruments are needed to address adequacy, affordability, equity, and externality concerns (Tinbergen 1952).

capacity, particularly in agriculture, industry, and energy, leading to lower potential growth and heightened inflationary pressures. In water-stressed economies, external balances may deteriorate due to rising food and energy imports.

External Sector

Figure 5 illustrates the main potential transmission channels of water scarcity and drought risks to balance of payments. A significant amount of water is embedded in traded goods and with greater water scarcity and drought, net exports of these goods could experience a decline. Examples include coffee (approximately 19,000 liters per kilogram of roasted beans)[34], jeans (approximately 7,500-10,000 liters per pair)[35], and raw cotton (approximately 10,000 liters per kilogram).[36] The total virtual blue water (that is, blue water embedded in final demand exports and imports) is estimated at 93 billion m^3 per year whereas the total virtual green water is estimated at 750 billion m^3 per year. Table 1 lists the top 10 countries with the greatest amounts of blue water embedded in total exports and imports, respectively.[37] Additionally, many countries rely significantly on hydroelectric power generation and in the face of water scarcity they could see higher imports of electricity to meet their power needs (see Box 1). When drought leads to lower agricultural output, the shortfall may require higher net imports of food.[38] Lastly, countries that have a significant part of their GDP rely on international tourism sectors could experience lower revenues during prolonged droughts or severe water shortages.

The capital and financial accounts could also be negatively impacted by growing water scarcity and drought risk. This could occur through lower foreign investment in natural resources and water-related assets, lower direct foreign investment or portfolio investment in water-related private enterprises, and higher international borrowing (external debt or trade credits) and aid flows to cover the current account or budget impacts arising from water scarcity and drought. Lastly, depending on the financial sector and prevalence of insurance, rising water scarcity and drought could change the use of finance derivative weather-linked instruments.

[34] Chapagain, A.K. & Hoekstra, A.Y. (2003).

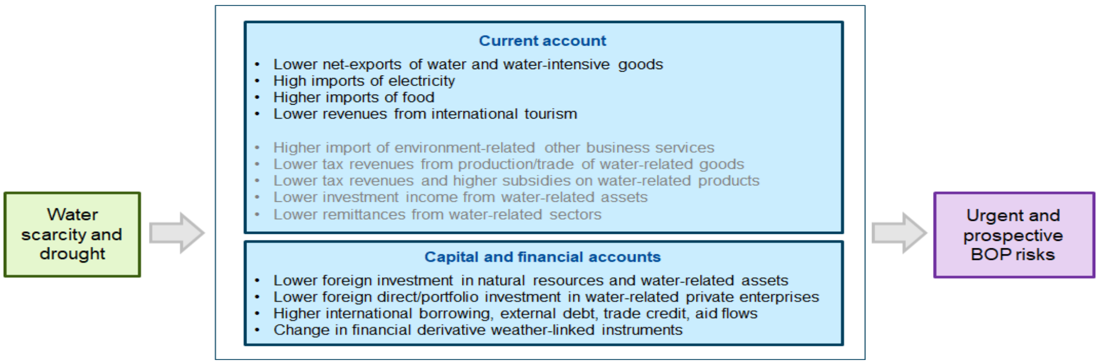
[35] United Nations. (2019, March 22). The environmental cost of a pair of jeans. United Nations News. https://news.un.org/en/story/2019/03/1035391

[36] Water Footprint Network. (2017). A guide to reducing the water footprint of cotton cultivation in India. https://waterfootprint.org/resources/A_guide_to_reduce_water_footprint_of_cotton_cultivation.pdf

[37] Additionally, it is important to consider that international price effects may lead to distributional impacts, especially if the exporting or importing country is large enough to influence global markets. Countries with abundant water resources and water-intensive export products, or those less impacted by climate change, could potentially benefit through favorable price adjustments. This dynamic suggests that water scarcity risks may create winners and losers, emphasizing the need for country-specific policies.

[38] Santini et al. (2022) highlight that the world's major crop producing countries are exposed to concurrent drought risks, such as North America, Ukraine, Brazil, Argentina and France for wheat, North America, India, Paraguay, and Argentina for soybean and Canada, Argentina and Romania for Maize, exposing global supply chain to systemic risks.

Figure 5. Water Scarcity and Drought and their Direct Balance of Payments Transmission Channels



Source**:** IMF staff based on IMF (2009) Balance of Payments and International Investment Position Manual, Sixth Edition (BPM6).
Note: Light grey text indicates smaller quantitative impacts.

Table 1. Top 10 Countries with Highest Virtual Blue Water in 2022

Rank	**Countries**	**Virtual Blue Water Export (Million m³)**	Total Exports (Billion US$)	**Countries**	**Virtual Blue Water Import (Million m³)**	Total Imports (Billion US$)
1	United States	57,083	1,979	United States	53,094	3,175
	India	23,177	475	Iraq	38,082	75
3	China	16,313	3,645	Egypt	19,445	103
4	Brazil	12,087	347	China	19,421	2,158
5	Thailand	12,061	335	India	15,971	726
6	Mexico	11,919	593	Pakistan	13,258	80
7	Spain	10,892	398	Iran	11,616	55
8	Australia	10,756	436	Mexico	9,903	530
9	Egypt	7,016	58	Saudi Arabia	9,268	187
10	Germany	6,996	1,600	Spain	9,258	482

Source: IMF staff estimates based on Eora 26 and BACI International Trade Database at the Product Level 2022[39] Note: Virtual water is calculated as the value of total import and export times gross blue water intensity as defined in Annex III.

GDP

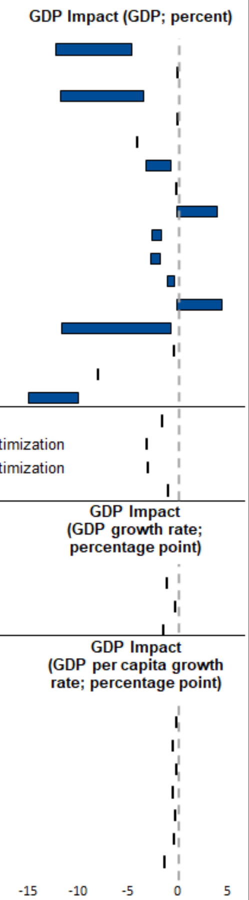
The economic implications from increasing water scarcity and drought are substantial. There are a range of estimates in the literature, based on different models, scenarios, and countries. Table 2 summarizes the key findings.[40]

[39] CEPII - BACI

[40] Beyond risks, a small but growing literature documents the macroeconomic benefits of water-related solutions, including irrigation sector reforms (Dudu and Chumi, 2012) and investments in water infrastructure under climate change (Bartolini et al., 2025).

Table 2. Macroeconomic Impact of Water Scarcity and Drought

Hazard	Study & Scope	Scenario	Method
Water scarcity	Roson and Damania 2017, MENA *	2050 SSP1	CGE
	Roson and Damania 2017, Global *	2050 SSP1	CGE
	Roson and Damania 2017, MENA *	2050 SSP3	CGE
	Roson and Damania 2017, Global *	2050 SSP3	CGE
	Van Heerden et al. 2019, Uganda	Climate change and water shortage in 2050	CGE
	Teotonio et al 2020, Portugal	2050 RCP8.5	CGE
	Teotonio et al 2020, Portugal	2050 RCP4.5	CGE
	WB 2020, Iraq	20% reduction in water supply	CGE
	WB 2020, Jordan	20% reduction in water supply	CGE
	WB 2020, Syrian Arab Republic	20% reduction in water supply	CGE
	WB 2020, Lebanon	10% reduction in water supply	CGE
	Bardazzi 2022, Middle East	2030 RCP8.5	CGE
	Bardazzi 2022, Middle East	2030 RCP2.6	CGE
	Briand et al 2023, South Africa	Scarcity increases by 17% in 2030	CGE
	GCEW 2024, HICs	Climate change and water constrain in 2050	CGE
	GCEW 2024, LICs	Climate change and water constrain in 2050	CGE
Drought	Horridge et al. 2005, Australia	A drought happened in 2002-2003	CGE
	Ortuzar et al. 2023, India	Droiught in India in 2016	Input-Output Analysis + Optimization
	Ortuzar et al. 2023, Middle East	Drought in Middle East in 2016	Input-Output Analysis + Optimization
	Clevy and Evans 2025, Uruguay	A significant drought in 2022-2023	Empirical analysis + DSGE
	Fuje et al. 2023, Global	A drought happened	Empirical analysis
	Fuje et al. 2023, AEs	A drought happened	Empirical analysis
	Fuje et al. 2023, EMDEs	A drought happened	Empirical analysis
	Felbermayr and Groschl 2014, Global	Droughts happened in 1979-2010	Empirical analysis
	Zaveri et al. 2023, Global	1 SD dry shock happened	Empirical analysis
	Zaveri et al. 2023, HICs	1 SD dry shock happened	Empirical analysis
	Zaveri et al. 2023, Developing Countries	1 SD dry shock happened	Empirical analysis
	Akyapi et al. 2024, Global	Harsh drought prevalence	Empirical analysis
	Tintchev and Jaramillo 2024, FCSs	2024-2060 RCP8.5	Empirical analysis
	Tintchev and Jaramillo 2024, FCSs	2061-2100 RCP8.5	Empirical analysis



Source: IMF staff

Note: CGE = Computable General Equilibrium; DSGE = Dynamic Stochastic General Equilibrium; MENA = Middle East and North Africa; HICs = High Income Countries; LICs = Low Income Countries; FCSs = Fragile and Conflict-Affected States; AEs = Advanced Economies; EMDEs = Emerging Market and Developing Economies.

*Roson 2017 utilized similar projection methods based on slightly different datasets and is omitted in this table

By 2050, water scarcity driven by altered precipitation patterns, rising temperatures, and increasing water demand is projected to significantly impact global economic output. The Global Commission on the Economics of Water estimates GDP losses of up to 8 percent in high-income countries and 10–15 percent in lower-income countries.[41] At the global level, model-based projections by Roson and Damiana (2017) suggest that under scenarios without water reallocation, average global GDP could decline by 0.19–0.24 percent (SSP1 and SSP3), whereas Roson (2017) estimates even higher losses of 0.37–0.49 percent.[42] While shifts in water-intensive production and trade may mitigate global impacts, regional losses are expected to be

[41] Global Commission on the Economics of Water (2024).

[42] In Roson and Damiana's (2017) projection, climate impacts on water availability were averaged across alternative scenarios of wet, medium, and dry per the GCAM simulation. The economic impact is estimated using the GTAP. SSP1, is termed the Sustainability scenario in which "Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed toward environmentally friendly processes, including lower carbon energy sources and high productivity of land." SSP3 is termed the Regional Rivalry scenario in which: "Unmitigated emissions are high due to moderate economic growth, a rapidly growing population, and slow technological change in the energy sector, making mitigation difficult." O'Neill et al. (2014).

much more severe. For instance, the MENA region could face GDP contractions of 11.8–12.2 percent (SSP3 and SSP1 with no water reallocation, respectively), and in South Asia 4.9–5.9 percent under SSP3 and SSP1 scenarios, respectively, with no water reallocation.[43] Country-level assessments by the World Bank (2024a) further underscore the risks, with projected GDP losses reaching 6.8 percent in Burkina Faso, 11.9 percent in Niger, and 16.7 percent in the Dominican Republic under dry and pessimistic climate scenarios.

Similar GDP impacts are to be expected from droughts, with both direct and indirect economic consequences. Ortuzar et al. (2023) find that a 5 percent drop in water availability in key hotspot regions—such as China, India, MENA, and Southern Europe—can lead to global GDP losses ranging from 0.1 percent (drought originating in India) to 0.47 percent (drought originating in China), with country-specific GDP contractions reaching 2.8 percent (China) to 3.1 percent (India). While empirical evidence on the direct GDP impact of droughts remains limited, recent studies provide important insights. Akyapi, Bellon, and Massetti (2025) estimate that a positive one standard deviation in harsh drought exposure can reduce per capita GDP growth by 0.21–0.25 percentage points. Similarly, Fuje et al. (2023) show that severe droughts during key crop-growing months can reduce same-year GDP growth by 1.4 percentage points in developing economies but has no impact in advanced economies. Felbermayr and Gröschl (2014) also find that prolonged rainfall deficits (measured as 50 percent below the long-run monthly average for at least 3 consecutive months) can lower per capita GDP growth by 1.3 percentage points. Evaluating longer-term effects in Fragile and Conflict-Affected States (FCSs), Tintchev and Jaramillo (2024) project that under high-emissions scenarios, drought conditions could reduce annual GDP per capita growth by 0.32 percentage points in FCSs with debt levels above 60 percent of GDP, and by 0.35 percentage points in those with social spending below 1 percent of GDP.

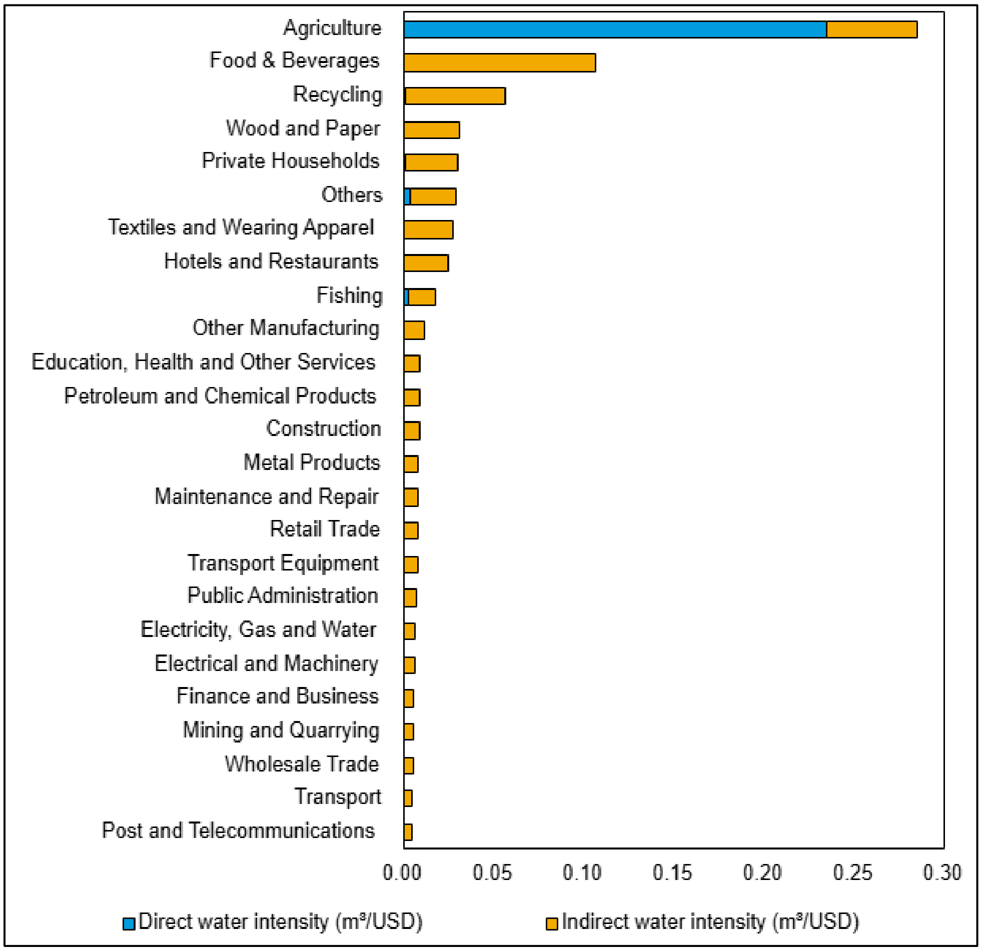
Sectoral Impacts

Figure 6 shows average direct and indirect blue water intensity for economic activities calculated based on consumptive water use[44] globally. Whereas direct blue water consumption constitutes a dominant share (approximately 90 percent of total blue water intensity) for the agricultural sector, indirect blue water intensity (that is, those embedded via backward inter-industry linkages dominates for all other industries (see Annex III for estimation methodology). In fact, downstream industries such as food and beverages, recycling, wood and paper industries are increasingly aware of water-related risks posed to their economic activities. CDP (2024) conducted an analysis of 3,163 large firms with an annual revenue exceeding US$250 million regarding water related risks, which revealed that approximately 50 percent of firms are engaged in water related risk management such as inclusion of water related aspects in procurement requirements and collection of water data. One in 5 firms also disclose their water-related risks in supply chains.

[43] See Roson and Damiana (2017).

[44] Please see annex for descriptions related to consumptive vs. non-consumptive use of water.

Figure 6. Global Average Direct and Indirect Water Intensity of Economic Activities



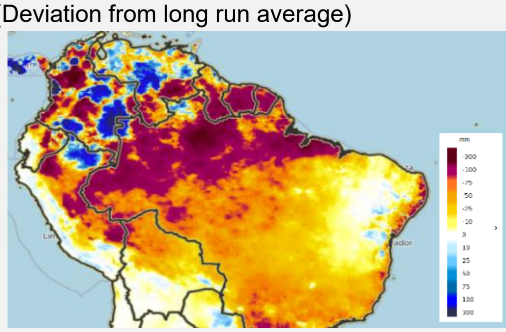
Source: IMF staff estimates based on the Eora 26 database.
Note: Direct and indirect water intensity refers to intensity of consumptive water use. See Annex III for the estimation methodology used.

Water—primarily through non-consumptive use—also serves as critical inputs to industries such as energy production, mining, and maritime transport. As witnessed in the recent electricity crisis of Ecuador (Box 1), reduction in water availability poses significant risk to macroeconomy for countries dependent on hydropower production. Analyzing hydrological data between 1975–2016, Wan et al. (2021) estimated that a 1 in 10-year drought will cause annual hydropower production to decline by more than 20 percent in 67 out of 134 countries. The estimated reduction exceeded 40 percent for 18 countries, with larger reductions estimated in Africa, MENA, and Central Asia. Based on the analysis of 20 countries with heavy reliance (>75 percent) on hydropower, CDRI (2023) similarly notes that under a high emissions scenario, 7 out of 20 countries would experience annual average losses of hydropower estimated at greater than 10 percent of production due to droughts. Lesotho, Costa Rica, and Afghanistan were among the most exposed, experiencing estimated annual average hydropower production losses of approximately 30 percent relative to expected production levels under no drought. In Panama during the 2023-24 El Niño-induced drought which saw rainfall 43 percent lower than average, cargo ships were forced to wait for weeks during low flow, with restrictions placed on ship depths. A special auctioning system was set up for shippers to reserve the right of passage or they were forced to opt for detours. Toll revenues were reduced by US$100 million per month and GDP growth slowed (Reuters, 2024).[45] Finally, shifts in water availability impact additional sectors including mining and industrial processing, but the magnitude of such impacts is less understood due to limited evidence (Caretta et al. 2022).

Box 1. Ecuador: Macroeconomic Implications of the 2024 Electricity Crisis

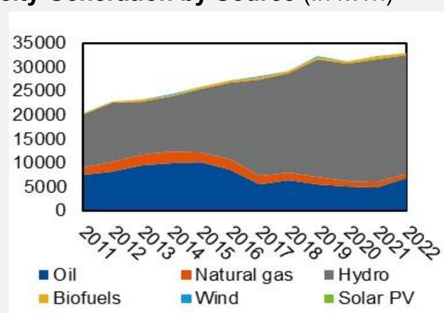
In late 2024, Ecuador experienced a severe electricity crisis triggered by the most intense drought in decades, underscoring the macro-critical vulnerabilities of the country's energy system to climate-related shocks. With hydropower accounting for approximately 75 percent of electricity generation, the sharp decline in river flows significantly curtailed hydroelectric output, leading to nationwide blackouts beginning in September. The crisis disrupted economic activity, strained public finances, and highlighted structural weaknesses in the energy sector that could pose recurring risks to macroeconomic stability.

Rainfall During July-September 2024
(Deviation from long run average)



Source: United States Geological Survey

Electricity Generation by Source (In kWh)



Source: IEA, IMF staff calculations

The authorities implemented a swift policy response to mitigate the crisis and prevent lasting scarring. Emergency measures included boosting thermal generation through rented barges and turbines, reducing VAT on electric generators, subsidizing household electricity bills, and launching a temporary cash transfer program. Electricity imports from Colombia resumed in late November, helping to alleviate the supply shortfall.

The crisis exposed structural and climate-related vulnerabilities in Ecuador's electricity sector. Hydropower's dominance, while supporting low electricity costs and a low-carbon energy mix, leaves the system highly exposed to hydrological variability, which is expected to intensify with climate change and El Niño events. The situation was exacerbated by operational challenges at key facilities, including Coca Codo Sinclair—Ecuador's largest power plant—which lacks a reservoir and is undergoing repairs that limit its capacity. The crisis also revealed a persistent structural deficit in electricity generation, particularly during the dry season, and a growing mismatch between supply and rising demand, especially from industry.

[45] Water also serves a critical role in thermal power cooling. Lohrmann et al. (2019) estimated that currently approximately 500 km^3 of water (including fresh and saline) is withdrawn annually for thermal power production, of which 25 km^3 are considered water consumption. Increasing temperature, including the risk of heat waves, poses significant impacts on the availability of cooling water, as seen in the recent shutdowns of nuclear facilities in Europe seen during the heatwave of 2025 due to excessive warming of river water (Mulky et al. 2025). Jones et al. (2025) estimates that freshwater temperatures have already risen in the recent decades (that is, 0.5–0.8 °C higher than those observed between 1981–2000) is projected to continue rise between 1.3–4.1 °C by the end 21st Century under alternative climate scenarios. Rising temperature, along with variable water flows, will cause thermal power cooling capacities to decline. Under the current water temperature and flow availability, during the month of June for example, approximately 70 percent of the installed thermal power capacity globally is estimated as usable, which is projected to decline by 6 percent (SSP1-2.6) and 11 percent (SSP3-7.0) by end 21st century. Larger declines in thermal power cooling capacity are projected for the United States, Europe, and eastern Asia (Vliet et al. 2016).

Box 1. Ecuador: Macroeconomic Implications of the 2024 Electricity Crises (continued)

The electricity crisis had broader macroeconomic implications—it weighed on export performance in Q4 2024 and increased reliance on high-cost electricity imports. The crisis underscores the need to integrate climate risks into macroeconomic and structural policy frameworks. Enhancing energy security through diversification of the generation mix, improving the resilience of hydropower infrastructure, and strengthening regional interconnections will be critical to reducing vulnerability to climate shocks. In parallel, fiscal frameworks should account for contingent liabilities arising from climate-related disruptions, while social protection systems must be equipped to respond swiftly to mitigate the impact on vulnerable households. Addressing these challenges will be essential to safeguard macroeconomic stability and support Ecuador's transition to a more resilient and inclusive growth path.

Sources: World Bank CCDR (2024b), IMF Ecuador Article IV 2024, IMF Selected Issue Paper "Securing Electricity Sufficiency and Reliability".

Fiscal Implications

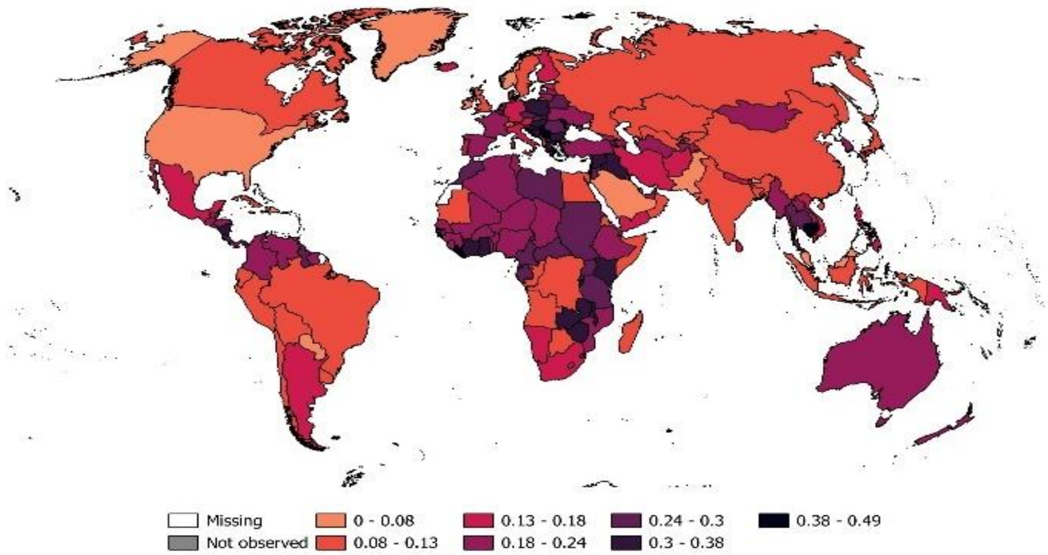
Fiscal Impacts from Water-Related Risks

The fiscal impacts (to revenue, expenditure, and other fiscal variables, such as public debt) arising from water scarcity and drought have been less studied than other macroeconomic variables. Recent empirical evidence highlights the fiscal vulnerabilities associated with drought shocks, particularly in emerging markets and developing economies. Fuje et al. (2023) find that moderate droughts (Palmer Drought Severity Index (PSDI) of –2 during crop-growing seasons) reduce government revenues by 0.5 percent of GDP globally, with a more pronounced impact of 0.7 percent in EMDEs and no significant effect in advanced economies. In fiscally constrained EMDEs, droughts also lead to a decline in public spending and deteriorate fiscal balances, especially when access to official development assistance is limited. However, Akyapi, Bellon, and Massetti (2025) find that exposure to severe droughts (PDSI below –3 or –4) increases expenditure-to-GDP ratios and contributes to widening fiscal deficits, with the magnitude of impact varying by country exposure (Figure 7).[46] Studying Europe and the United States, Pintus et al. (2024)[47] document short-term fiscal deterioration following precipitation shocks, including a temporary increase in deficits and debt, though effects tend to normalize within a business cycle. Box 2 discusses the macro-fiscal impacts of Zambia's most severe drought experienced in 40 years during 2023-2024.

[46] Akyapi et al 2025 found that harsh droughts affect both the government expenditure and GDP. While the drought variable used in this study aims to measure the impact of severe drought during a one-year period, drought-prone countries tend to experience continuous/multiple episodes of prolonged droughts, with compounding effects. It is also important to note that Figure 7 reports the direct impact of drought on additional expenditure. However, governments may face significant indirect/opportunity costs when reallocating expenditures away from priority items (such as infrastructure and social spending) toward emergency response.

[47] Pintus, F. et al. (2024)

Figure 7. Impact of Severe Droughts on Government Expenditure (Percent of GDP)

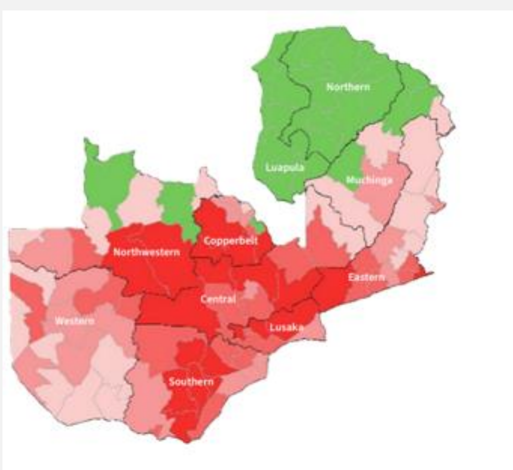


Source: IPCC; Akyapi, Bellon, and Massetti (2025); and IMF staff calculations.

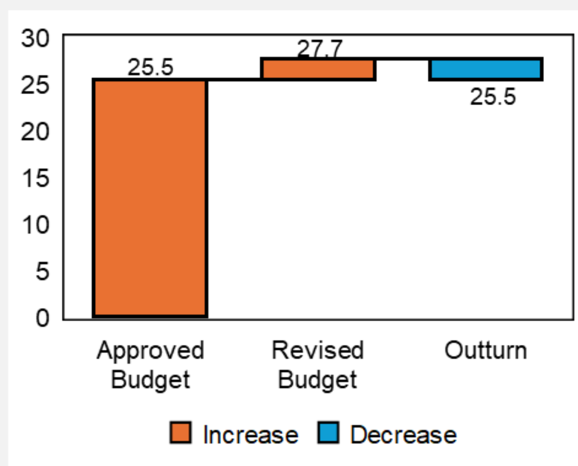
Box 2. Zambia: Fiscal Challenges Amid the 2023/24 Drought

Zambia experienced its most severe drought in over 40 years, triggered by an El Niño-induced dry spell during the 2023–2024 agricultural season and prolonged drought conditions into 2024. The crisis affected 84 of the country's 116 districts—primarily in the Southern, Eastern, and Western regions—and impacted an estimated 9.8 million people, nearly half of the population.

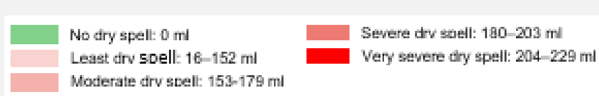
Severity of Dry Spell in Drought-Affected Districts



Government Spending in 2024 (Percent of GDP)



Source: Ministry of Green Economy and Environment. Zambia: 2023/24 rainfall deficit situation. Lusaka. [Cited on July 20th, 2024]. Internal document.



Source: Zambian authorities and IMF staff calculations.

Box 2. Zambia: Fiscal Challenges Amid the 2023/24 Drought (Continued)

Although Zambia has faced major droughts before, the 2023–2024 event stands out as one of the most severe, disrupting several productive sectors—agriculture, livestock, energy, and mining—while also worsening food security and health. In view of these challenges, the President declared the prolonged drought as a national disaster on February 29th, 2024.

The drought destroyed large parts of Zambia's maize crop, resulting in a 20 percent contraction in agriculture output in 2023 and 9 percent contraction in 2024. The drought also impacted water storage and hydropower generation (which accounts for 90 percent of the country's power generation). Low water levels in Lake Kariba—covering for around 80 percent of the country's electricity supply—reduced generation to less than 10 percent of normal output. This sharp decline led to load shedding of up to 21 hours per day, severely disrupting essential services, businesses, and households. The energy shortfall impacted key productive sectors, particularly mining, which is heavily dependent on electricity. Copper production declined by 23 percent in 2023. As a result, exports fell from 11.6 percent of GDP in 2022 to 4.9 percent in 2023, contributing to a worsening in the current account balance from a surplus of 3.7 percent of GDP in 2022 to a deficit of 3 percent of GDP in 2023. In 2024, amid power shortages, authorities approved an emergency electricity tariff increase and boost electricity and oil imports in 2024. Electricity access was prioritized for the mining sector and large corporations to support critical economic activity. In addition to lowering GDP growth, the drought's adverse impact on agricultural and electricity outputs exacerbated inflation. In 2024, inflation averaged 15 percent, up from 11 percent in 2023 and 2022, driven by rising food and fuel costs, emergency electricity tariff hikes, and previous depreciation of the exchange rate.

The direct fiscal impact of the drought on the government budget is visible in 2023 and 2024 on revenues, expenditures, and borrowing needs. Mining royalties dropped from 2.1 percent of GDP in 2022 to 1.4 percent in 2023, before rising 27 percent in 2024 due to increased copper production and exports. In response to the drought, the Government revised the 2024 budget to prioritize humanitarian aid, early recovery, and resilience efforts and reduced investment spending. Disaggregated budget data is mainly available for school transfer and emergency cash transfers (ECT), accounting for K9.3 billion (1.3 percent of GDP) where the social cash transfer

(SCT) was doubled to K400 per month via a drought-related top-up and an ECT of the same amount was introduced for households severely affected by the drought, bringing the total number of recipients of SCT to 2.3 million. Additional spending covered school feeding programs (expanding the program to cover an additional 37 districts—106 out of 116), water resource management, and livestock disease control, while drought-related maize and electricity imports added an estimated US$420 million in financing needs. To close the financing gap, authorities reprioritized spending, raised additional revenues, and secured multilateral and bilateral support—including a 30 percent of quota increase in IMF ECF access approved in June 2024—which helped ease fiscal and external financing pressures. The budget outturn for 2024 was better than expected from the revised budget, helped by significantly stronger-than-projected growth, but with lower overall financing, spending was generally constrained with social spending targets being achieved.

The recent drought highlights the urgent need for climate adaptation investments and energy diversification to reduce Zambia's dependence on hydropower. While the government's shift to alternative energy sources, including imported diesel, and prioritization of electricity for key sectors helped sustain growth in mining, construction and other sectors, households bore the brunt of load shedding. Social protection programs were expanded, but broader reforms in further areas are essential to ensure a reliable energy supply for businesses, expand rural energy access, and strengthen climate resilience. Key priorities include improved water management, irrigation, extension services, and climate information to support sustainable, inclusive growth.

Source: IMF, Zambia Third, Fourth, and Fifth Reviews 2023-2025; World Bank, Poverty Equity Brief, October 2024; World Bank Country Partnership Framework. 2024; Declaration of Drought as A National Disaster and Emergency. – cabinet office
Note: K = the Zambian Kwacha.

Spending Needs

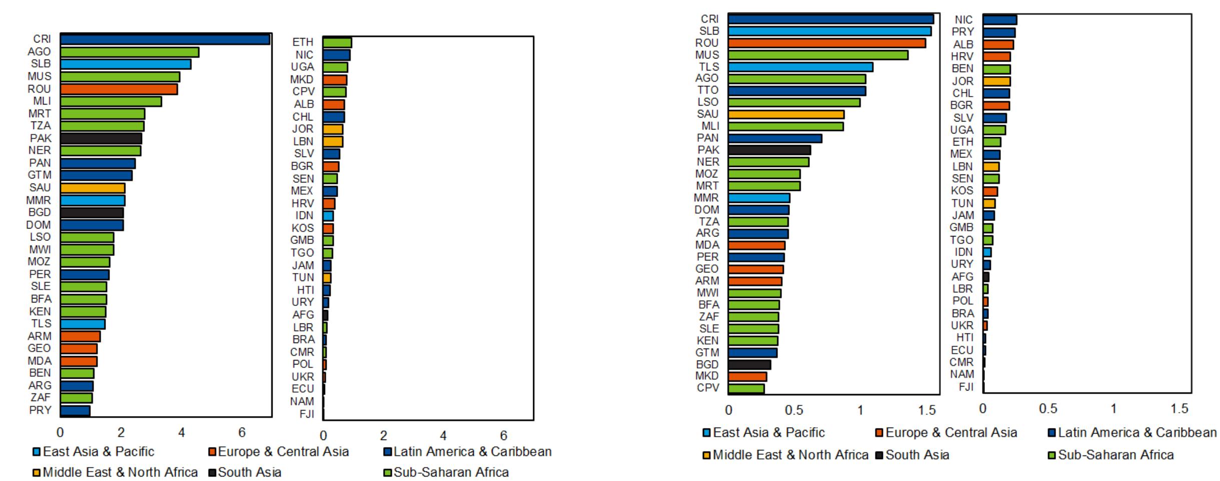
Ensuring access to the water sector services, more generally, can also have large fiscal implications. This may include spending to achieve SDG and adaptation objectives, including water-related investments to expand water access, and through subsidies and foregone revenue. Inefficiency of public spending and poor management of water-related infrastructure (primarily managed through state-owned enterprises) can also raise costs.

Water-Related Spending

Close to US$165 billion (0.6 percent of global GDP) is invested in water- related service provision each year.[48] The vast majority of which—more than 90 percent—is undertaken by the public sector (including state-owned enterprises) and funded by domestic financing sources.[49] About three-quarters of public spending on water goes toward water supply and sanitation, while only 8 percent is spent on irrigation and 2 percent on hydropower. Close to two-thirds of spending is allocated towards capital expenditure (investment), with the remainder for current operations (including wages) and maintenance. However, public spending on water makes up only a very small portion of the total government spending in most countries (Figure 8A and B).

Figure 8. Annual Public Spending in the Water Sector (2020)

A. Percent of Government Expenditure **B. Percent of GDP**



Source: World Bank Funding a Water-Secure Future Database.
Note: Country names are represented using ISO codes. The data includes spending in water supply and sanitation, irrigation, hydropower, and water transportation.

The low level of public sector spending on water is exacerbated by low execution rates. World Bank analysis of countries' budget execution rates over 2009-2020 shows an average execution rate of 72 percent for water, with substantial heterogeneity across years and countries.[50] However, compared to average execution rates of 92 percent for the overall budget and 85 percent for capital expenditures, spending on water

[48] Joseph et al. (2024). 2017 prices.

[49] Official development assistance covers about 7 percent of annual spending, while the private sector contributes less than 2 percent.

[50] Joseph et al. (2024).

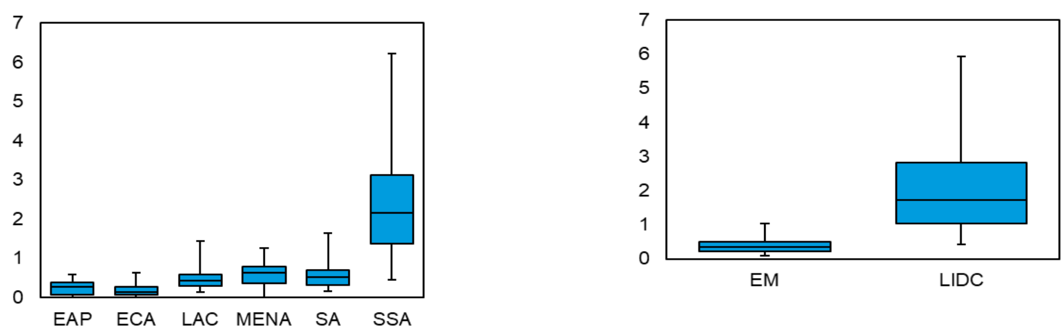
faces considerable challenges that derive, in part, from weak public investment management processes and slow project implementation.[51]

SDG Costs

Water will play a key role in achieving the Sustainable Development Goals (SDGs).[52] SDG6 is directly focused on water—ensuring the availability and sustainable management of safe water, sanitation, and hygiene (WASH) services for all by 2030. But water also plays an important role in achieving several additional SDGs, including SDG1 (no poverty), SDG2 (zero hunger), SDG3 (good health and well-being), SDG5 (gender equality), and SDG7 (energy access). The IMF estimates that countries will require an annual additional average investment of 1.2 percent of 2030 GDP (median 0.5 percent of 2030 GDP) on WASH.[53] But these estimates vary widely depending on region and income group (Figure 9A and B). Sub-Saharan Africa, for example, will need to spend an additional annual average of 2.7 percent of 2030 GDP (median 2.1 percent of 2030 GDP), compared to developing Europe and Central Asia which only needs an additional annual investment of 0.3 percent of 2030 GDP on average (median 0.2 percent of 2030 GDP). The spending needs are also stark when measured by income group, with low-income developing countries annual investment needs exceeding emerging market countries by close to five-fold.

Figure 9. Additional Spending Needs for SDG 6 in 2030 (Percent of 2030 GDP)

A. By Region **B. By Income Group**



Source: IMF staff calculations, based on IMF SDG Costing Tool, third edition.
Note: Horizontal lines inside the boxes are the median spending need values. The top and bottom parts of the boxes are the upper and lower quartiles. The top and bottom horizontal lines of the "whiskers" are 95th percentile and 5th percentile. ECA = Europe & Central Asia; MENA = Middle East & North Africa; SSA = Sub-Saharan Africa; LAC = Latin America & Caribbean; EAP = East Asia & Pacific; SA = South Asia; EM = Emerging Markets; LIC = Low Income Countries.

[51] World Bank's BOOST data covering 32 countries over the period 2010-2022. Boost Portal. More comprehensive, but older, PEFA data (2007-2017) covering 94 countries shows average spending under execution of 2 percent. determinants-of-budget-credibility-june-2020.pdf

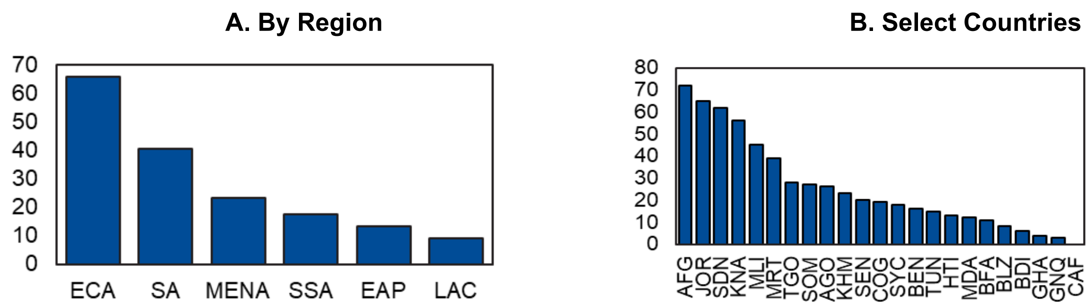
[52] The IMF acknowledges that achieving the SDGs by 2030 faces significant headwinds (The 4th Financing for Development Conference-Contribution of the IMF to the International Financing for Development Agenda)

[53] Carapella et al. (2023).

Adaptation Spending Needs

Water systems also lie at the core of climate adaptation. Water resilience is an adaptation priority for most countries—84 percent of National Adaptation Plans (NAPs) identify water as a priority sector (UNEP 2024). Countries increasingly recognize that adaptation in the water sector requires adequate technological transfer, institutional building and climate finance. Based on the technological needs assessment conducted across 90 countries between 2011-2023, the water sector accounts for the largest share of identified technology needs (37 percent among 566 technologies) with countries frequently reporting the needs for options such as irrigation systems, water storage/harvesting and barriers for coastal protection. Likewise, strengthening of regulatory environments, monitoring of climate impacts and community engagement in water resource management are identified as institutional capacity building needs (*ibid*). Finally, adaptation financing needs in the water sector are high, estimated around US$170 billion (2021 value) annually—almost equal to what is currently being spent (UNEP 2023). It also constitutes a large portion of countries' adaptation portfolios (Figure 10).[54]

Figure 10. Water Investment as a Share of Total Adaptation Finance Needs (Percent)



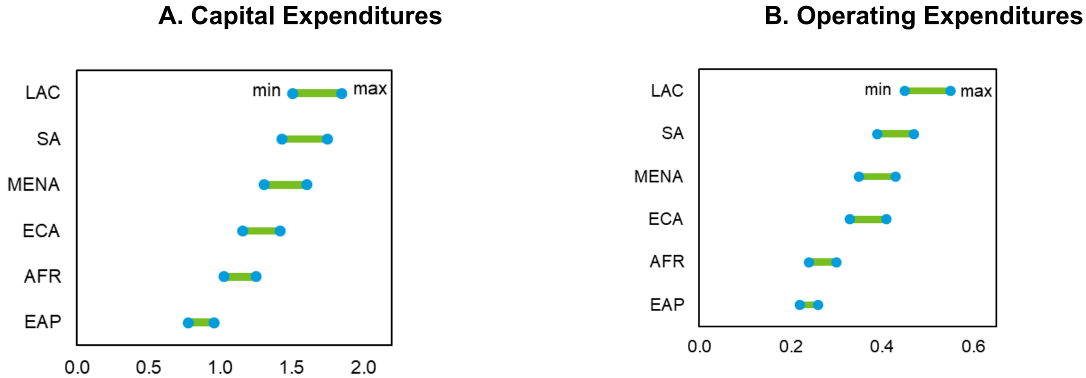
Source: Lost Water: Challenges and Opportunities. S&P (2023).
Note: Country names are represented using ISO codes. ECA = Europe & Central Asia; MENA = Middle East & North Africa; SSA = Sub-Saharan Africa; LAC = Latin America & Caribbean; EAP = East Asia & Pacific; SA = South Asia.

Subsidies

Water pricing faces inherent trade-offs across environmental sustainability, financial sustainability, economic efficiency, and social concerns, requiring a set of complementary policies. Water is often provided at prices below cost-recovery levels, which can result in large explicit and implicit fiscal costs to the budget. These costs are mostly covered through subsidies and transfers to water utility companies (SOEs) and irrigation authorities, or financial losses accumulated in these entities.

[54] S&P Global. "Lost Water: Challenges and Opportunities".

Figure 11. Subsidies to Water Utility Companies (Average Percent of GDP)



Source: Andres et al. (2019). Doing More with Less: Smarter Subsidies for Water Supply and Sanitation, World Bank, Washington, D.C.
Note: Country names are represented using ISO codes. ECA = Europe & Central Asia; MENA = Middle East & North Africa; SSA = Sub-Saharan Africa; LAC = Latin America & Caribbean; EAP = East Asia & Pacific; SA = South Asia.

Water utility company subsidies are substantial and widespread. Low levels of cost and technical (production) efficiency, exacerbated by limited adjustment to water tariff rates, hamper the financial performance of water utility companies. Based on data from the World Bank's IBNET database (2010–2015), Andres et al. (2019) estimates that globally, water utility company subsidies covering operating and capital expenditures are equivalent to 0.46-0.56 percent of GDP annually, with wide variation across regions and income levels (Figure 11A and B). On average, networked water services receive 64 percent of total subsidies, with the remainder allocated to sanitation. Advanced economies direct a larger share of subsidies to sewered sanitation, whereas Sub-Saharan Africa and East Asia and Pacific allocate only 6 percent and 11 percent, respectively. Only 14 percent of water utility companies (220 out of 1,549) fully cover their costs, and just 35 percent manage to cover operations and maintenance (O&M) without subsidies.

Despite the large scale of public support, water supply and sanitation (WASH) subsidies are often poorly targeted. Analyzing the piped-water subsidies across 10 countries[55] Andres et al. (2019) found that the subsidies are regressive, benefiting generally the wealthier households, with subsidies reaching 56 percent for the top and 6 percent for the bottom quintile respectively. This reflects a WASH access divide, with poor households often lacking piped water connection.

Subsidies in irrigation are also pervasive, though comprehensive data remain limited.[56] Estimates of their size vary: Van Beers and de Moor (2001) suggest US$20–25 billion annually in developing countries, Myers and Kent (2001) estimate US$29 billion for developing countries, and Brown et al. (2000) place the global figure at US$33 billion.[57] These figures all exclude externalities. In addition to direct subsidies, irrigators often benefit from cross-subsidies from power users who gain from shared infrastructure.[58] Cost recovery in irrigation is often hindered by technical challenges (for example, measuring water use), social and political factors (for example, affordability and food security), and institutional constraints. Alternative approaches, such

[55] Ethiopia, Mali, Niger, Nigeria, Uganda, El Salvador, Jamaica, Panamá, Bangladesh, and Vietnam
[56] GSI 2008; OECD 2003.
[57] GSI 2008. For OECD countries water subsidies are estimated at $15 billion annually, with the majority for irrigation.
[58] Ward (2010) documents such arrangements in countries including Spain, France, India, Jordan, China, Turkey, Mexico, Egypt, Indonesia, Morocco, and Ukraine.

as involving water user associations—community-based organizations formed by individuals or groups who use water from a common source typically utilized in rural or semi-rural areas where water management is decentralized—have shown mixed results.[59]

Water-related subsidies can also have adverse environmental impacts. This is because competing objectives and incomplete information sharing prevent policymakers from seeing the complete consequences of their policy actions. Take, for example, the case of India, which has an output subsidy regime, which guarantees procurement of water-intensive crops such as rice and wheat at fixed prices. Originally introduced during the Green Revolution in the 1960s to ensure food security, this policy has expanded beyond its initial scope and now incentivizes continued cultivation of these crops even as production exceeds national consumption and buffer stock requirements by over 30 percent. As a result, India's groundwater depletion has accelerated dramatically over the past half-century, with water consumption increasing by over 500 percent and average water tables falling more than 8 meters, reaching depths of 30 meters in some regions.[60] In Punjab, rice procurement rose from 4.4 to 13 million tons between 1981 and 2015, contributing to a 50–65 percent decline in groundwater levels, with annual reductions of 1.2–2 percentage points.[61] Similar patterns are observed elsewhere, where fiscal measures in Ireland and crop insurance subsidies in the United States have also encouraged water-intensive agricultural practices, underscoring the need for more environmentally aligned subsidy frameworks.[62]

Non-Revenue Water

Non-revenue water (NRW)—the difference between water abstracted and water billed to end users—represents not merely an operational inefficiency but a systemic fiscal and climate-related macroeconomic vulnerability. NRW comprises water that is lost, or produced but unbilled due to leaks, theft, or metering inaccuracies, and thus serves as an indicator of infrastructure performance, financial fragility, and governance in the water and sanitation sector. Losses stem from aging pipes, under-registering meters, illicit taps, and unbilled consumption. By eroding utility revenues, high NRW undermines the financial viability of water systems, constrains public and private investment in resilience, and transfers the fiscal burden to governments through explicit or implicit subsidies (Box 3). Under climate stress, elevated NRW worsens water scarcity during droughts, heightens budgetary pressures by requiring additional subsidies or transfers to cover lost water and repair costs, and amplifies macro-fiscal risks via higher sovereign debt ratios and contingent liabilities. In short, inefficiencies in the water sector can generate substantial fiscal burdens and impede economic growth.

On average, roughly 36 percent of water produced is lost (NRW)—equivalent to 0.15 percent of a country's GDP. Global NRW is estimated at 126 billion m^3 annually, with economic costs amounting to US$39

[59] Aarnoudse et al. (2018).

[60] The role of farm subsidies in changing India's water footprint | Nature Communications

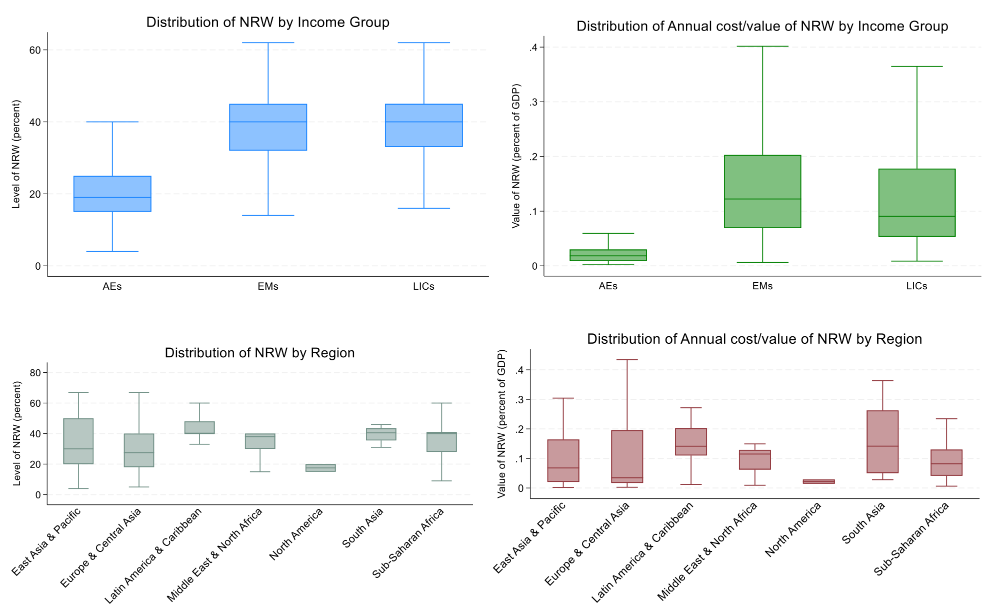
[61] The role of farm subsidies in changing India's water footprint | Nature Communications

[62] Template - Research Series (Green); Crop insurance premium subsidy and irrigation water withdrawals in the western United States | The Geneva Papers on Risk and Insurance - Issues and Practice; Improvements in the efficiency of resource use—such as water-saving irrigation technologies—can lead to an overall increase in resource consumption. This rebound effect complicates the design of environmentally beneficial subsidy programs, suggesting that efficiency-enhancing measures must be paired with regulatory or pricing mechanisms to ensure net reductions in resource use. See, for example, Jevons' Paradox and Efficient Irrigation Technology.

billion per year, equivalent to about 0.1 percent of global GDP.[63] While NRW is on average lower for advanced economies at about 20 percent, two-thirds of countries report NRW rates above 30 percent (Figure 12). There is substantial heterogeneity (within and across regions and income groups), but the average water loss for the average EMs and LICs is about 40 percent, valued at around 0.2 percent of GDP. To put it in perspective, public spending in water and sanitation services in 2016 in selected EMs and LICs was 0.4 and 0.2, respectively (World Bank's BOOST database). These losses are universally felt when utilities erode revenue and governments step in with subsidies or debt. Furthermore, the cost or value of NRW represents about 30 (80) percent and 6 (22) percent of the median (average) water and sanitation infrastructure investment required by 2030 to meet the SDG targets in EMs and LICs, respectively.[64] Addressing these inefficiencies in water management is crucial not only for economic sustainability but also for achieving the SDGs that aim to ensure water and sanitation for all.

High NRW, combined with below-cost-recovery tariffs, impose a substantial fiscal burden on governments. In emerging markets and developing economies (excluding China and India), government subsidies to cover only the operational, maintenance, and repair costs of existing water supply and sanitation infrastructure are estimated at between 0.35 percent and 0.43 percent of GDP annually. When capital transfers for new infrastructure investment are included, this estimate rises significantly to between 1.59 percent and 1.95 percent of GDP annually.[65]

Figure 12. Level of NRW and its Annual Cost by Income and Region



Source: IMF Staff's calculations using data from Liemberger and Wyatt (2019).

[63] Liemberger and Wyatt (2019). The average economic cost is conservatively valued at US$0.31 per m³ of water produced, and differs for each country, with averages that range from US$0.37 in AEs, US$0.31 in EMs, and US$0.24 in LICs. In terms of quantities, the estimated global volume of non-revenue water is equivalent to the total annual freshwater withdrawals of Germany, France, Spain, Italy, and the United Kingdom combined (S&P Global. "Lost Water: Challenges and Opportunities").

[64] Carapella et. al (2023) estimates that the infrastructure spending needs to achieve SDGs by 2030 on the water and sanitation services goals is 0.27 percent of GDP for EMs and 1.7 percent of GDP for LICs.

[65] Andres et. al. (2020).

Note: Each box depicts the distribution of non-revenue water (NRW), the level on chart a) and as percent of GDP in chart b) by income group. The central line marks the median (50th percentile), while the lower and upper edges of the box correspond to the 25th and 75th percentiles (the interquartile range, IQR), capturing the middle 50 percent of observations. Whiskers extend to the most extreme values within 1.5 × IQR of the box.

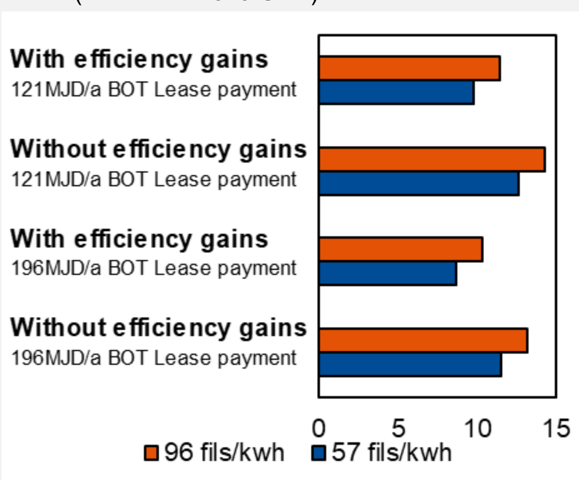
Box 3. Jordan: Tackling Scarcity, Fiscal Pressures, and Sustainability Challenges

Jordan is one of the most water-scarce countries globally, with renewable freshwater availability at just 61 m³ per capita in 2021, projected to fall to 35 m³ by 2040 due to population growth and climate change. The water sector faces acute fiscal and operational challenges. Over half of drinking water is lost as NRW, and in 2021, customers paid only one-third of the total cost of water and wastewater services.

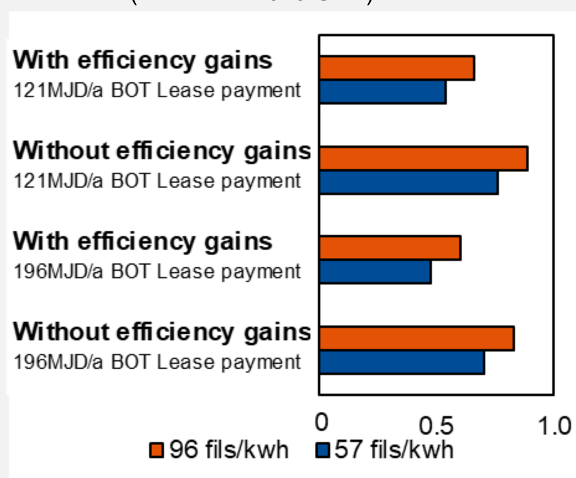
To address these challenges, Jordan is pursuing a comprehensive reform agenda. A cornerstone initiative is the Aqaba-Amman Conveyor (AAC) project, which will deliver 300 million m³ of desalinated water annually from the Red Sea to Amman. The AAC project is expected to significantly improve water supply but will require substantial public and private financing. According to World Bank estimates, water sector debt could reach 7.9 billion JD by 2040 with the ACC and efficiency gains, and up to 12.8 billion JD with the ACC without efficiency gains. Sector deficits are projected to range from 430 million JD to 798 million JD depending on reform progress.

Jordan Water Sector Projected Financials in 2040

A. Debt (Percent of 2040 GDP)



B. Deficit (Percent of 2040 GDP)



Source: World Bank Jordan CCDR 2022.
Note: 96 fils/kwh refers to the high cost and 57 fils/kwh low-cost scenarios respectively, representing the potential energy costs for treating and pumping water once the AAC is operational. The high cost scenario (196 MJD/a) is equal to 3 times the cost of the Disi pipeline, as the AAC is planned deliver 300 MCM per year of water. 121 MJD/a is equal to 1.85 times the cost of the Disi pipeline.

In response, Jordan adopted the Water Sector Financial Sustainability Roadmap (FSR) in 2022, outlining reforms to reduce NRW, improve energy efficiency, and revise tariffs. NRW was reduced from 50 percent in 2022 to 45 percent by end-2024, and a revised tariff plan out to 2028 was published. Under the IMF's Resilience and Sustainability Facility (RSF), Jordan will update the FSR by early 2027, incorporating the impact of AAC and maintaining an annual NRW reduction target of at least 2 percentage points on average. The updated roadmap will provide a policy framework for 2026–2042, aiming for full operational and maintenance (O&M) cost recovery by 2032 and full recovery including BOT capital charges by 2042.

Jordan is also enhancing private sector participation to improve service delivery and financial sustainability. A performance-based management contract is expected to be tendered by end of 2025 for Yarmouk Water Company (YWC), one of three regional utilities, which faces high NRW, aging infrastructure, and low bill collection. The selected firm will be responsible for meeting key performance indicators such as water sales, energy consumption, and collection ratios, with fees linked to performance. This initiative complements the World Bank's Jordan Water Sector Efficiency Project and represents a structural shift toward private sector engagement.

Box 3. Jordan: Tackling Scarcity, Fiscal Pressures, and Sustainability Challenges (Continued)

In the wastewater sector, Jordan is a regional leader in treated wastewater (TWW) reuse, supplying about one-quarter of irrigation water. To further expand TWW use and reduce pressure on freshwater resources, the authorities plan to tender five-year O&M contracts for at least 50 percent of national wastewater treatment capacity (excluding As-Samra) by May 2027. The goal is to increase TWW use to 35 percent of freshwater by 2027 and 45 percent by 2030.

Jordan's strategy combines supply-side investments—such as desalination and wastewater reuse—with demand-side reforms, including tariff restructuring and efficiency improvements. By leveraging private sector expertise and investment, Jordan aims to modernize its water sector, improve service reliability, and ensure long-term sustainability under conditions of extreme water scarcity.

Source: IMF staff, World Bank CCDR (2022), IMF Jordan Third Review.

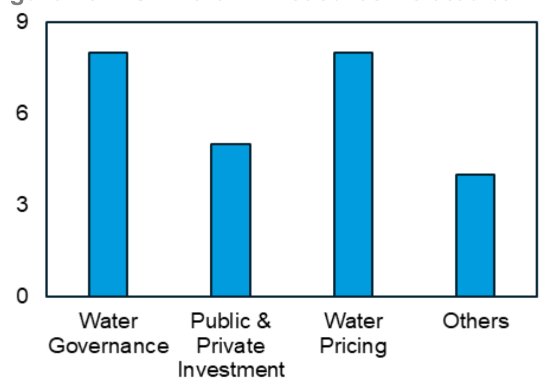
IMF Engagement on Water

The significant macro-fiscal implications of water-related challenges indicates there is a continued role for the IMF. While other development partners are better positioned to finance and implement water infrastructure projects, such as irrigation systems, the economic and budgetary consequences of water scarcity, drought, and mismanagement suggest that the IMF can contribute meaningfully across several key areas and it is already doing so. These include enhancing data collection and sharing to address substantial information gaps; assessing macro-fiscal impacts and quantifying associated fiscal risks; and promoting the integration of water-related constraints and risks into macroeconomic and development planning frameworks. The IMF can also provide technical advice on fiscal instruments to facilitate the efficient allocation of water resources by signaling appropriate investment decisions (for example, in infrastructure and water quality improvements) and encouraging behavioral responses (for example, conservation and efficient usage). In addition, the IMF can support countries in strengthening public investment management systems to ensure effective oversight of water-related investments, reforming water pricing and subsidy regimes, and improving governance structures in the water sector. Increasing water scarcity also presents mounting challenges for public utilities. Expanding water supply services entails rising costs, making it imperative for public utilities to generate adequate revenues, reduce operational losses, and pursue cost-efficiency measures—particularly to safeguard affordability for low-income households.

Moreover, growing drought and water scarcity risks underscore the need for proactive approaches to build resilience and adapt in the face of climate change. Effective drought and water resources management goes beyond water policy and requires coordinated action across sectors. Sustainable land-use, ecosystem restoration, and adaptive agricultural practices can help retain water in the soil, regulate hydrological cycles, and enhance resilience. Vulnerable regions face heightened water risks due to limited adaptive capacity. Strengthening resilience through drought-resistant agriculture, improved water governance, and international cooperation will be critical to mitigating the socio-economic impacts of intensifying droughts. Addressing these challenges demands decisive, coordinated, and forward-looking action across sectors and stakeholders.

The IMF is already supporting water-related reforms in several Resilience and Sustainability Facility (RSF) programs.[66] Out of the 26 RSF programs approved through July 2025, 16 countries include water-related reforms to help build resilience and adapt to climate change (Figure 13). Many of these macro-critical reforms are related to water pricing, with the IMF or other development partners providing capacity development support (for example, Benin, Cabo Verde, Mauritania, and Pakistan). Other water-related reforms cover management and allocation of water resources (for example, Benin, Egypt, Madagascar, Morocco, and the Gambia) and financial sustainability and management (for example, Jordan), with support provided by other development partners. The IMF's Climate Policy Diagnostic has also recommended water pricing policy reforms and governance-related reforms.[67]

Figure 13. RSF Reform Measures Related to Water



Source: IMF Staff Calculations.
Note: *Water Governance* refers to those RMs improving institutional frameworks for management and allocation of water resources including data-sharing. Public & Private Investment refers to those improving or incentivizing public and private investment related to water. *Water pricing* refers to reforms of both urban and rural water supply tariffs. *Others* includes measures such as the use of shock responsive social assistance against drought, etc. Please see Annex V for the full list of water-related RMs.

Conclusions

Water is a foundational input to economic activity, human health, and environmental sustainability, yet its macroeconomic significance remains underappreciated in policy frameworks. This paper demonstrates that water scarcity and drought risk are increasingly macro-critical, with direct and indirect impacts on growth, fiscal balances, and external stability. Global water withdrawals have risen by over 25 percent in the past three decades, driven by population growth, economic expansion, and agricultural demand. Despite improvements in water-use efficiency, almost 50 countries face high water stress, and climate change is intensifying drought conditions across all continents. Agricultural and hydrological droughts are becoming more frequent and severe, with atmospheric evaporative demand increasing by 40 percent since the 1980s.

Water-related shocks can significantly reduce GDP growth, particularly in low-income and water-dependent economies. Estimates in the literature suggest that droughts can lead to GDP losses of up to 3

[66] Water-related reforms have also been included in UCT programs but have primarily been from the angle of improving financial performance of SOEs or adjusting water tariffs to reduce budget subsidies. For example, Jordan's 2024-27 IMF program under the Extended Fund Facility includes a focus on improving the financial sustainability of the water sector given its macro-criticality.
[67] See, for example, IMF Climate Policy Diagnostic reports for Cabo Verde, Honduras, Papua New Guinea, and Sierra Leone.

percentage points in countries like India and China, and 1.4 percentage points in developing economies during key crop-growing months.[68] Fiscal impacts are also substantial: moderate droughts reduce government revenues by 0.5–0.7 percent of GDP in EMDEs, while severe droughts increase expenditure-to-GDP ratios and widen fiscal deficits. Sectoral analysis reveals that agriculture, which consumes 98 percent of blue water in low-income countries, is especially vulnerable, with downstream industries such as food processing and textiles also exposed through inter-industry linkages.

Water-related inefficiencies further exacerbate fiscal vulnerabilities. NRW averages 36 percent globally, with economic losses equivalent to 0.1 percent of global GDP. In EMDEs, subsidies to cover operational and capital costs of water utilities range from 0.35 to 1.95 percent of GDP annually. And at the same time, public spending on water remains low, averaging just 0.6 percent of global GDP, and execution rates are significantly below those of other sectors. Investment needs to ensure the availability and sustainable management of water and sanitation for all and meet the climate adaptation goals are substantial, with low-income countries requiring annual investments of 1.7 percent of GDP for water and sanitation alone.

Given the critical role of water as a factor of production and its growing importance under climate stress, further analytical work is needed to better understand how water-related risks and policies affect macroeconomic outcomes. Future research should explore ways to improve policies and systems to better manage water-related challenges and their broader economic impacts. The following areas highlight important topics for further research and analysis:

- **Integrating water shocks into fiscal risk assessments.** Integrating water shocks into fiscal risk assessments is increasingly important, as events such as droughts, floods, and long-term water scarcity can disrupt economic activity, strain public finances, and undermine macroeconomic stability—particularly in climate-vulnerable and water-stressed economies. More research is needed to develop and refine modeling tools that quantify the fiscal impacts of these shocks on public spending, revenues, and economic performance, and how they contribute to fiscal pressures or contingent liabilities especially in water-dependent sectors like agriculture, energy, and industry.[69] Advancements in artificial intelligence may also be explored as part of the research, focusing on how these technologies can enhance the collection, integration, and analysis of water-related data—from satellite imagery to hydrological and socio-economic indicators—to improve forecasting of water shocks and support timelier, risk-informed fiscal planning and public investment decisions.
- **Balancing efficiency, equity, and sustainability in water pricing reform.** Balancing economic efficiency, financial sustainability, and equity in water pricing is a complex challenge, making it essential to clarify policy priorities. Considerations can be given to address social imbalances through complementary policy instruments, such as well-designed social safety net. The increasing competition for water resources suggests a need for signaling scarcity and creating incentives for using water in an efficient, equitable, and sustainable manner. Water pricing that accounts for externalities can inform efficient allocation and support investments but it also poses equity challenges by increasing costs for vulnerable populations. Setting an economic price that includes not only the direct costs of supply and

[68] Whereas water scarcity and drought risk in general affect macroeconomic outlook negatively, there is also emerging evidence that investment to improve water use efficiency may be associated with positive macroeconomic growth in selected countries. Using data related to NRW from urban water utility companies in Sub-Sahara African countries, an empirical analysis finds that a 1 percentage point increase in NRW (that is, lower efficiency) correlates with a cumulative effect over a 3-year horizon of -0.17 percentage points and -0.11 percentage points, for GDP and productivity growth, respectively (see Annex IV).

[69] Existing IMF's modeling tools related to this topic includes the Quantitative Climate Risk Assessment Fiscal Tool (Q-CRAFT) and the Debt-Investment-Growth and Natural Disasters (DIGNAD) model.

infrastructure but also the externalities —such as pollution, overuse, or health impacts— is complex due to data gaps, the complexity of quantifying environmental and social externalities and the sensitivity of the size of the externality to the local context. At the same time, analytical research could focus on methodologies to estimate the economic cost of water, draw lessons from water-stressed countries that have implemented economic pricing frameworks, and include distributive impact analysis to assess the feasibility, equity implications, and political and social acceptance of pricing reforms (Box 4).

- **Adaptive water governance in climate-stressed countries.** Water governance is a prerequisite for effective water management and is essential for mitigating the impacts of climate change on water resources. It is also macro-critical, as weak water governance can affect economic growth, public finances, and poor and vulnerable groups. A potential area for analytical research is the assessment of how water governance systems can adapt to climate change through legal, financial, and policy frameworks that are conducive to sound water management. In particular, research could examine the experience of climate-vulnerable and water-stressed countries that have strengthened their capacity to manage water sustainably, identifying key governance functions they have established or enhanced and assessing through which channels these functions have supported growth and macro-stability (Box 5).

Box 4. Integrated Approach to Water Pricing

Well-designed water pricing policy helps allocate water more efficiently by providing the right signals for investment (e.g., in water supply infrastructure) and behavioral responses (e.g., water conservation), while addressing equity concerns. While there are debates on specific design features of water pricing policy, it is widely accepted in the literature and among policy practitioners that water price should be reflective of financial costs of water supply, the scarcity of water, and external costs of water use (Rogers et al 2002; Wheeler et al 2023; OECD 2023; Zetland 2021; Andres et al 2021).

Water scarcity and externalities justify public interventions and suggest economic cost pricing of water. To provide a conceptual framework, assume that water resources can be abstracted from multiple sources (e.g. groundwater, surface water, ocean) and may be used directly at source or involve different water supply sectors (e.g. water utilities, irrigation systems, desalination and/or reclamation processes). Denote p_e as the efficient price of water—the economic cost per unit of water use at a specific time and location/country:

$$p_e = \sum_i w_i * r_i + \sum_i e_i(c_i) + \sum_j w_j * s_j + \sum_j e_j(c_j) + t + \sum_{i,j} S_{i,j}$$

Where,
r = unit cost of water resource abstraction from source i (i = groundwater, river, lake, ocean…)
s = unit cost of water supply process j (j = utility, irrigation, desalination, reclamation, rainwater harvesting…)
e = shadow price reflecting scarcity and externalities of water abstraction from source i or from water supply process j; assuming that $e'(c)$ > 0 and convex (potentially integrating climate impacts on water scarcity)
c = consumption/abstraction of water from source i or supply process j
w = weight associated with abstraction from source i or supply process j
t = unit cost of water transmission and distribution
S = unit producer subsidy to abstraction from source i or water supply process j

The above equation illustrates how a package of fiscal instruments can be deployed to improve allocation efficiency across the water value chain. Fiscal policy has a role to play in:

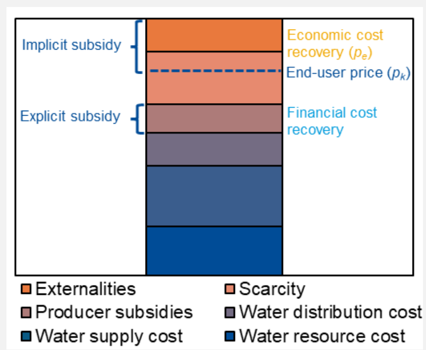
1) Setting appropriate prices/cost structure for resource abstraction, r, and for water supply sectors, s, considering associated external costs, e;
2) Providing the right incentives and/or targeted subsidies, S, for certain water supply sectors; and
3) Establishing end-use water tariff, p_k, at the level that fully recovers the economic cost of water, p_e.

Box 4. Integrated Approach to Water Pricing (Continued)

While p_e provides an aggregate measure of the economic cost of water across the value chain in an integrated manner, the same framework can be applied to specific sub-sectors, e.g., in an irrigation scheme, groundwater, or urban water supply. The Figure illustrates a hypothetical case where $p_e > p_k$ indicating the existence of implicit and explicit subsidies. Here, the producer recovers financial costs, but the end-user price does not internalize the scarcity and externalities. When $p_e = p_k$, end-user price is set at the efficient price, allowing full economic cost recovery.

Valuing water scarcity and externalities are key elements of establishing an efficient water price. Numerous studies have estimated the scarcity value of water. The central estimate of the shadow prices of water used for irrigation is US\$0.50/m^3, US\$1.45/m^3 for domestic use in urban areas, and US\$15.54/m^3 for industrial use, based on around 30 studies surveyed by this paper. The process of water abstraction and production often results in environmental damages, such as water contamination and discharge of pollutants. There is an emerging literature on the externalities associated with water use. A meta-analysis of about 200 studies suggests that the global economic value of groundwater quality is US\$518 per hectare per annum on average (Brouwer and Neverre 2020). The cost of water pollution in the European Union is expected to be as high as US\$12 per kilogram per year of nitrogen and phosphorus pollution (EC 2021).

Measuring Economic Cost of Water and Water Subsidy



Source: IMF staff.

Box 5. Water Governance in the Context of Climate Change

Why water governance matters? Water governance refers to the institutions, legal frameworks, policies, and decision-making processes that determine how water is allocated, accessed, and managed. It shapes who participates in decisions, how conflicts over competing demands are resolved, and how resources are distributed across sectors and regions. As climate change exacerbates water demand-supply imbalances, effective governance becomes essential to ensure effective coordination, equitable access, and informed planning and decision-making.

Challenges in water governance. The multi-level governance of water management, both across sectors and level of government, presents already challenges to water management - climate change adds further complexity. Water governance is often undermined by fragmented institutional responsibilities, leading to overlapping jurisdictions that undermine effective water resource management and service delivery. Mismatches between administrative and hydrological boundaries, and poor coordination across social and productive sectors on allocation and use of water resources further undermine its effective management. In terms of resource allocation management, long-term planning is challenged by uncertainty in future water availability, shifting demand patterns, and the need to balance short-term needs with sustainable, climate-resilient investments. While decentralization enables local governments to make decisions tailored to local context, there are often capacity gaps, making it difficult to deliver services effectively. In transboundary context, where over 260 river basins are shared by two or more countries, weak cooperation frameworks can lead to conflicts over water allocation, pollution control, and infrastructure development. Climate change could further intensify this, affecting water quality, quantity, and availability.

Elements for effective water governance. The complexity of water management requires integrated, context-specific approaches, stakeholder collaboration, and robust policy frameworks. At the national level, governments need to establish clear institutional arrangements across national, regional, and local levels, empower authorities to monitor and enforce rules, and foster coordination among sectors such as agriculture, energy, natural resources, health, and the environment. Regional cooperation is equally critical—particularly in shared river basins—to harmonize standards, implement agreements, and provide incentives for upstream and downstream users to collaborate. Using climate and water data to guide planning and response, ensuring stakeholder participation, and tailoring governance responses to local realities are all vital for building a resilient and sustainable water management system.

Source: WAREG (2023), OECD (2013), Global Commission on the Economics of Water (2024), Global Water Partnership (2015), Fuje. et al. (2023), Jiménez et al. (2020).

Annex I. Definitions

Below lists key terms relevant to water scarcity and drought:

- *Physical water scarcity*, is the "mismatch between the demand for fresh water and its availability, quantified in physical term" and is often used interchangeably with the term *water stress*.[1] It is most often measured as "the ratio of demand and availability, accounting for environmental flow requirements".[2]
- *Economic water scarcity* is distinguished from physical water scarcity and is defined as "human, institutional, financial capital limit access to water, even though water in nature is available".[3]
- *Drought* is generally defined as "drier than normal conditions. That is, a moisture deficit relative to the average water availability at a given location and season".[4] However, there are various forms of drought to be distinguished between:
    - *Meteorological droughts* where "precipitation is below normal for an extended period of time"[5];
    - *Agricultural droughts* are "plant stress from a combination of evaporation and low soil moisture" and triggered by *meteorological droughts*[6]; and
    - *Hydrological droughts* which occur as a result of below normal "runoff, streamflow, and reservoir storage".[7]

Also, two types of water are distinguished in this paper:

- *Blue water*, which includes "rivers, lakes, reservoirs, and renewable groundwater stores"[8]; and
- *Green water*, which includes "terrestrial precipitation, evaporation, and soil moisture."[9]

Further, this paper distinguishes two primarily types of water use, namely:

- *Consumptive use:* also referred to as water consumption. It is "the part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not available for immediate use. Water returned to a different watershed than the point of withdrawal (interbasin transfer) is ***not*** considered a consumptive use."[10]
- *Non-consumptive use*: it is a type of water use which "does not substantially change the withdrawn water, almost all of it returning to the system.[11] Also most in-stream water uses are non-consumptive. include activities such as recreational use of water bodies, in-stream uses water for cooling, navigation, etc.

[1] Caretta et al. (2022), p. 560.
[2] Ibid.
[3] Ibid. Unless explicitly stated, we will use water scarcity to refer to physical water scarcity.
[4] Douville et al. (2022), p. 1157.
[5] Ibid.
[6] Ibid.
[7] Ibid.
[8] Wang-Erlandsson et al. (2022), p. 380.
[9] Ibid, p. 280.
[10] Water-Use Terminology | U.S. Geological Survey
[11] FAO (2010) Disambiguation of water statistics

Annex II. Classification of Countries

Country	Income group	water stress	Regional group 1: UN	Regional group 2: WB
Afghanistan	Low Income	High water stress	Central and Southern Asia	South Asia
Albania	Middle Income	High water stress	Europe and Northern America	Europe & Central Asia
Algeria	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Angola	Middle Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Argentina	Middle Income	Mid water stress	Latin America and the Caribbean	Latin America & Caribbean
Armenia	Middle Income	Mid water stress	Northern Africa and Western Asia	Europe & Central Asia
Australia	Advanced Economies	Mid water stress	Australia/New Zealand	East Asia & Pacific
Austria	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Azerbaijan	Middle Income	Mid water stress	Northern Africa and Western Asia	Europe & Central Asia
Bahrain	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Bangladesh	Low Income	Mid water stress	Central and Southern Asia	South Asia
Belarus	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Belgium	Advanced Economies	High water stress	Europe and Northern America	Europe & Central Asia
Belize	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Benin	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Bhutan	Low Income	Low water stress	Central and Southern Asia	South Asia
Bolivia	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Bosnia and Herzegovina	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Botswana	Middle Income	High water stress	Sub-Saharan Africa	Sub-Saharan Africa
Brazil	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Brunei Darussalam	Middle Income	Low water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Bulgaria	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Burkina Faso	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Burundi	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Cambodia	Low Income	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Cameroon	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Canada	Advanced Economies	Low water stress	Europe and Northern America	North America
Central African Republic	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Chad	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa

Chile	Middle Income	High water stress	Latin America and the Caribbean	Latin America & Caribbean
China	Middle Income	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Colombia	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Costa Rica	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Côte d'Ivoire	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Croatia	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Czech Republic	Advanced Economies	Mid water stress	Europe and Northern America	Europe & Central Asia
Cyprus	Advanced Economies	High water stress	Northern Africa and Western Asia	Europe & Central Asia
Denmark	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Djibouti	Low Income	Mid water stress	Sub-Saharan Africa	Middle East & North Africa
Dominican Republic	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Democratic Republic of the Congo	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Ecuador	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Egypt	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
El Salvador	Middle Income	Mid water stress	Latin America and the Caribbean	Latin America & Caribbean
Equatorial Guinea	Middle Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Eritrea	Low Income	High water stress	Sub-Saharan Africa	Sub-Saharan Africa
Estonia	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Ethiopia	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Finland	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
France	Advanced Economies	Mid water stress	Europe and Northern America	Europe & Central Asia
Gabon	Middle Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Gambia, The	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Georgia	Middle Income	Low water stress	Northern Africa and Western Asia	Europe & Central Asia
Germany	Advanced Economies	Mid water stress	Europe and Northern America	Europe & Central Asia
Ghana	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Greece	Advanced Economies	High water stress	Europe and Northern America	Europe & Central Asia
Guatemala	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Guinea	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Haiti	Low Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Honduras	Low Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Hungary	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Iceland	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia

India	Middle Income	High water stress	Central and Southern Asia	South Asia
Indonesia	Middle Income	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Iran	Middle Income	High water stress	Central and Southern Asia	Middle East & North Africa
Iraq	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Ireland	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Israel	Advanced Economies	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Italy	Advanced Economies	High water stress	Europe and Northern America	Europe & Central Asia
Jamaica	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Japan	Advanced Economies	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Jordan	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Kazakhstan	Middle Income	Mid water stress	Central and Southern Asia	Europe & Central Asia
Kenya	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Kuwait	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Kyrgyz Republic	Low Income	Mid water stress	Central and Southern Asia	Europe & Central Asia
Lao P.D.R.	Low Income	Low water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Latvia	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Lebanon	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Liberia	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Libya	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Lithuania	Advanced Economies	Mid water stress	Europe and Northern America	Europe & Central Asia
Luxembourg	Advanced Economies	Mid water stress	Europe and Northern America	Europe & Central Asia
North Macedonia	Middle Income	Mid water stress	Europe and Northern America	Europe & Central Asia
Madagascar	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Malawi	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Malaysia	Middle Income	Low water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Mali	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Mauritania	Low Income	Mid water stress	Sub-Saharan Africa	Sub-Saharan Africa
Mexico	Middle Income	High water stress	Latin America and the Caribbean	Latin America & Caribbean
Moldova	Low Income	Low water stress	Europe and Northern America	Europe & Central Asia
Mongolia	Middle Income	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Morocco	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Mozambique	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Myanmar	Low Income	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Namibia	Middle Income	High water stress	Sub-Saharan Africa	Sub-Saharan Africa
Nepal	Low Income	Mid water stress	Central and Southern Asia	South Asia
Netherlands	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia

New Zealand	Advanced Economies	Low water stress	Australia/New Zealand	East Asia & Pacific
Nicaragua	Low Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Niger	Low Income	High water stress	Sub-Saharan Africa	Sub-Saharan Africa
Nigeria	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Norway	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Oman	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Pakistan	Middle Income	High water stress	Central and Southern Asia	South Asia
Panama	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Papua New Guinea	Low Income	Low water stress	Oceania (excluding Australia and New Zealand)	East Asia & Pacific
Paraguay	Middle Income	Low water stress	Latin America and the Caribbean	Latin America & Caribbean
Peru	Middle Income	High water stress	Latin America and the Caribbean	Latin America & Caribbean
Philippines	Middle Income	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Poland	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Portugal	Advanced Economies	Mid water stress	Europe and Northern America	Europe & Central Asia
Qatar	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Congo, Republic of	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Romania	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Rwanda	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Saudi Arabia	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Senegal	Low Income	Mid water stress	Sub-Saharan Africa	Sub-Saharan Africa
Sierra Leone	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Slovak Republic	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Slovenia	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Somalia	Low Income	Mid water stress	Sub-Saharan Africa	Sub-Saharan Africa
South Africa	Middle Income	High water stress	Sub-Saharan Africa	Sub-Saharan Africa
Korea	Advanced Economies	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Spain	Advanced Economies	High water stress	Europe and Northern America	Europe & Central Asia
Sri Lanka	Middle Income	Mid water stress	Central and Southern Asia	South Asia
Sudan	Low Income	Low water stress	Northern Africa and Western Asia	Sub-Saharan Africa
Sweden	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Switzerland	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
Syria	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Tajikistan	Low Income	Mid water stress	Central and Southern Asia	Europe & Central Asia
Tanzania	Low Income	Mid water stress	Sub-Saharan Africa	Sub-Saharan Africa
Thailand	Middle Income	High water stress	Eastern and South-Eastern Asia	East Asia & Pacific

Togo	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Tunisia	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Türkiye	Middle Income	High water stress	Northern Africa and Western Asia	Europe & Central Asia
Turkmenistan	Middle Income	High water stress	Central and Southern Asia	Europe & Central Asia
Uganda	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Ukraine	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
United Arab Emirates	Middle Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
United Kingdom	Advanced Economies	Low water stress	Europe and Northern America	Europe & Central Asia
United States	Advanced Economies	Mid water stress	Europe and Northern America	North America
Uruguay	Middle Income	Mid water stress	Latin America and the Caribbean	Latin America & Caribbean
Russia	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Uzbekistan	Low Income	High water stress	Central and Southern Asia	Europe & Central Asia
Venezuela	Middle Income	Mid water stress	Latin America and the Caribbean	Latin America & Caribbean
Vietnam	Low Income	Mid water stress	Eastern and South-Eastern Asia	East Asia & Pacific
Yemen	Low Income	High water stress	Northern Africa and Western Asia	Middle East & North Africa
Serbia	Middle Income	Low water stress	Europe and Northern America	Europe & Central Asia
Zambia	Low Income	Low water stress	Sub-Saharan Africa	Sub-Saharan Africa
Zimbabwe	Low Income	Mid water stress	Sub-Saharan Africa	Sub-Saharan Africa

Note: Regional group 1 is applied to figure 2; Regional group 2 is applied to figures 9-13.

Annex III. Methodology for Input-Output Analysis

We conducted the global sectoral input-output (IO) analysis to measure blue and green water consumption, respective water intensity, and other variables. The IO analysis, initially developed by Leontief, is an important tool to understand the interdependence of industries. A multi-regional input-output (MRIO) method covers the relationships between industries of several economies.

We used the multi-region multi-sector input-output Eora database (https://worldmrio.com/) as the main data source. The Eora database is a global database, covering 186 countries in the world, each region, as well as satellite data of blue, green and grey water consumption. For ease of interpretation, we estimated 26-industry models.

To understand the pattern of blue water consumption and intensity, we adopted the MRIO model as described by Zhang et al (2011). In addition to monetary trade, water consumption and water intensity are the primary input into the MRIO model, and the water interdependence of industries can be reflected via the Leontief matrix calculation namely:

$$X_i = \sum_{j=1}^{n} x_{ij} + y_i$$

$$X = AX + Y$$

$$X = (I - A)^{-1}\, Y$$

Where X_i is the gross economic output of industry i; n is total number of industries; x_{ij} records the outputs from industry i to industry j; y_i is the final demand of industry i. X is the vector of total outputs; A represents the technical coefficients matrix; and Y records the vector of final demands. After solving X, we can obtain our Leontief inverse matrix $(I - A)^{-1}$.

We define blue water intensity as blue water consumption by one monetary unit of production. Specifically, by dividing blue water consumption by total production by industry for a country, we calculate direct water intensity as:

$$direct_i = \ water\ consumption_i / X_i.$$

To trace the upstream indirect water consumption, we use the Leontief matrix to calculate the gross water consumption as:

$$gross_i = \sum direct_i \times (I - A)^{-1}$$

Where indirect water intensity can be defined as $indirect_i = gross_i - direct_i$.

Annex IV. The Macroeconomic Linkages of Water Utilities' Operational Efficiency in Sub-Saharan Africa: Patterns and Correlations

We use data on a Water Supply and Sanitation (WSS) database compiled as part of the Africa Infrastructure Country Diagnostic (AICD). The database collects primary data on institutional development and sector performance in 50 water utilities companies that operate in the urban water space across countries in Sub-Saharan Africa over 1995-2007.[1] Representation is high because the largest utilities—those that contribute to the bulk of residential connections—were chosen for each country. Overall, representation is on average 65 percent of urban households. While most utilities primarily serve urban areas, some extend their services nationwide, including to rural populations. Water consumption is defined as the total volume of water sold to customers (by customer type) m3/year, and Water production as the Total volume of water into supply (including volume produced and purchased from a bulk supplier) m^3/year. The average NRW is 32 percent, with an interquantile range between 20 and 40 percent of water losses, and the average annual changes at around 0.4 percentage points (p.p.) and an interquantile range between -2.4 and 1.6 p.p.[2]

Our analytical approach involves assessing the dynamic impacts of the water operational efficiency of utility companies, defined as non-revenue water, on macroeconomic outcomes. We employ Jorda's (2005) local projections methodology within a panel data framework, estimating the following equation:

$$\Delta\, y_{i,t+h} = \alpha_{ut,i} + \alpha_t + \theta_h \Delta NRW_{ut,i,t} + \beta(L)\Delta NRW_{ut,i,t-1} + \gamma(L)\,\Delta\,(X_{i,t-1}) + \delta(L)\Delta y_{i,t-1} + \mu_{i,t}$$

where $\Delta\, y_{i,t+h} = (y_{i,t+h} - y_{i,t-1})$ represent the cumulative log change in real GDP and RTFP (real total factor productivity at constant national prices) in country *i* from the World Bank's World Development indicators and the Penn World Tables, respectively. $\Delta NRW_{ut,i,t}$ denotes the change in non-revenue water in utility company *ut* in country *i* and year *t*, calculated as the ratio of water consumption sold by the utility company to water production by the utility company, multiplied by 100. The coefficients of interest are θ_h that captures the macroeconomic effects of water operational efficiency at horizons h=0,1,2,3. The data used includes 21 utility companies in 14 Sub-Saharan African countries over 1995-2007 with at least 3 non-missing observations.[3] To address potential concerns and enhance the robustness of our analysis, we include several time-varying control variables. Specifically, we incorporate lagged terms for non-revenue water to mitigate issues related to serial correlation and the persistence of water inefficiencies changes over time. Additionally, the model controls for the lagged values of utility's water (paid) consumption growth and water production growth and the share of the population served by the water utility company, to control for time-varying consumption and production patterns and relative weight of the provider in the country and allow us to focus on the operational efficiency of water and sanitation providers. Other country-level controls, denoted by $\Delta\,(X_{i,t-1})$, with L=1, include agricultural value-added growth, agriculture/GDP ratio, the employment share of agriculture, and the log of GDP per capita

[1] For the macroeconomic data, real GDP, real Agriculture, forestry, and fishing value added, agriculture/GDP, and the employment share of agriculture, we use data from the World Bank's World Development Indicators.

[2] The distribution of NRW in the region is similar to the findings in Liemberger and Wyatt (2019), which provides a snapshot of the NRW, and therefore we are not able to use this data to estimate the dynamic effects of changes in NRW on GDP or productivity.

[3] Similar results are obtained when we construct the weighted non-revenue water at national level and run the same specification at country level with country fixed effects, instead of utility fixed effects.

in PPP terms. These controls are intended to capture the past behavior of aggregate demand (higher growth can lead to higher water demand), the time-variant heterogeneous structure of the economy (the higher the agricultural sector, a water intensive sector, may lead to larger effects of changes in water efficiency), and the level of development and adaptation capacity of each country that may affect how water efficiency affects GDP and productivity growth. Lastly, we control for the contemporaneous and lagged change in precipitations to control for natural water availability that can affect both, water production and water consumption.[4] Furthermore, to account for heterogeneity across countries and time periods, we include utility and time fixed effects that controls for time-invariant utility characteristics (institutional setting, utilities' water management policies, among others) and common climate and macroeconomic shocks in the region. Exploiting the unbalanced panel nature of the dataset allows us to capture cross-country variation in the operational efficiency of water and sanitation services providers and time variation over the specified sample period.

Table AIV.1 presents the ordinary least squares (OLS) results. Column (1) indicates that a 1 percentage point (p.p.) increase in NRW (i.e., lower efficiency) correlates with an immediate reduction in GDP and TFP growth by nearly 0.07 and 0.03 p.p., respectively, though this is not statistically significant.[5] Column (2) shows that after a year, this effect accumulates to a statistically significant decline of about 0.15 p.p. and 0.16 p.p., respectively. Lastly, the cumulative effect at the 3-year horizon is -0.17 p.p. and -0.11 p.p., for GDP and productivity growth, respectively. In other words, a one standard deviation increase in the change of NRW is correlated with a 1-year reduction in GDP growth of approximately 0.9 p.p. and 1 p.p. for TFP growth. In conclusion, this paper provides suggestive evidence that operational inefficiencies in water and sanitation provision are associated with GDP and productivity losses.

Table AIV.1. The Effects of Water Efficiency on GDP Growth and Productivity

	Impact effect	1-year effect	2-year effect	3-year effect
Output	(1)	(2)	(3)	(4)
GDP	-0.072	-0.148**	-0.066*	-0.168**
Coeff. (s.e.)	(0.087)	(0.055)	(0.035)	(0.061)
RTFP	-0.028	-0.160**	-0.038	-0.109***
Coeff. (s.e.)	(0.081)	(0.060)	(0.071)	(0.036)

Note: The table reports the coefficient θ_h from the estimated regression:

$$\Delta\, y_{i,t+h} = \alpha_{ut,i} + \alpha_t + \theta_h \Delta NRW_{ut,i,t} + \beta(L)\Delta NRW_{ut,i,t-1} + \gamma(L)\, \Delta\, (X_{i,t-1}) + \delta(L)\Delta y_{i,t-1} + \mu_{i,t}$$

where $\Delta\, y_{i,t+h} = (y_{i,t+h} - y_{i,t-1})$ represent the cumulative change in real GDP and RTFP in country *i* (real total factor productivity at constant national prices). $\Delta NRW_{ut,i,t}$ denotes the change in non-revenue water in utility *ut* in country *i* and year *t*, calculated as the ratio of water consumption sold by the utility company to water production by the utility company, multiplied by 100. The data includes 21 utility companies in 14 Sub-Saharan African countries over 1995-2007 with at least 3 non-missing observations. X includes controls, such as the share of population served by the utility company, lagged growth of utility's water consumption and production, primary sector value-added growth, the agricultural share in GDP, agricultural employment share, change in precipitations, and log of GDP per capita in PPP terms. $\alpha_{ut,i}$ and α_t are utility and time fixed effects. Standard errors are clustered at the utility level. *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels.

[4] For precipitation data, we use Massetti and Tagklis (2024).

[5] A note of caution on estimated impacts as, by definition, a 1 p.p. increase in non-revenue water does not have a uniform interpretation—it may stem from leakages, poor infrastructure, or theft, each of which may have different economic consequences.

However, these findings should be interpreted with caution. The analysis undertaken in this paper does not prove causality and only establish correlations. The empirical model does not fully address potential endogeneity, and changes in non-revenue water (NRW) may themselves be endogenous to economic conditions. As such, the interpretation of NRW changes as exogenous shocks should be treated with caution. The observed relationship between utilities' operational efficiency and GDP/TFP growth may be partially driven by unobserved factors, such as underlying infrastructure quality or governance effectiveness. Additionally, economic outcomes may be influenced by reverse causality (that is, economic downturns could reduce investment in water infrastructure or increase theft, leading to higher non-revenue water, rather than inefficiencies causing slower growth), omitted factors (e.g., unobserved institutional factors, such as governance and regulatory capacity, might influence both operational efficiency and macroeconomic performance), and data limitations (for example, the accuracy of metering and billing systems may affect the reported non-revenue water ratio, potentially leading to misclassification of efficiency losses). These limitations underscore the correlational nature of the findings and the need for further research to establish causal pathways.

Annex V. RSF Reform Measures on Water

Country	Reform Measure (RM)	Classification
Barbados	Adopt a set of measures consisting of: (i) Government to approve the Planning and Development Act to improve the climate resilience of roads through improved drainage and other interventions; (ii) Government to table in parliament the Water Re-use Bill, incorporating the new water re-use policy; (iii) Government to fully operationalize the National Environmental and Conservation Trust.	Others
Benin	Institutionalize a mechanism for water tariffication in urban areas based on the following parameters: (i) a tariff study; (ii) a transparent tariff structure in conformity with international good practices; and (iii) a financial equilibrium model.	Water Pricing
Benin	(1) Adopt a revised decree of the National Water Council, which would include a mandate to monitor groundwater and surface water resources and equip the Council with sufficient human and financial resources to discharge its mission; and (2) Realize a strategic groundwater assessment and have the National Water Council supervise and validate this assessment.	Water Governance
Cabo Verde	To support reform initiatives, which will require substantial infrastructure investment the government will, (i) determine the cost-recovery rate for the provision of water (fully reflecting operational and capital cost), (ii) identify any discrepancy between the existing tariff and so defined cost recovery, (iii) undertake a distributional impact assessment, and (iv) publish and adopt regulations establishing a methodology for adjusting water tariffs to the identified cost-recovery rate, to be applied by the regulator (thereby achieving full cost recovery) by the test date, with transparent periodic adjustments, and/or by financing infrastructure investment transparently from the budget, with a view to ensure sustainability of the water sector. (National Water and sanitation Agency (ANAS) and MoF)	Water Pricing
Côte d'Ivoire	Establish a system for tagging of climate-related investment expenditure and integrate and publish it with the climate budget statement. Adopt a ministerial arrêté establishing a system for tagging climate related investment expenditure at the stage of public investment programming, then integrate this system into the 2026 budget preparation process with coverage initially limited to five (5) ministries including those in charge of energy, agriculture, environment and sustainable development, hydraulique et assainissement, and water and forests. Prepare and publish on this basis a first climate budget statement attached to the 2026 budget law, presenting the climate-related investment expenditure expected for these entities.	Public & Private Investment
Egypt	Authorities to establish the National Water Council through a Prime Ministerial decree, chaired by the Prime Minister and including key ministers and stakeholders from MALR, MWRI, MHUUC, MoE, MPEDoIC, which will: (1) oversee the generation, sharing, and publication of data on water demand and supply by sector/subsector/region and analysis to support informed decisions on water allocation by June 2026; (2) introduce a formal process to be defined in the first review for water allocation among sectors/regions to manage conflicting demands on water resources at the policy and project planning stage, in line with best international practices, by August 2026	Water Governance

Jordan	To address the operational and financial challenges facing Yarmouk Water Company (YWC), the government will pursue the engagement of a qualified and cost effective firm to manage and improve water and wastewater service delivery within YWC's jurisdiction, by concluding a performance based management contract tender, in line with international best practices, with fixed and variable fees linked to jointly agreed annual targets for key performance indicators, including water sales, non-revenue water reduction, energy efficiency, operational income, and billing collections.	Public & Private Investment
Jordan	Cabinet to adopt and publish an updated Water Sector Financial Sustainability Roadmap (FSR), revised in line with international best practices, to ensure the financial sustainability of the sector, as well as adequate and equitable water delivery across Jordan. The new FSR will update all underlying pillars and model assumptions, factoring in the impact of the additional water supply from the AAC and maintaining an annual NRW reduction target of at least 2 percentage points. The FSR will include a policy framework for 2026–2042, with implementation starting in early 2027, to ensure that revenues are sufficient to achieve water and wastewater services operational and maintenance (O&M, including O&M cost of BOT projects) cost recovery by 2032, and to achieve full recovery of both O&M and BOT capital charges by 2042.	Water Pricing
Jordan	Government to launch tenders for the operations and management of a duration of at least 5 years for wastewater treatment plants in a competitive and transparent manner, covering at least 50 percent of total treatment capacity (excluding As-Samra), with the aim of reaching 35 percent of treated wastewater usage for irrigation relative to freshwater by 2027.	Public & Private Investment
Kenya	National Treasury to adopt priority fiscal incentives in agriculture, water, and land management sectors, as listed in the draft National Green Fiscal Incentive Policy Framework.	Public & Private Investment
Madagascar	Water governance. Approve in Cabinet a bill to update the 1998 Water Code, with a view to integrating climate change in the overall water policy and reinforcing the overall policy framework for Integrated Water Resource Management (IWRM), including by strengthening the National Authority for Water and Sanitation's (ANDEA) institutional framework.	Water Governance
Mauritania	The Council of Ministers will adopt a decree to institutionalize the national social safety net program Tekavoul, including the climate shock-responsive cash transfer component (Takavoul choc). GoM will expand the Takvoul choc component to vulnerable households affected by drought while ensuring cover adequate funding.	Others
Mauritania	The Ministry of Water and Sanitation and the Ministry of Environment will sign an interministerial partnership agreement (PA) on areas of cooperation (environmental assessments, enforcement, data management, monitoring of groundwater-dependent ecosystems (GDEs) and other hydrogeological data) and implement the agreement overseen by a technical committee, created as part of the PA.	Water Governance
Mauritania	The Ministry of Water and Sanitation will revise and publish the water tariff regulations (2007 Order no2624/MHETIC/MCI) in line with IMF recommendations.	Water Pricing
Mauritania	The Ministry of Water and Sanitation and the Ministry of Environment will (i) adopt an inter-ministerial order on environmental assessments and monitoring of water resources, informed by the experience of the partnership agreement and (ii) publish a pilot joint inventory of GDEs and hydrogeological data on the Boulenoir aquifer.	Water Governance

Morocco	The Ministry of Economy and Finance will mitigate the impact on the population from measure RM11 by expanding cash transfers under the new Unified Social Registry and helping farmers replace gas butane with solar pumps in small fields irrigation.	Others
Morocco	The Ministry of Water and Equipment will submit to the Inter-Ministerial Water Commission a study that assesses the actual cost of water and presents principle of cost recovery that could inform a tariff-setting methodology based on international benchmarks. The Ministry of Water and Equipment will also adopt two ministerial decrees for the implementation of the Water Law (36-15) so as to reinforce the protection of groundwater resources (the decree on the protection and prohibition perimeters; and the decree on immediate, close or distant protection perimeters).	Water Pricing
Niger	Government to publish flood and drought risk assessments in key exposed areas on the National DRM Data Platform: www.risques-niger.ne	Others
Pakistan	Adoption and implementation of the e-Abiana irrigation service charge collection system by the irrigation authorities of Sindh, Khyber-Pakhtunkhwa, and Balochistan	Water Pricing
Pakistan	Introduce an irrigation water tariff adjustment mechanism in Punjab and Sindh with the aim to recover the operational and maintenance costs of irrigation infrastructure	Water Pricing
Rwanda	MINECONFIN to adopt a green taxonomy adapted to Rwanda's NDC covering seven sectors of the economy (agriculture, energy, construction, transportation, manufacturing, wastewater, management, and ICT)	Public & Private Investment
Senegal	Approve an inter-ministerial decree that defines the roles and responsibilities and the procedures allowing each actor to assume their role and responsibilities for water, including the steps to take to be accountable for their actions.	Water Governance
Tanzania	Present and implement a long-term power sector plan that is aligned with climate mitigation goals and coordinated with the long-term plans of other sectors, including water and agriculture.	Water Governance
Tanzania	Identify and integrate climate policy-related key performance indicators (KPIs) in the existing conditional tariff structure and business plans of the water utilities.	Water Pricing
The Gambia	The Ministry of Fisheries and Water Resources to issue regulations for licensing procedures that will effectively control groundwater abstraction and impoundment, in accordance with good international practices.	Water Governance

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