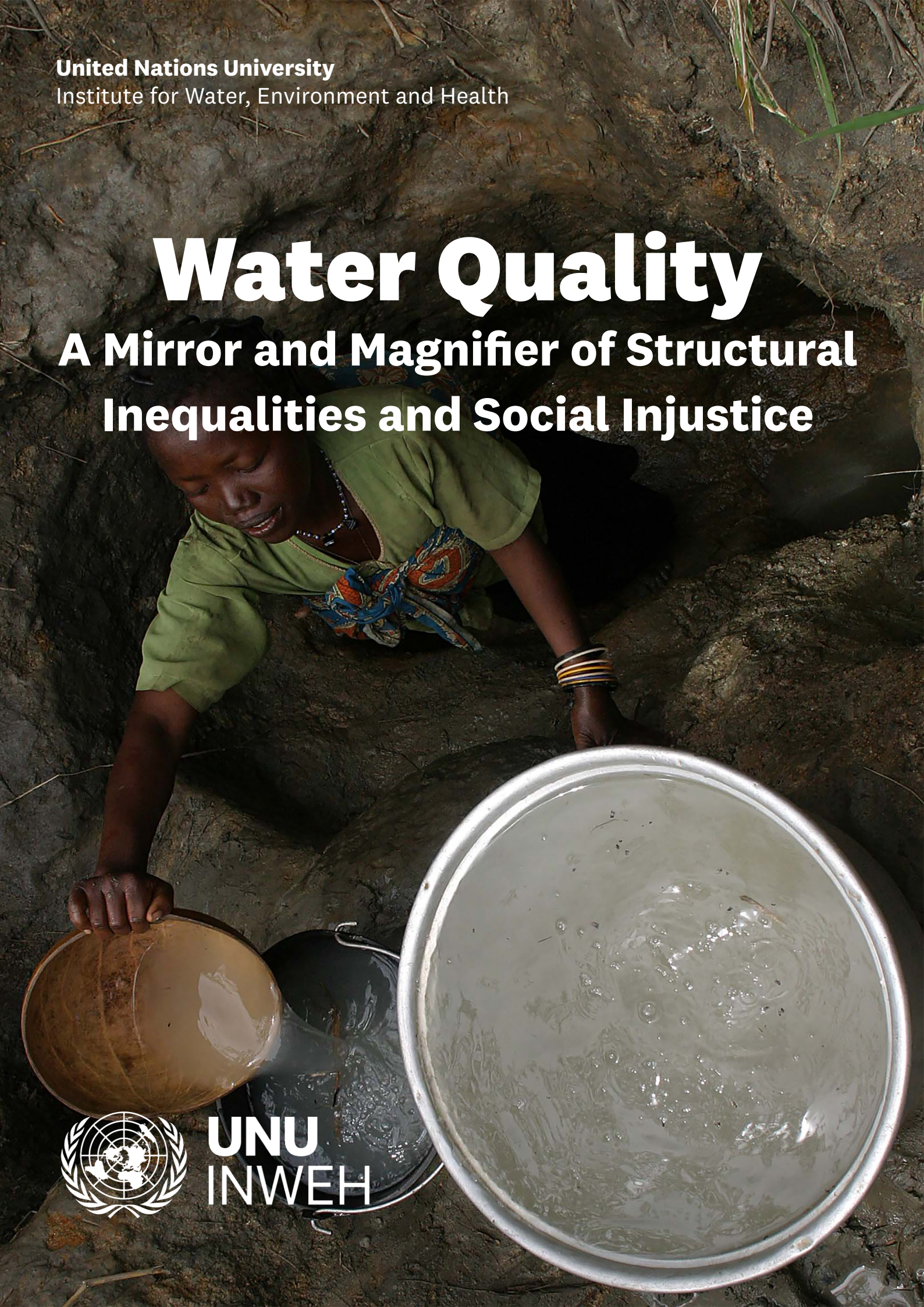
United Nations University
Institute for Water, Environment and Health

Water Quality

A Mirror and Magnifier of Structural Inequalities and Social Injustice



UNU INWEH



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The United Nations University Institute for Water, Environment and Health (UNU-INWEH) is one of 13 institutions comprising the United Nations University (UNU), the academic arm of the United Nations. Established in 1996 through an agreement with the Government of Canada, UNU-INWEH is headquartered in the City of Richmond Hill, Ontario.

UNU-INWEH specializes in addressing critical global security and development challenges at the intersection of water, environment, and health. Through research, capacity development, policy engagement, and knowledge dissemination, the institute bridges the gap between scientific evidence and the practical needs of policymakers and UN member states, with particular attention to low- and middle-income countries. By collaborating with a diverse array of partners—including UN agencies, governments, academia, the private sector, and civil society—UNU-INWEH develops solutions that advance human security, resilience, and sustainability worldwide.

Water Quality

A Mirror and Magnifier of Structural Inequalities and Social Injustice

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Authors:

Grace Oluwasanya
Ayodetimi Omoniyi
Mir Matin
Reem Abu Shomar
Kaveh Madani

Front cover image: A woman collecting water from a scoop hole in Africa. Photo by hdptcar retrieved from Wikimedia.

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**United Nations University Institute
for Water, Environment, and Health
Richmond Hill, Canada, 2026**

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This scene of communal water collection in Rajasthan highlights the reliance on a public water source and how water quality reflects governance choices and the extent of infrastructure. Inequities become most visible where communities depend on limited, shared systems to meet basic needs. Source: Department of Foreign Affairs and Trade. Source: Wikimedia

Executive Summary

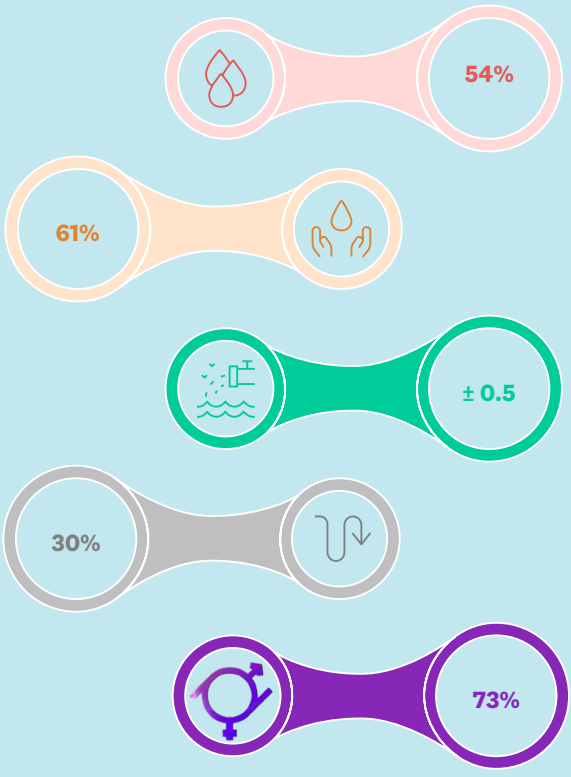


A boy transporting water by bicycle in Taha, Northern Region, Ghana, illustrates how gaps in public water governance and infrastructure compel mobile, household-level adaptations. These adaptations shift responsibility for water access onto younger generations, compromise water quality, and impose physical, health, and time burdens on households. Photo by Evans Ahorsu.

In many initiatives aimed at improving water quality across the Global South, there is a prevailing assumption that advances in economic development and gender equality will inherently lead to cleaner water outcomes. However, this presumed causal link often overlooks the complex, context-specific factors that mediate environmental health. This report by the United Nations University Institute for Water, Environment and Health (UNU-INWEH) on its 30th anniversary interrogates that gap, challenging deterministic narratives and unpacking the complex socio-environmental fabric that shapes water security. Drawing on data from 138 countries across seven regions, three key indices were integrated: the Drinking Water Safety Index (DWSI), the International Wealth Index (IWI), and the Gender Inequality Index (GII), to develop a novel composite **Water Quality Vulnerability Index (WQVI)**.

This holistic metric captures environmental, economic, and gender-related dimensions, highlighting systemic vulnerabilities and resilience patterns. Findings show that while the drinking water safety is strongly correlated with both wealth and gender equality, causation is far from straightforward. Nations with similar income classifications often exhibit starkly divergent WQVI scores, and even among high-income economies, performance varies widely. These disparities point to hidden drivers, such as quality or effectiveness of governance, infrastructure investment, cultural norms, climate change, and conflict, that mediate or override the influence of wealth and gender equity. Hotspots (e.g., Niger, Nigeria, Namibia, Guyana) illustrate that structural deficits, environmental conditions, and deeply rooted socio-political factors can undermine water safety, even where economic or gender metrics appear favourable. In contrast, some states, such as Mauritius, Morocco, Jordan, Sri Lanka, and Vietnam, manage to keep their drinking water safe, even with modest incomes, demonstrating the power of effective policies, equitable resource allocation, and targeted smart investments. Quadrant mapping of the WQVI reveals that only 39% of the Global South falls into the “win–win–win” category (high drinking water safety, high wealth, and high gender equality), leaving the majority with moderate to extreme vulnerabilities, affecting approximately 2 billion people.

Key Highlights



Over half (54%) of the 138 Global South countries have normalized DWSI scores below the preferred threshold, indicating widespread poor water quality.

61% face combined socioeconomic and water security challenges, impacting approximately 2 billion people.

Europe's developing countries are the least vulnerable, followed by countries in South America, Asia, Central America, the Caribbean, the Pacific Islands, and Africa, with vulnerability differences up to ±0.5 across regions.

Quadrant mapping identifies a critical “lose-lose-lose” cluster - poor drinking water safety, low wealth, and wide gender gaps - in roughly 30% of countries, highlighting a development bias toward short-term gains at the expense of sustainability

Surprisingly, water reflects inequality - 73% of global variations in drinking water quality are linked to disparities in wealth and gender.

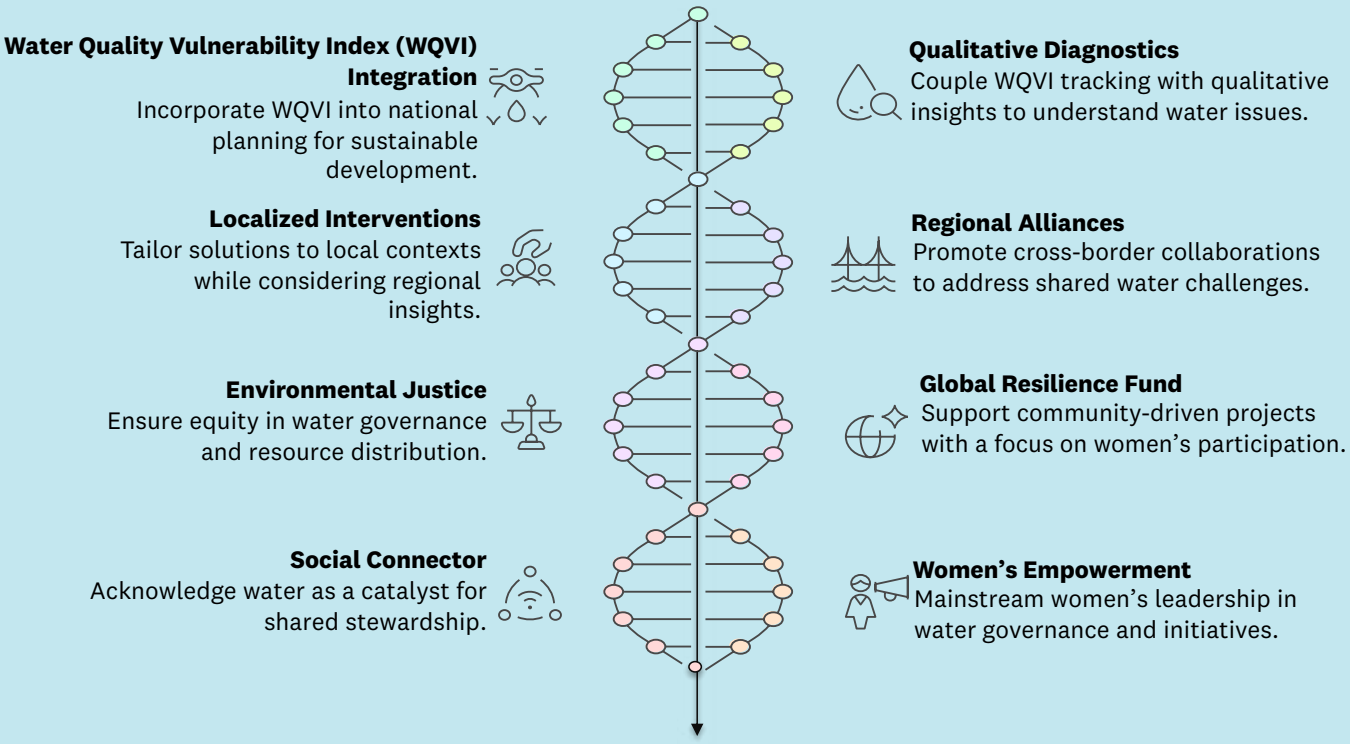
Approximately one-third of the assessed countries fall into a “lose–lose–lose” condition, reflecting simultaneous deficits across all three dimensions.

These results expose a crucial policy blind spot: without identifying causal mechanisms, reliance on correlated indicators risks misdirecting interventions, perpetuating inequities, and missing the systemic levers that could yield lasting gains.

This report, developed on the occassion of UNU-INWEH's 30th anniversary, advocates a shift from assumed linear pathways to evidence-based, integrated strategies that treat drinking water safety, economic capacity, and gender equality as interdependent but non-deterministic variables. These strategies could include incorporating WQVI into national plans to support fair and sustainable development, and utilizing WQVI data in conjunction with interviews or case studies to understand the root causes. Additionally, prioritizing interventions that are locally tailored yet regionally informed and forming regional water security alliances to tackle context-specific issues, such as aridification and salinization. The report also recommends embedding environmental justice principles into water governance to ensure equity in decision-making and resource allocation, and establishing a Global Water Resilience Fund to support community-driven projects that prioritize women’s participation. These strategies align with the UN Sustainable Development Goals, particularly SDG 5 (gender equality), SDG 6 (clean water and sanitation), and SDG 10 (reduced inequalities), while avoiding the pitfalls of policies based solely on correlation.

By reframing the narrative from “wealth and equality result in safer drinking water quality” to “multiple, interacting systems shape water outcomes,” this report offers a more nuanced understanding of the water and inequality landscape in the Global South, one that recognizes both statistical associations and the deeper causal architectures beneath them. The quality of drinking water is both a mirror and a magnifier of a nation’s social fabric. Addressing it effectively requires a commitment to both equity and infrastructure. The call to action is clear: invest in water, invest in equality - the returns will flow for generations.

Integrated approaches to build resilient water systems for inclusive development.



1 Introdution



Heightened health risk. Children playing in muddy water highlights how deficiencies in water infrastructure exacerbate water quality risks and reproduce structural inequality, experienced at the scale of everyday life, placing vulnerable populations at heightened health risk. Source: Freepik.

Water quality tells a powerful story about who holds power and who gets left behind. Safe water is not just an environmental issue; it reflects how resources are shared. In many cities, wealthy neighbourhoods enjoy treated water, while poorer communities often rely on polluted sources. These disparities underscore broader inequities associated with wealth, class, and geography. In this way, water becomes a lens through which justice and equity can be assessed. When governments prioritize infrastructure investments in privileged areas while neglecting underserved regions, it signals systemic disregard for vulnerable populations. This neglect reinforces cycles of poverty and public health challenges. Such patterns, rarely incidental but rather strategic, often stem from deeply-rooted biases that favour the powerful, positioning water as both a symbol and a measure of societal well-being.

In the past, unequal access to safe water has often reflected social hierarchies, many of which are rooted in colonial history. Colonial powers designed water systems to serve settlers and extractive industries, leaving indigenous and local populations with degraded or inaccessible supplies.1 These inequities persist in many post-colonial states, where inherited infrastructure and governance structures continue to marginalize certain groups and fuel conflicts over water rights.2,3 Environmental stressors, such as droughts, further intensify these challenges. Climate variability disproportionately affects regions already burdened by poor governance and limited adaptive capacity. In such contexts, discriminatory policies and weak institutions fail to deliver equitable responses, deepening the impacts of climate change and reinforcing cycles of marginalization.4

Central to debates in water governance is the tension between viewing water as a fundamental human right versus treating it as a commodity. The United Nations' recognition of water as a human right in 2010 marked a significant shift, emphasizing universal access regardless of economic status.5 Yet, many countries continue to adopt market-driven models that treat water as a tradable good. Privatization schemes often prioritize profit over public welfare, leaving marginalized populations reliant on unsafe alternatives and widening health and economic gaps.6,7 Advocates of the human rights framework argue that commodification undermines social cohesion by transforming a life-essential resource into a privilege.8 In contrast, framing water as a right promotes inclusive policies that address structural inequalities, such as gendered burdens in water collection and economic barriers to access. Ultimately, how societies navigate this tension reflects their broader commitment to equity and justice. Access to safe water, in this context, reflects deeper ethical and institutional realities.

In the Global South, nearly 2 billion people face both water insecurity and social challenges that increase their vulnerability.9 Limited access to safe water undermines health, education, and economic opportunities, particularly for disadvantaged populations. For many, daily life involves fetching contaminated water from distant sources, contributing to preventable diseases like cholera and diarrheal, which claim millions of lives annually.10 These burdens fall disproportionately on rural communities and informal urban settlements, where inadequate infrastructure perpetuates poverty and reinforces deprivation.

Regional disparities across Africa, Asia, and Latin America often reflect the legacy of colonialism and uneven development trajectories. In sub-Saharan Africa, colonial-era water systems prioritized export-oriented agriculture, sidelining basic services for local populations and cementing ethnic and class divisions.11 In South Asia, rapid urbanization widened the gaps between megacities and their suburbs, with water diverted to industrial zones, echoing historical patterns of resource extraction.12 In Latin America's Andean regions, stark contrasts exist between indigenous highlands (where rivers are polluted and infrastructure is lacking) and coastal urban elites who benefit from modern water systems. These imbalances drive migration toward urban centers, straining fragile water systems and intensifying social tensions. Wealthier households often secure private solutions, such as boreholes and bottled water, while poorer communities face heightened risks. Gender dynamics further exacerbate these challenges, as women, who are typically responsible for household water management, bear increased health and time burdens 13, especially under climatic stress.

Water, as a result, functions as both a symptom and driver of social fragmentation. As a symptom, degraded water quality signals governance failures and economic neglect. As a driver, it fuels conflict, erodes institutional trust, and divides communities along lines of access. In many locales, water disputes have sparked protests and violence, disrupted social cohesion, and hindered inclusive development.14, 15 Addressing these challenges requires integrated approaches that go beyond technical fixes to confront the root causes of inequality and fragmentation.

A shift from purely technical solutions to a deeper understanding of social contexts is crucial. Engineering interventions, such as dams or purification plants, often overlook cultural, economic, and relational dimensions that shape water access and use. Imported technologies may fail to align with local knowledge systems, leading to inefficiencies and community disengagement.16 Applying a social lens reveals that water issues are

not solely hydrological but deeply tied to trust, participation, and equity. Insights from sociology and anthropology may also help policymakers understand resistance to change, informal water-sharing networks, and the relational dynamics that influence water management. An integrated approach will promote more adaptive and inclusive strategies, reframing water as a social connector rather than just a commodity.

Additionally, the interconnections between water, gender, and wealth underscore the need for holistic perspectives. For instance, gender inequalities often manifest in water access, with women in low-income households spending hours collecting water, limiting their educational and economic opportunities.17 Wealth disparities exacerbate this issue, as affluent groups typically secure premium supplies while poorer communities rely on polluted sources, perpetuating health and social inequities.18 In the Global South, these dynamic dimensions form a nexus where poverty restricts water infrastructure investment, and gender roles amplify vulnerability.19 Climate change deepens these pressures, disproportionately affecting marginalized women and reducing their agency.

So, the effectiveness of water interventions often hinges not only on technical solutions but also on the strength of a society's socioeconomic fabric - the economic capacity, networks of trust, cooperation, and shared values that bind communities together. Where social cohesion is strong, communities are better equipped to mobilize collective action. This is evident in successful watershed cooperatives, where inclusive decision-making fosters equitable distribution and long-term maintenance of water resources.20 On the other hand, weak social systems, where exclusion, corruption, or historical conflicts persist, can enable powerful groups to take control and negatively impact project outcomes. While strengthening social cohesion may require sustained investment in education, dialogue, and community empowerment, the design of water initiatives should also promote participation and resilience, evolving into platforms for broader social transformation. Viewed through this lens, safe water is not only a magnifier of inequality but also a potential catalyst for change.

Thus, this report introduces the Water Quality Vulnerability Index (WQVI), which quantifies the interplay between drinking water safety, gender inequalities, and economic dimensions across the Global South, highlighting systemic vulnerabilities and patterns of resilience within the region. In addition, it challenges deterministic narratives and unpacks the complex socio-environmental structure that shapes water security, offering actionable insights to guide equitable water management and inform sustainable policy interventions.



Women and children performing water infrastructure functions. In low-resource settings where safe water and formal water infrastructure are limited or unreliable, domestic water access often depends on sustained human labour. This labour, frequently borne by women and children, substitutes for engineered systems of storage, conveyance, and distribution. In this way, people, most often women and girls, are compelled to perform infrastructural functions, exposing structural gaps in water governance and public investment. Open water source in Taha, Ghana. Photo by Evans Ahorsu.

2 Mapping Water Vulnerabilities in the Global South



Children's exposure to infrastructural deficit. A child drawing water from an open, unprotected well highlights how the absence of safe water infrastructure transfers contamination risks and daily labour onto children, exposing them to preventable health hazards and reflecting systemic failures in water governance and public provision. A self-supply hand dug well, Abeokuta, Nigeria. Photo by Grace Oluwasanya.

A weighted average method was applied to develop the Water Quality Vulnerability Index (WQVI) for 138 countries across the Global South. The index is grounded in the theoretical frameworks of Intersectionality, Feminist Political Ecology, and Environmental Justice, and integrates three key indicators: the Drinking Water Safety Index (DWSI), the International Wealth Index (IWI), and the Gender Inequality Index (GII). The DWSI measures unsafe drinking water, reflecting both water quality (in terms of its safety and health impact) and infrastructure performance, using the age-standardized DALY rate (disability-adjusted life years lost per 100,000 people) due to exposure to unsafe drinking water. The IWI measures the economic situation of households in developing countries, and GII quantifies gender-based disadvantages in reproductive health, empowerment, and the labour market for various countries. To ensure analytical precision, redundant gender metrics were excluded. Data were standardized using Z-score normalization, followed by Min-Max rescaling to a [0,1] range. Pearson correlation analysis revealed strong relationships: DWSI positively correlated with IWI ($r = 0.77$) and negatively with GII ($r = -0.79$). These relationships were further supported by regression analysis, with simple linear models yielding R^2 values between 0.601 and 0.624, and a multiple regression model explaining 73.4% of the variation in water quality ($R^2 = 0.734$).

For comparative vulnerability assessment, countries were grouped regionally based on the International Monetary Fund (IMF) classification. Also, to identify priority areas for developmental action, a quadrant mapping analysis was conducted using rescaled values of the DWSI, IWI, and the inverted Gender Inequality Index (1–GII). DWSI was plotted on the x-axis as the independent variable, while IWI and 1–GII were plotted on the y-axis as the dependent variables. All indicators were normalized and benchmarked at the 50th percentile to divide the dataset into four quadrants. Countries in Quadrant 4, characterized by unsafe drinking water quality, low wealth, and high gender inequality, were flagged as requiring urgent, multidimensional intervention. Additionally, countries were categorized by Gross National Income (GNI) per capita using the World Bank's income classification system. This enabled comparative analysis across economic tiers: low-income (< $1,145), lower-middle ($1,146–$4,515), upper-middle ($4,516–$14,005), and high-income (> $14,005) economies.

Detailed information on the methodology and analytical components is provided in Appendix I.

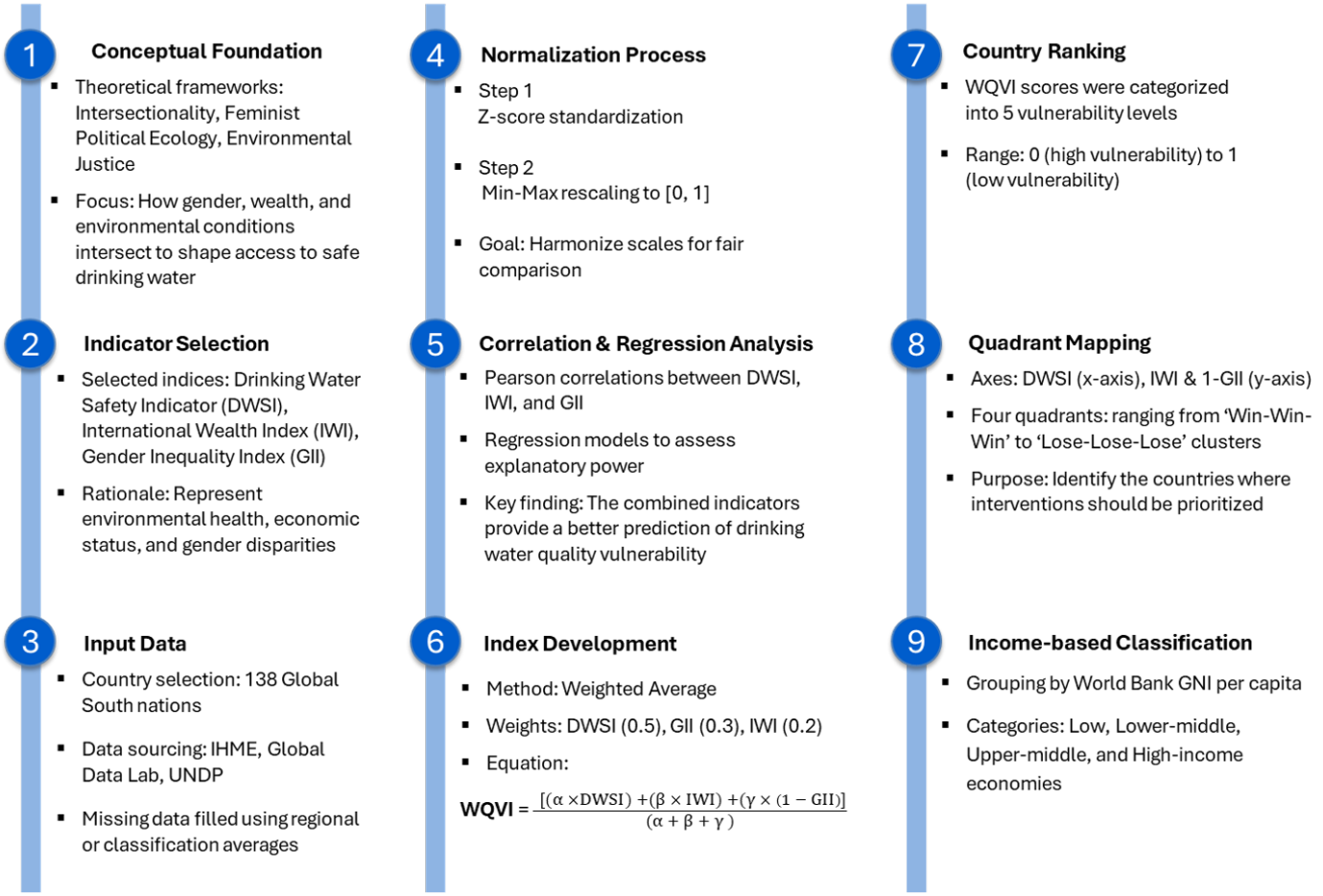


Figure 1. From theory to the integrated Water Quality Vulnerability Index: A holistic approach to mapping vulnerability.

3 Drinking Water Safety, Wealth, and Gender Inequality Indicators: An Overview



Cost of infrastructural deficits. A young Mosotho girl carrying a bucket of water illustrates how infrastructural deficits externalize the costs of water access and quality. When water must be collected rather than delivered, responsibility shifts from public systems to households, shaping daily routines from an early age. Time, physical effort, and opportunity costs are absorbed by those with the fewest resources, revealing how unequal infrastructure translates directly into unequal lived experiences. Photo by Joelwrightphotography. Free License

The study examined the Drinking Water Safety Index, International Wealth Index, and Gender Inequality Index to provide an overview of these three critical indicators across various regions and countries in the Global South. These indicators offer valuable insights into the complex interactions between drinking water safety, gender inequality, economic resources, and their intersectional impacts.

Among the 138 countries in the Global South, 54% fall below the preferred threshold of 0.50, underscoring widespread challenges to drinking water safety. Regionally, developing countries in Europe lead with an average DWSI of 57.1, followed by South America, Asia, Central America, the Caribbean, the Pacific Islands, and Africa, which has the lowest average at 17.7. The top performing countries are Brunei (Asia), Chile (South America), Poland (Europe), Mauritius (Africa), Costa Rica (Central America), Trinidad and Tobago (Caribbean), and Tonga (Pacific Islands). The lowest Performers: Albania, Guyana, Pakistan, Guatemala, Haiti, Kiribati, and Niger, with a country-level range from 1.7 (Niger) to 79.9 (Brunei).

The observed wide gap in the drinking water safety across regions may be attributed to differences in water system infrastructure design, technical and human resource capacities, management practices (inclusive vs. exclusive), and the nature and scale of financial investments in water treatment technologies. Inadequate treatment of water and wastewater contributes to pollution of water sources, posing serious public health and environmental risks, particularly for vulnerable populations such as children and the elderly.[21-24] Africa's low performance may be attributed to limited access to safe water, underdeveloped infrastructure, and weak water management systems, in contrast to Europe's advanced capabilities. Additionally, rapid urbanization in Africa may have created further challenges, as infrastructure development has lagged behind the pace of urban expansion.

The IWI reflects national economic resources, with higher values indicating greater wealth. The index reveals stark disparities. Regionally, developing countries in Europe rank highest with a regional average of 80.2, followed by countries in South America (79.5), Asia (73.8), Central America (74.9), the Caribbean (73.6), Pacific Islands (59.8), and Africa (47.2). Top-performing countries are Mexico (Central America), Kuwait (Asia), North Macedonia (Europe), Venezuela (South America), Barbados (Caribbean), Mauritius (Africa), and Samoa (Pacific Islands), while the lowest-performing nations are Papua New Guinea (Pacific Islands) and South Sudan (Africa). The country-level Range from 14.2 (South Sudan) to 99.9 (Mexico).

This result highlights a significant economic divide. Europe and South America rank highest, while Africa again records the lowest scores, with conflict-affected and low-income countries like Chad, Mozambique, and Eritrea facing severe resource constraints. Economic resources play a crucial role in a country's ability to address unsafe drinking water quality through investments in infrastructure, sanitation, hygiene, and public health. Unsafe drinking water quality incurs substantial economic costs, including healthcare expenses, ecosystem degradation, high water treatment costs, reduced property values, and negative impacts on agriculture and manufacturing.[25] Poverty exacerbates these challenges by limiting access to safe water and sanitation, perpetuating cycles of disease and economic stagnation. [24,26]

The GII assesses gender-based disparities, where higher values indicate greater inequality. The index also reveals significant regional and national differences. The regional averages show that developing countries in Europe have the smallest gender gap (0.165), followed by Asia (0.368), South America (0.375), Central America and the Caribbean (0.379), the Pacific Islands (0.462), and Africa (0.539). The top performing nations include Belarus (Europe), Kazakhstan (Asia), Chile (South America), Costa Rica (Central America), Libya and Tunisia (Africa), Barbados (Caribbean), and Fiji (Pacific Islands). The lowest performers include Yemen (Asia), Papua New Guinea (Pacific Islands), Nigeria (Africa), Haiti (Caribbean), Venezuela (South America), Guatemala (Central America), and Romania (Europe), with a country-level range from 0.104 (Belarus) to 0.82 (Yemen). Africa and parts of Asia exhibit the widest gender gaps, with significant implications for access to education, healthcare, and water-related decision-making. In contrast, developing countries in Europe have made notable progress toward achieving gender parity.

Gender inequality is closely linked to water-related health outcomes, as women and girls are often responsible for water collection and household water management.[27] When water sources are scarce or contaminated, they bear a disproportionate burden - often at the expense of education and economic opportunities. Moreover, the systemic exclusion of women from healthcare, education, and decision-making processes further intensifies the impacts of poor water quality. These compounded vulnerabilities underscore the need for gender-responsive water policies and inclusive governance frameworks that address the intersection of gender, health, and environmental justice.[28]

These findings underscore the need for a more nuanced and intersectional approach to addressing the global water-health-gender nexus. Tackling drinking water safety challenges requires integrated strategies that consider economic, social, and gender dimensions, in addition to technical solutions.

4 Integrated Water Quality Vulnerability Index: The Framework, Outcomes and Implications



Women lifting a heavy water bowl directly from an open water source in Taha, Northern Region, Ghana. This frames water quality as a material manifestation of social injustice, in which exposure to environmental risks falls at the margins of equity and is shaped by power relations rather than by absolute scarcity. This also reflects gendered divisions of labour, where responsibility for water provision disproportionately falls on women and girls, often at the expense of their health, time, and economic opportunities. Photo by Evans Ahorsu.

Beyond the individual insights from the three critical indicators, this assessment introduces the WQVI, an integrated metric designed to capture the intersectional dynamics of drinking water safety, economic capacity, and gender equity. The WQVI offers a more nuanced understanding of systemic vulnerabilities that may be overlooked when indicators are considered in isolation. Unlike traditional water indices that focus solely on physical and chemical properties, the WQVI incorporates socioeconomic and gender dimensions, providing cross-sectional insights into how environmental quality interacts with economic conditions and social equity. This holistic approach enables a broader perspective on public health, livelihood resilience, and a country's ability to cope with water-related challenges, particularly in the Global South. Additionally, the WQVI is designed to support continuous monitoring of how changes in drinking water safety affect different demographic, socioeconomic, and gender groups. It enables dynamic tracking for improved monitoring and evaluation, and supports timely adjustments to water, health, and gender-related policies and programs. Ultimately, this integrated approach provides a robust framework for measuring national and regional progress toward the UN SDGs, particularly SDG 6 (Clean water and sanitation) and SDG 5 (Gender Equality).

The WQVI scores illustrate significant disparities. Developing European countries such as Brunei, Chile, Belarus, Serbia, and Poland rank among the top performers. In contrast, Africa and parts of Asia show lower WQVI scores, suggesting persistent challenges in drinking water safety and heightened social and gender vulnerabilities.[29] Within the regions, Africa shows stark internal disparities. Countries like Mauritius, Tunisia, and Algeria perform relatively well, while Niger, Nigeria, and Eritrea rank among the lowest, highlighting a gap between North African and sub-Saharan nations. Asia presents a mixed picture. Nations such as Brunei, Armenia, and Kazakhstan perform well, whereas Afghanistan, Pakistan, and Yemen lag behind. In the Caribbean and Central America, Costa Rica and Barbados lead, while Haiti and Guatemala face significant hurdles, likely exacerbated by internal conflict and climate-related events. In South America, Chile and Uruguay emerge as front-runners, while Bolivia and Guyana require targeted interventions to improve performance across water, wealth, and gender indicators. These disparities underscore the need for tailored context-specific approaches to address drinking water safety challenges, economic development gaps, and gender inequality in the most vulnerable nations.

Uneven Vulnerability across Regions in the Global South

The WQVI results generally highlight uneven vulnerability across regions in the Global South. Developing countries in Europe exhibit the lowest vulnerability, as measured by the WQVI scores, followed by countries in South America, Asia, Central America, the Caribbean, the Pacific Islands, and Africa. The regional vulnerability spread, of up to ±0.5, is not just a statistical variation. It suggests that the assumption that all developing regions face similar water-related risks is inaccurate, reflecting deep-rooted structural, historical, and governance-related disparities in water security across the Global South.

The relatively low vulnerability in Europe's developing countries may be attributed to stronger institutional frameworks, consistent investment in water infrastructure, and relatively lower gender

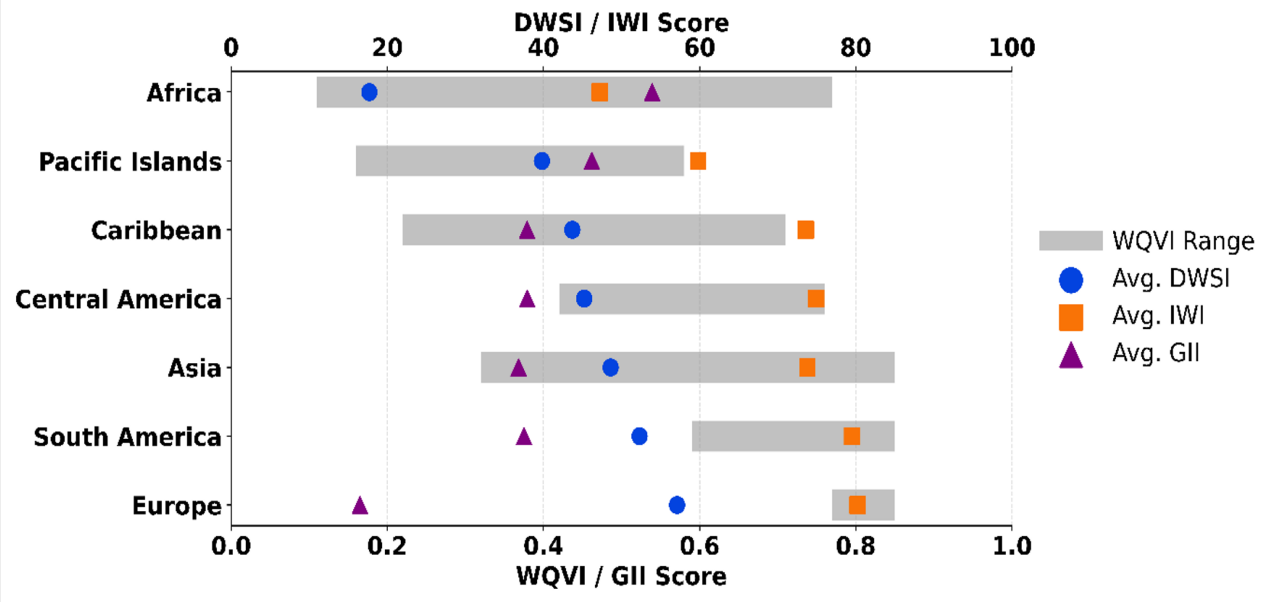


Figure 2. Regional Averages of Key Indices - DWSI-Drinking Water Safety Index, IWI-International Wealth Index, GII-Gender Inequality Index, and WQVI-Water Quality Vulnerability Index in the Global South.

inequality.[30] In contrast, regions such as Africa and the Pacific Islands face compounded challenges, including weak governance, limited financial resources, climate volatility, and entrenched social inequalities.[31] These factors intensify water insecurity, especially in marginalized communities where access to safe water remains unaffordable.

These results underscore the need for region-specific strategies rather than one-size-fits-all solutions. For instance, while infrastructure investment may yield rapid improvements in South America, Africa may require governance reforms and community-led water management models to address foundational issues. The ±0.5 vulnerability spread also signals that some regions within the Global South are significantly more fragile, necessitating urgent prioritization in global aid and policy frameworks. Importantly, this calls for the integration of non-economic indicators, such as gender inequality and governance quality, into water vulnerability assessments. Economic metrics alone fail to capture the lived realities of water insecurity, especially for women and low-income households. In regions with high gender inequality, women disproportionately bear the burden of water collection and exposure to contaminated sources, reinforcing cycles of poverty and poor health.[32]

Multidimensional Determinants of Water Vulnerability

Significant heterogeneity in water quality vulnerability exists within income groups across the Global South. Notably, high-income economies show wide-ranging WQVI performance, indicating that economic prosperity alone does not guarantee improved drinking water safety or gender equality outcomes. This finding challenges the conventional assumption that higher income levels or economic prosperity automatically translate into better water-related conditions.

While income is often associated with improved infrastructure and service delivery, this analysis reveals a more complex reality. High-income economies within the Global South exhibit wide disparities in WQVI scores, highlighting that wealth alone is insufficient to ensure equitable water outcomes. Instead, governance quality, infrastructure robustness, and cultural norms emerge as critical, non-economic factors that determine water vulnerability.

This finding is significant for several reasons. First, it disrupts the traditional development narratives in water resources management, where economic indicators are frequently used as proxies for progress. Such assumptions can lead to the misallocation of resources and ineffective interventions.[33] For example, a country with a rising Gross Domestic Product (GDP) may still experience poor water governance, leading to contamination, unequal access, and gendered burdens in water collection. Second, the results highlight how cultural norms, particularly those related to gender roles in water management, can perpetuate inequality even in economically advanced settings. In many cases, women and girls continue to bear the brunt of water insecurity, facing health risks and time poverty despite national affluence.[34]

The implications are profound. Policymakers must recognize that water vulnerability is multidimensional, shaped by intersecting social, political, and environmental factors. Development strategies that focus solely on economic indicators risk overlooking systemic inequities that undermine progress. Moreover, the persistence of poor water outcomes in wealthier nations suggests that institutional reform and cultural transformation are as vital as financial investment. Beyond pipes and pumps or infrastructure,

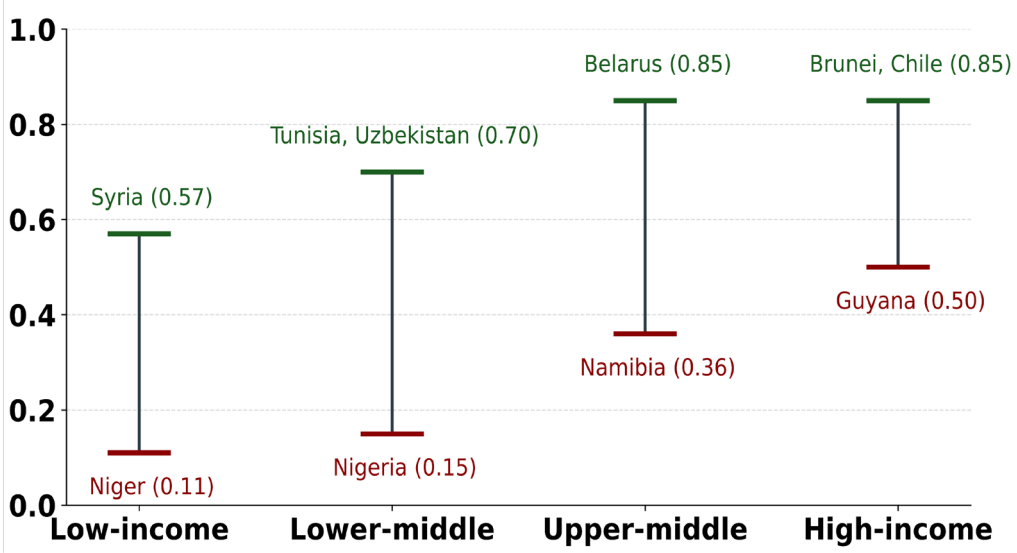


Figure 3. Range of the Water Quality Vulnerability Index scores across the income-level groupings in the Global South.

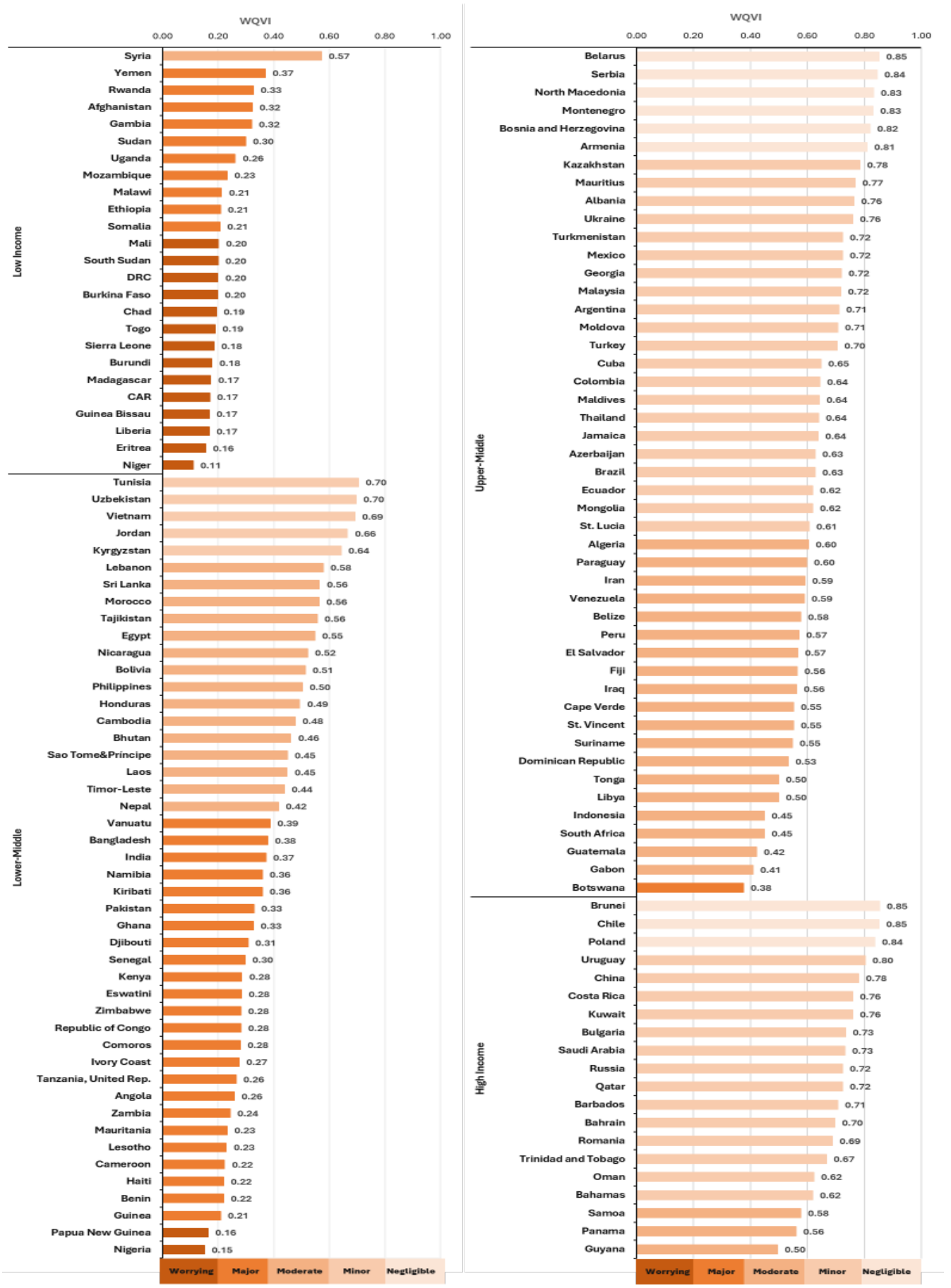


Figure 4. National ranking of the Water Quality Vulnerability Index scores across the income-level groupings in the Global South.

investments should target education, behavioural change, and cultural shifts that dismantle gender biases and promote equitable water access.

The Triple Trap of Social Inequality

The quadrant mapping analysis illustrates the regional and national influence of the Drinking Water Safety-Wealth-Gender nexus, identifying priority areas for targeted development action across the Global South. Of the 138 countries assessed, 54 countries (e.g., Mauritius, Armenia, Qatar, Russia, Uruguay) fall into Quadrant 1, characterized by excellent drinking water safety (DWSI), high wealth (IWI), and low gender inequality (high 1–GII) - a "win-win-win" scenario. 20 countries (e.g., Egypt, South Africa, Cambodia, Indonesia, Philippines) are in Quadrant 3, with poor DWSI but relatively high IWI and 1–GII. 41 countries (e.g., Central African Republic, Chad, Guinea-Bissau, South Sudan, Papua New Guinea) fall into Quadrant 4, reflecting poor DWSI, low IWI, and low 1–GII - a "lose-lose-lose" cluster. No country met the criteria for Quadrant 2, which would represent excellent DWSI alongside low IWI and 1–GII. The remaining 23 countries occupy intersections between quadrants, forming mixed categories:

- Lose–Win–Lose: 9 countries (e.g., India, Guatemala, Botswana)
- Win–Win–Lose: 7 countries (e.g., Algeria, Iraq, Venezuela)
- Lose–Lose–Win: 5 countries (e.g., Namibia, Rwanda, Timor-Leste)
- Win–Lose–Win: 2 countries (Nicaragua, Sri Lanka)

At the regional level, five of the seven regions are predominantly in Quadrant 1, with one region each in Quadrants 3 and 4. Importantly, **no country or region** was found in the **'win-lose-lose'** quadrant, where environmental protection is prioritized over economic and gender-inclusive development.

These findings indicate that only 39% of countries in the Global South fall within the **"Model Quadrant,"** demonstrating strong performance across all three indices. The remaining 61% exhibit varying degrees of vulnerability, such as the **15%** in a **lose–win–win** category, where socioeconomic progress outpaces water security and the **30%** within the **lose–lose–lose** quadrant, facing simultaneous challenges in drinking water quality, economic capacity, and gender equity, impacting an estimated **2 billion people**.

A key insight from the quadrant mapping analysis is a troubling development bias: a tendency to prioritize short-term economic gains over long-term sustainability and equity. This pattern is observed in at least 15% of the countries assessed, where socioeconomic progress has not translated into improved drinking water safety. Another critical finding is the identification of a "lose-lose-lose" cluster, comprising about 30% of the countries. These nations face unsafe drinking water quality, low wealth, and wide gender gaps, indicating compounded vulnerability. Countries in this cluster are not grappling with isolated challenges; rather, they are caught in a reinforcing cycle of environmental degradation, poverty, and gender inequality. This group represents the most fragile segment of the Global South, where systemic neglect has allowed foundational deficits to persist.[35] Poor drinking water safety

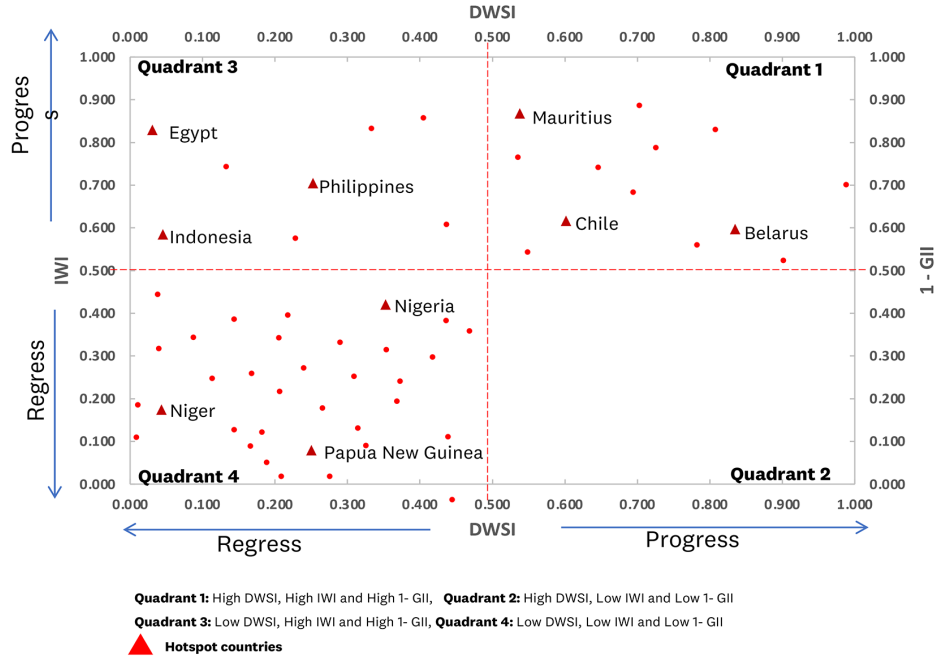


Figure 5. Drinking Water Quality-Wealth-Gender Nexus-based mapping, showing priority areas for development and critical hotspot countries across the Global South.

in these nations is not merely a technical issue; it reflects weak governance, underinvestment in infrastructure, and exclusionary social norms. Limited financial capacity further constrains the ability to invest in solutions, while wide gender gaps exacerbate the crisis by excluding half the population from decision-making and economic participation.

The implications are significant. This triple vulnerability undermines progress toward multiple SDGs, particularly SDGs 6 (clean water and sanitation), SDG 5 (gender equality), and SDG 1 (no poverty). Development strategies that focus narrowly on GDP growth or infrastructure expansion often fail to address the root causes of fragility. In many cases, water projects are implemented without considering gender dynamics or the socioeconomic context, leading to unsustainable outcomes and elite capture. Moreover, the "lose-lose-lose" cluster serves as a warning against development myopia. These countries are frequent recipients of fragmented aid and short-term pilot programs that do not build institutional capacity or community resilience. Without integrated approaches, including investments in resilient institutions, inclusive governance, and sustainable infrastructure, these nations risk falling further behind, especially as climate change intensifies water stress and social inequalities.

The Global South's Water Crisis: A Human Development Emergency

The country-level performance of normalized DWSI scores reveals a troubling reality: 54% of the 138 countries in the Global South fall below the preferred threshold of 0.50. Additionally, WQVI scores show that 61% of these countries face significant vulnerabilities related to water quality, affecting an estimated 2 billion people. This is not just a technical issue; it represents a humanitarian crisis with far-reaching implications for health, development, and equity.

These findings highlight the systemic fragility of water systems in the Global South, where poor drinking water quality both reflects and reinforces broader social and economic vulnerabilities. Water quality is foundational to public health, educational outcomes, and economic productivity.[24] Inadequate water systems contribute to increased disease burdens, particularly waterborne illnesses such as cholera and diarrheal diseases, which disproportionately affect children and women. Moreover, time poverty, especially among girls responsible for water collection, limits access to education and perpetuates gender inequality.[32] Economically, poor water infrastructure stifles growth, increases healthcare costs, reduces labour productivity, and discourages investment.[36]

The fact that 61% of these nations face overlapping challenges reflects a vicious cycle: poverty limits investments in water infrastructure, while poor drinking water quality exacerbates poverty through health shocks and lost opportunities. This cycle is intensified by weak governance, inadequate planning, and climate stressors such as droughts and floods, which further impair drinking water quality and disproportionately impact the most vulnerable populations.

Water must therefore be treated not only as a technical concern, but as a social and developmental priority. Tools like the WQVI can help identify critical hotspots and guide context-specific interventions, moving beyond generic solutions to address the root causes of water insecurity.

Socioeconomic and Gender Dimensions of Drinking Water Safety

A significant statistical relationship was observed between drinking water safety, wealth, and gender inequality indicators, underscoring the need for integrated approaches to address these interconnected factors. The DWSI shows a positive correlation of 0.77 with the IWI and a negative correlation of -0.79 with GII. Together, these variables explain 73.4% of the variation in water quality ($R^2 = 0.734$) in a multiple regression model.

This evidence presents a compelling case for rethinking water management strategies in the Global South. Water quality is not merely a technical or environmental issue; it is deeply embedded in socioeconomic and gender structures. While wealthier nations tend to have better water infrastructure, the persistence of poor drinking water quality in some high-income countries suggests that governance, cultural norms, and gender dynamics play equally critical roles.[34] The strong negative correlation with gender inequality also highlights how water insecurity disproportionately affects women and girls, limiting access to education, increasing health risks, and reinforcing time poverty through unpaid labour in water collection.[37]

The implications are far-reaching. Water quality serves as a mirror of societal health, reflecting how inclusive or exclusive development policies truly are. Nations that fail to address gender disparities and economic exclusion are likely to struggle with water insecurity, regardless of their GDP (Gross Domestic Product). As such, interventions focused solely on infrastructure or technology may fall short unless accompanied by social reforms that empower marginalized groups and promote equitable access.

5 Building Resilient Water Systems for Inclusive Development



Cost of infrastructural deficits. The participation of a young person in water collection reflects how infrastructural deficits can shape daily responsibilities early in life, affecting time available for rest, education, or other activities. Also, when water must be transported over a distance, the responsibility falls on household members rather than institutions. This shifts the costs of water access - time, energy, and physical strain - onto individuals with the least resources. Source: Freepik.

The water quality crisis in the Global South represents a reflective development emergency, revealing the intricate linkages between environmental degradation and human well-being. In over half of these nations, poor water quality exacerbates health disparities and perpetuates cycles of poverty and social exclusion. Contaminated water sources contribute to higher rates of infectious diseases and reduced workforce participation, undermining both public health and economic productivity.[38] This systemic issue intensifies vulnerabilities in already strained economies, where inadequate water systems discourage foreign investment and hinder agricultural productivity - critical for food security in regions reliant on subsistence farming.[39] The burden falls disproportionately on marginalized groups, leading to intergenerational impacts such as stunted child development and diminished educational opportunities, particularly for children involved in water collection tasks.[40]

The implications extend beyond immediate humanitarian concerns, reflecting broader failures in achieving the SDGs, especially SDG 6 on clean water and sanitation, which could undermine progress toward poverty alleviation (SDG 1) and gender equality (SDG 5). This calls for a paradigm shift from reactive interventions to development-centred strategies, such as climate-smart irrigation techniques and integrated planning. One promising approach is the creation of a Water Resilience Fund, coordinated through multilateral bodies such as the United Nations, which allocates resources based on WQVI assessments and targets high-vulnerability nations with grants for community-driven infrastructure projects. These projects should incorporate local knowledge to ensure sustainability and mandate gender-inclusive planning to address time poverty and health burdens, as demonstrated in Bangladesh's community-led sanitation initiatives.[41]

Regional Disparities and Structural Inequities

Regional disparities in water vulnerability reveal a gradient of inequality across the Global South. Historical legacies, such as colonial resource extraction in countries like the Democratic Republic of Congo and India[42], and varying institutional capacities, shape environmental outcomes. In contrast, developing countries in Europe benefit from stronger regulatory frameworks and more equitable resource distribution, while regions like Africa and the Pacific Islands face compounded risks from climate variability and limited fiscal space.[4] This uneven gradient suggests that uniform development aid is ineffective, as it fails to account for region-specific stressors, such as aridification in sub-Saharan Africa or salinization in small island states. Overlooking these localized challenges risks deepening global inequalities and intensifying migration pressures.[43] Moreover, integrating non-economic factors, such as gender dynamics, into vulnerability assessments reveals how social structures amplify risk. In high-inequality regions, women face heightened exposure to water-related hazards, obstructing broader societal progress.[44] These disparities challenge the assumption of uniform development trajectories and call for a re-evaluation of international cooperation frameworks to prevent further marginalization.

Policymakers must adopt differentiated approaches tailored to regional contexts, thereby avoiding the pitfalls of one-size-fits-all policies. A unique recommendation is to convene regional water security alliances focused on peer-to-peer knowledge exchange and customized capacity-building programs. These alliances could leverage WQVI data to prioritize interventions and embed gender-sensitive metrics to track equity.[45]

Beyond GDP: Rethinking Prosperity and Vulnerability

Importantly, economic prosperity does not inherently secure drinking water safety or gender equity. In the Global South, governance deficits and cultural barriers reveal hidden drivers that complicate traditional development paradigms. High-income economies with low WQVI scores demonstrate that wealth can coexist with systemic failures, such as corruption in resource allocation or patriarchal norms, leading to inefficient investments and persistent inequalities.[46]

This heterogeneity poses broader risks for sustainable growth, as unaddressed vulnerabilities can erode economic gains through health crises or social unrest, particularly in urbanizing areas where water demand outpaces supply.[47,48] It also highlights the limitations of GDP-centric metrics, which fail to capture the multidimensional nature of insecurity and the lived realities of vulnerable populations.[49] This requires a holistic approach that integrates social and institutional reforms alongside economic strategies to prevent reinforcing existing power imbalances.

The “Lose–Lose–Lose” Trap and the Need for Integrated Action

The identification of a "lose-lose-lose" quadrant in the WQVI mapping illustrates a triple trap: poor drinking water safety, low wealth, and wide gender disparities. Present in 30% of countries, this cluster signals entrenched structural failures, where fragmented aid and growth-focused policies exacerbate environmental degradation and social exclusion.[50]

The undermining of SDG synergies through siloed

approaches may lead to inefficient resource use and heightened conflict over scarce water resources in fragile states. [51] The exclusion of gender considerations in development planning perpetuates inefficiencies, as women's potential in water stewardship remains underutilized, stalling community resilience.[52]

This bias must be addressed through long-term, integrated frameworks that tackle root causes rather than symptoms. A tailored recommendation is to launch Integrated Vulnerability Reduction Programs in "lose-lose-lose" countries, coordinated through partnerships between the United Nations Development Programme (UNDP) and local governments. These programs should bundle sustainable infrastructure with gender empowerment initiatives.

Water as a Catalyst for Equity and Resilience

The correlations between drinking water safety, wealth, and gender inequality affirm their interconnectedness, positioning water management as a mirror of societal equity. Ignoring these linkages risks perpetuating vicious cycles, where gender gaps reduce economic productivity and wealth constraints limit water improvements, amplifying vulnerabilities amid global challenges like population growth and urbanization.[53] Water insecurity magnifies deeper systemic issues, disproportionately burdening women and low-income groups, and ultimately hampering national development trajectories and global stability.[54]

In sum, this report advocates for a shift from assumed linear development pathways toward evidence-based, integrated strategies that recognize drinking water safety, economic capacity, and gender equality as interdependent, yet non-deterministic variables. It further calls for transformative action from policymakers, international organizations, researchers, and civil society actors, working collectively to build resilient water systems that both reflect and strengthen the social fabric of nations. Informed by the WQVI assessment, the proposed recommendations, if effectively implemented, have the potential to reposition water quality from being a driver of inequality to a catalyst for social inclusion and resilience.



Direct consumption of water from open, shared containers. This shows how water quality risks often emerge not only at the source but during storage and use. In the absence of protected infrastructure, safety is managed at the point of consumption, increasing vulnerability to contamination and water-related health risks. Source: Freepik.

6 Conclusions: Reframing Water, Reclaiming Equity



Drinking Water Storage by Marginal Population in Coastal Bangladesh. An elderly woman collects water from an informal household rainwater harvesting system in Rural Bangladesh, highlighting how water quality reflects uneven access to infrastructure and protection. Where systems fail, everyday water practices reveal and reinforce structural inequalities. Photo by Md. Yousuf Ali.

Water quality is more than an environmental metric; it reflects a society's values, priorities, and capacity for justice. The WQVI developed in this study reveals the complex interplay between wealth, gender equality, and water security across 138 nations in the Global South. It uncovers not only the statistical correlations but also the deeper, often hidden structural factors that shape water outcomes. By integrating the DWSI, IWI, and GII, the WQVI offers a holistic lens to examine systemic vulnerability patterns across the water landscape of the Global South. Notably, 61% of these nations face compounded challenges, struggling simultaneously with socioeconomic disadvantages and water insecurity. These findings underscore the urgent need to reimagine water management as a cornerstone of equitable development.

This report challenges the conventional assumption that economic growth or gender equality alone ensures access to safe drinking water. While strong correlations exist between wealth and gender inequality, disparities in WQVI performance, even among high-income economies, highlight the influence of non-economic factors, such as governance quality, cultural norms, and historical legacies. The identification of a "lose–lose–lose" quadrant, where 30% of countries suffer deficits in drinking water safety, wealth, and gender equality, serves as a stark reminder of the triple trap that entangles the most vulnerable. These nations are not merely facing technical deficiencies; they are caught in cycles of exclusion, where environmental degradation, poverty, and social inequities reinforce one another, threatening progress toward the UN SDGs.

Yet, within this complex landscape lies an opportunity - to transform water quality from a mirror of societal fractures into a magnifier of collective resilience. The recommendations outlined, such as establishing a Global Water Resilience Fund and forming regional water security alliances, aim to shift the paradigm from reactive, siloed interventions to proactive, integrated strategies. These approaches recognize water as a social connector, capable of binding communities through shared stewardship and equitable access. By prioritizing community-driven projects, empowering women, integrating environmental justice into governance, and tailoring interventions to regional contexts, we can break the cycles of vulnerability and build systems that endure.The path forward demands a commitment to equity as much as to infrastructure.

Water quality is also a lens through which the health of a nation's social fabric can be assessed. It reveals fault lines of inequality - between men and women, rich and poor, urban and rural - and amplifies the consequences of neglect. But it also offers a pathway to inclusion, where investments in safe water yield cascading benefits: healthier communities, empowered women, thriving economies, and resilient societies.

The call to action is clear: investing in water is investing in humanity's shared future. Policymakers, international organizations, researchers, and civil society must unite in this effort, leveraging the WQVI to guide evidence-based, inclusive policies. By addressing the root causes of water insecurity, rather than relying solely on the inaccurate promise of economic growth, we can forge a future where safe water is not a privilege, but a universal right.

The stakes are high, but so too are the rewards Committing to a vision in which water quality becomes a catalyst for social cohesion, a driver of justice, and a foundation for sustainable progress will shape a world where equity and resilience are not aspirations, but realities.



Rohingya women collecting water near an IDP camp in Myebon, Rakhine State, Myanmar. This scene illustrates how water quality mirrors structural inequality and governance failures. The labor-intensive collection process highlights how social inequities determine who bears the heaviest burden of unsafe water. Source: Myanmar Now/Wikimedia Common

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Drinking Water Harvesting by Women of Marginal Population in Coastal Bangladesh. Photo by Subroto Kumar Sarker.

Appendix I : Methods and Input Data

The weighted average approach was applied to derive an integrated water safety and gender-wealth index, a statistical measure, to assess vulnerability to water quality at regional and national levels in the Global South. The theoretical basis for this water quality vulnerability index (WQVI) may be posited within the intersectionality and Feminist Political Ecology (FPE) frameworks. Intersectionality considers how multiple social categories (like gender, class, or race) crisscross to shape an individual's experiences and opportunities, aiming to understand how different dimensions of identity, including gender and wealth, interact to influence access to safe water and the ability to improve water quality. This presupposes that poor drinking water quality is predicted by the physical and chemical properties of water/environment and other human dimensions of identity, like gender and wealth. Similarly, FPE, which focuses on gendered relations of power in environmental contexts, explores how gender identities and roles shape water use, access, and management, including how unequal power relations affect drinking water quality. Additionally, an integrated analysis benefits from the concept of Environmental Justice. This addresses the fair distribution of environmental burdens/benefits, including access to clean water, considering how marginalized groups, often defined by gender and socioeconomic status, like wealth, bear disproportionate environmental risks and lack access to safe water. Drawing on these theoretical foundations, an integrated analysis of the Drinking Water Safety and Gender-Wealth nexus can explore the complex interactions between environmental conditions, social structures, and individual agencies to holistically identify barriers to equitable water access and sustainable management. Invariably, guiding policies and interventions for improving drinking water quality while addressing gender and wealth disparities.

The Global South, also called the developing countries or the Majority World (i.e., where most of the world's population resides), includes nations where the standard of living, income, and economic and industrial development remain (more or less) below average[55]. The International Monetary Fund (IMF), the United Nations Development Program (UNDP) and the World Bank classified developing countries differently. Of the 152 countries in the Global South used in this assessment, representing about 86% of the world's population,[56] only 138 were included, excluding 14 countries with no data of interest.

For the WQVI to accurately represent the overall data set, weights were assigned to individual indicators that form the elements/components of the analysis based on their relative significance. As a starting point, this assessment considered five indicators: the Drinking Water Safety Indicator (DWSI) and four human dimensional indices, namely the International Wealth Index (IWI), Gender Inequality Index (GII), Gender Parity Index (GPI), and Gender Development Index (GDI). However, the three gender-related indices (GII, GPI,

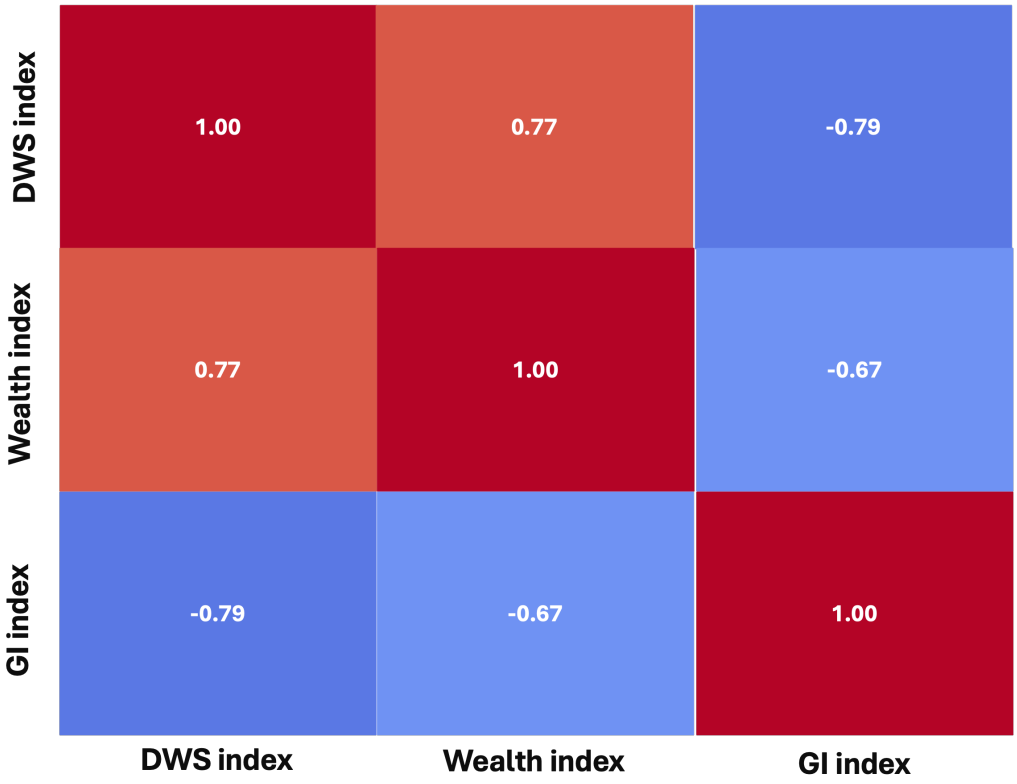


Figure I. Correlation coefficients between the DWSI, IWI and GII.

GDI) do not measure the direct impact of water quality on gender differences. Besides, water safety is not explicitly included in their calculations. To avoid duplicating the gender effect in this assessment, only GII was retained with DWSI and IWI as below. These indices were selected to comprehensively view environmental health, gender disparities, and economic status across countries. The Drinking Water Safety Index (DWSI) measures unsafe drinking water, reflecting both water quality (in terms of its safety and health impact) and infrastructure performance, using the age-standardized DALY rate (disability-adjusted life years lost per 100,000 people) due to exposure to unsafe drinking water. It is an outcome-based indicator derived from IHME (Institute for Health Metrics) data and used in the Environmental Performance Index (EPI), capturing the public health impact of water safety rather than direct water quality parameters. The Gender Inequality Index quantifies disparities between men and women in critical areas such as health, education, and labour market participation. The Wealth Index represents the economic status of a country, indicating the level of prosperity and resources available for infrastructure and social services. The underlying assumption was based on the principle that the DWSI captures the core drinking water-related factor, the IWI highlights socioeconomic inequalities that influence vulnerability to drinking water quality, and the GII mirrors pre-existing gender-related conditions. The data year and sources of DWSI, IWI, and GII are presented as below.

Given the disparate scales of these indices, a two-step normalization process was implemented to ensure fair comparison and analysis. Initially, Z-score normalization was applied to standardize each index, transforming the data with a mean of 0 and a standard deviation of 1. This was done to eliminate bias from the original units or ranges of the indices. The Z-score normalization was then calculated using the formula $Z = (x - \mu) / \sigma$, where x is the original data point, μ is the mean of the dataset, and σ is the standard deviation[57,58]. Following this, Min-Max rescaling was employed to further normalize the indices to a common range of [0, 1]. This helped create a composite index and ensured a balanced comparison across all variables[59].

A correlation analysis was used to quantify the relationships between gender inequality, water safety, and wealth across countries was utilized. Pearson correlation coefficients were calculated between the

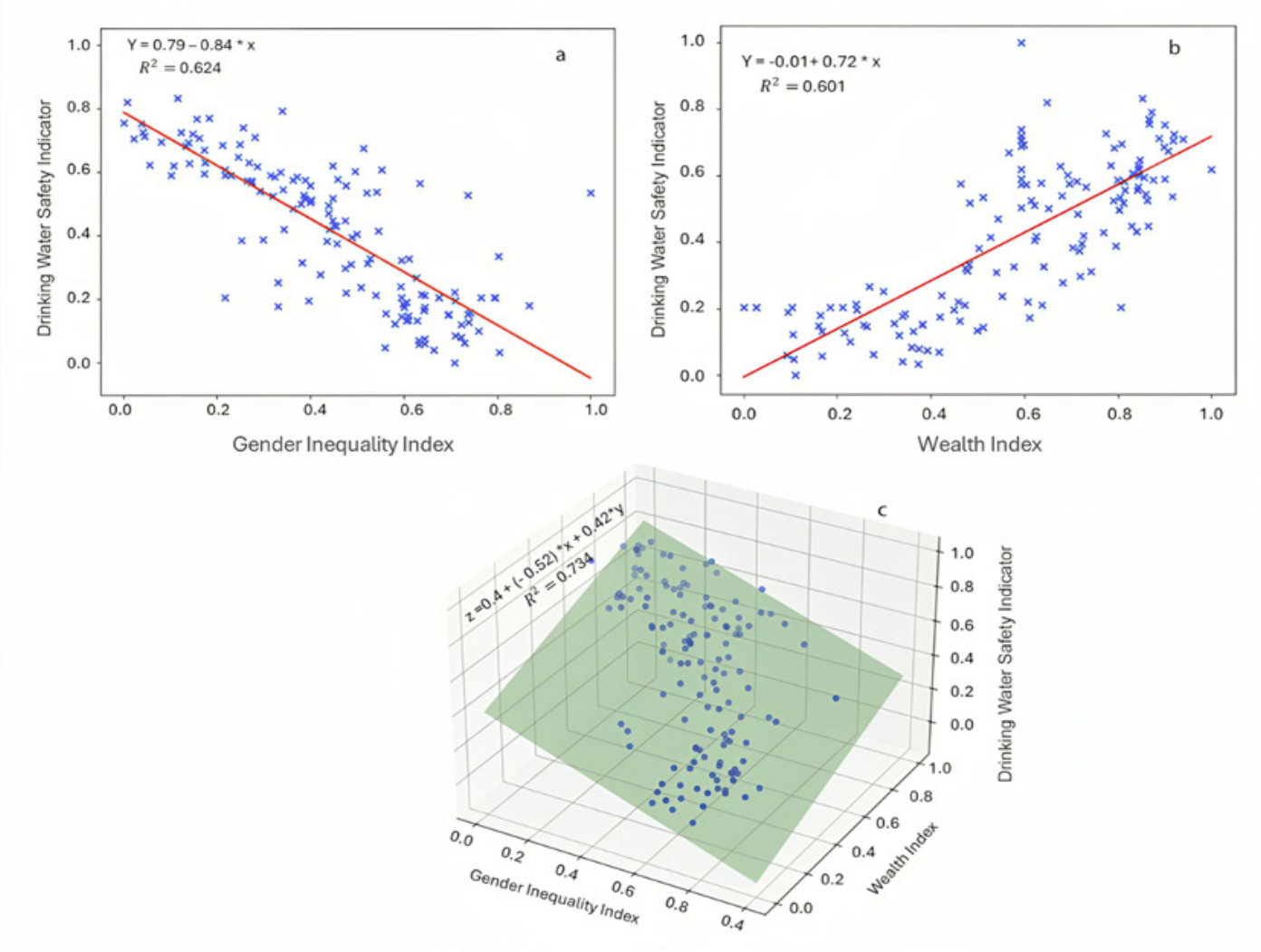


Figure II. Relationship between Drinking Water Safety Indicator and (a) Gender Inequality Index, (b) Wealth Index, and (c) combined GI and Wealth Index.

normalized indices to assess the strength and direction of their linear relationships. This analysis provided valuable insights into how these variables are interconnected on both global and regional scales. A strong positive correlation (0.77) was found between the Drinking Water Safety Indicator (DWSI) and the Wealth Index (IWI); a strong negative correlation (-0.79) was observed between the DWSI and Gender Inequality Index (GII); and a moderate negative correlation (-0.67) was found between the Wealth Index and Gender Inequality Index.

Also, the regression analysis showed a statistically significant negative relationship between gender inequality and water safety ($R^2 = 0.624$, $p = 0.001$). Similarly, a statistically significant positive relationship between wealth and water safety ($R^2 = 0.601$, $p = 0.001$) was observed. However, the multiple regression analysis illustrated that the combination of gender inequality and wealth has better explanatory power for water safety ($R^2 = 0.734$) than either variable. These findings support the development of an integrated water safety-gender-wealth or water quality vulnerability index (WQVI) to holistically evaluate countries on their ability to cope with changes in water quality.

So, these normalized indices were empirically combined to derive the integrated index, WQVI, using a weighted average method[60]. The Weighted Average Method is selected for this assessment due to its ability to incorporate multiple dimensions - Wealth, Gender Inequality, and Water Safety - in a way that reflects their relative importance. This method is widely used in vulnerability assessments[61,62] and multi-criteria decision analysis (MCDA) because of its simplicity and flexibility[63]. Assigning different weights allows policymakers to emphasize factors such as wealth, which is crucial for infrastructure development, or gender inequality, which affects equitable access to clean water[64]. The method's transparency in how weights are applied makes it ideal for creating an index that can be easily interpreted and adjusted according to changing priorities or specific research objectives[65]. Moreover, the approach ensures that the impact of both social inequities and economic capabilities is reflected in the final score, making it a valuable tool for assessing water management performance across countries.

In this study, the assessment emphasizes the combined vulnerabilities associated with water safety, gender inequality, and wealth. To reflect the critical role of water safety in shaping overall vulnerability, it was assigned the highest weight of 0.5 in the WQVI. Gender inequality and wealth, which significantly influence resilience and access to clean water, were given weights of 0.3 and 0.2, respectively. This weighting scheme ensures a reasonable consideration of these interconnected dimensions while prioritizing water safety. Each indicator was weighted with its assigned score and calculated empirically to give a single WQVI score, such that each country's final WQVI score is, practically, the sum of its three weighted indexes' scores, as equation 1 denominator, the sum of the assigned weights equals one. The maximum obtainable WQVI score is 1 point, and the minimum is zero, giving an overall measure of vulnerability to water safety. The principle is that the higher the values of the WQVI score, the lower the vulnerability to changes in water safety, indicating a better overall condition. This WQVI, credited to this paper, not only evaluates a country's overall drinking water quality status but also accounts for the socio-economic factors that shape its ability to cope with changes in water quality. The derived equation is expressed as:

$$WQVI = ([(\alpha \times DWSI) + (\beta \times IWI) + (\gamma \times (1 - GII)])/((\alpha + \beta + \gamma))$$

where α, β, and γ are weights assigned based on each index's relative importance or priority to the concept, with the sum of the weights equal to 1. The term (1-GII) is used to invert the GII score so that higher values correspond to greater gender equality, making it consistent with the other indices, whose higher values indicate better conditions. Missing data were accounted for, but only in countries with data for at least two indices to ensure coverage and sufficient representation of the Global South. For DWSI, missing data for 7 countries (Central African Republic, Chad, Libya, Somalia, South Sudan, Sri Lanka and Yemen) were filled with their respective regional average. For the IWI, missing data for 12 countries (Argentina, Bahamas, Bahrain, Brunei, Bulgaria, Oman, Poland, Qatar, Romania, Russia, Sri Lanka, and St. Vincent) were filled with data from countries in the same IMF 2023 GDP classification. For the GII, missing data for 5 countries (Comoros, Djibouti, Eritrea, Kiribati, and Vanuatu) were filled with their regional average.

The next step was to rank countries by their national WQVI scores. Five categories of national WQVI were defined, adopting a widely used vulnerability classification[66,67,62]. Category 1: Countries in this class have low index scores, indicating a very high vulnerability to changes in water safety. This is a worrying situation. Category 5: Countries that reach this stage have a total WQVI score close to 1. These countries are considered models with negligible vulnerability and better conditions to cope with water safety threats. This approach is designed to aid comparative purposes and to put countries' aspirations into perspective.

Table I. Gender-based indices: Overlapping areas of focus

	Gender Inequality Index	Gender Parity Index	Gender Development Index
Health	Captures reproductive health	Health and survival	Indirectly incorporates health through the Human Development Index (HDI)
Education	Includes empowerment, which likely involves educational factors	Educational attainment	Indirectly incorporates education through the HDI
Economic participation	Captures labour market participation	Economic participation and opportunity	Indirectly incorporates income through the HDI
Scoring	Utilize a 0-1 scale	It uses a 0-1 scale	It uses a ratio of female-to-male HDI values

Table II. Water Safety- Gender- and Wealth-related indices, data source and assigned weights

Index	Description	Empirical Symbol	Data Year	Data Source and Link	Assigned weights
Drinking Water Safety Indicator (DWSI)	Measures unsafe drinking water, reflecting both water quality (in terms of its safety and health impact) and infrastructure performance, using the age-standardized DALY rate (disability-adjusted life years lost per 100,000 people) due to exposure to unsafe drinking water. A score of 100 indicates a country with the lowest DALY rates, while a score of 0 indicates the highest.	α	2022	Institute for Health Metrics & Evaluation's (IHME) Global Burden of Disease (GBD) https://epi.yale.edu/epi-results/2022/component/uwd	0.5
International Wealth Index (IWI)	Measures the economic situation of households in developing countries. It compares societies' performance in wealth, inequality, and poverty. IWI ranges from 0 to 100, with 0 representing households lacking assets and the lowest-quality housing and 100 representing all assets and the highest-quality housing.	β	Most recent year	Global Data Lab https://globaldatalab.org/areadata/table/iwi/	0.2
Gender Inequality Index (GII)	Quantifies gender-based disadvantages in reproductive health, empowerment, and the labour market for various countries. It indicates the potential loss in human development due to gender inequality, ranging from 0 to 1, where one gender performs as poorly as possible in all measured dimensions.	γ	2022	United Nations Development Programme https://hdr.undp.org/data-center/thematic-composite-indices/gender-inequality-index#/indicies/GII	0.3

Table III. National Water Quality Vulnerability Index (WQVI) Scores and Ranking

National Water Quality Vulnerability Index Score	Description	Rank
> 0.80	Negligible: very low vulnerability	5
0.61 – 0.80	Minor: low vulnerability	4
0.41 – 0.60	Moderate vulnerability	3
0.21 – 0.40	Major: high vulnerability	2
< 0.20	Worrying: very high vulnerability	1

Furthermore, a quadrant mapping analysis was performed by exploring the intersections of the rescaled DWSI and IWI, cross-referenced with the inverted gender inequality index (1-GII), to identify priority areas for developmental action in various countries and regions. The quadrant mapping was done by retaining DWSI as the independent variable plotted on the x-axis and IWI and 1-GII as dependent variables on the vertical axis. DWSI values between 0-45 are often considered excellent water quality, while DWSI > 45 mirrors moderate to poor water quality status[68]. However, the actual values of DWSI[69] in this study reflect excellent water quality for a score of 100 and the lowest for a score of 0. This was then normalized alongside both IWI and GII values. All the values for DWSI, IWI and (1 - GII) were benchmarked at the 50th percentile, such that the indices were divided into two equal halves, with 50% of the data points falling above and below. In all, four quadrants were obtained, which provided the basis for further categorization of countries and regions - those in Quadrant 4 (with poor DWSI and low IWI and 1-GII) are critical, requiring urgent attention simultaneously in all aspects of the WQVI.

Also, the World Bank income-based classification, the Gross National Income (GNI) per capita[70], is a key indicator of national economic capacity and development levels, allowing for more straightforward comparisons across countries, regardless of geographic location. So, the WQVI of the Global South countries were further categorized based on the World Bank's national GNI per Capita. These are the low-income economies (GNI < 1,145 USD), lower-middle (1,146 < GNI < 4,515 USD), upper-middle (4,516 < GNI < 14,005 USD), and high-income economies (GNI > 14,005 USD).

Table IV. Description of sections of the quadrant mapping analysis for the Water Quality Vulnerability Index

Quadrant	Description	Status
Quadrant 1	Excellent DWSI; High IWI; High 1-GII	Win-Win-Win
Quadrant 2	Excellent DWSI; Low IWI; Low 1-GII	Win-Lose-Lose
Quadrant 3	Poor DWSI; High IWI; High 1-GII	Lose-Win-Win
Quadrant 4	Poor DWSI; Low IWI; Low 1-GII	Lose-Lose-Lose

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