European Water (2026) 90:2

A brief review of water scarcity indices

I. Villa[1*], A.-F. Papathanasiou[1], I.M. Kourtis[2], A. Bournas[1], E. Stromboula[3], A. Melli[3], V.A. Tsihrintzis[2] and E. Baltas[1]

[1] *Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens (NTUA), 9 Heroon Polytechniou St., Zografou, 15780, Athens, Greece*
[2] *Centre for the Assessment of Natural Hazards and Proactive Planning & Laboratory of Reclamation Works and Water Resources Management, School of Rural, Surveying and Geoinformatics Engineering, National Technical University of Athens (NTUA), 9 Heroon Polytechniou St., Zografou, 15780, Athens, Greece*
[3] *Regulatory Authority for Energy, Waste and Water (RAAEY), 132 Peiraios, 11854, Athens, Greece*
[*] *e-mail:* i_villa@mail.ntua.gr

Abstract: Water scarcity has emerged as one of the most critical environmental and socio-economic challenges of the 21st century. As climate change intensifies hydrological variability (hydrological cycle) and global demand for freshwater continues to rise, robust and comparable indicators for water scarcity assessment are essential tools for mapping the magnitude, drivers and enablers, and consequences of water scarcity across diverse spatial and temporal scales. The present work provides a brief review of twenty widely used water scarcity indices, ranging from simple hydrological ratios to more sophisticated frameworks integrating social vulnerability, ecological needs, and water quality considerations. The indices differ in terms of conceptual basis, data requirements, interpretability, and suitability for specific applications. While traditional indices offer transparency and low data needs, multidimensional indicators can capture the complex socio-hydrological nature of water scarcity; however, these require substantial datasets and, in some cases, subjective weighting. The current review highlights the fact that no single index can fully represent all facets of water scarcity; instead, complementary use of multiple indices provides a more comprehensive understanding of the phenomenon.

Key words: Water scarcity; indices; climate change; integrated water resources management.

1. INTRODUCTION

Growing pressure on water resources has intensified global concern over the ability of societies and ecosystems to meet future water and energy needs (Jacque et al., 2024; Ravinandrasana, and Franzke, 2025). Water scarcity occurs when the demand for freshwater exceeds the volume that is naturally available, accessible, and usable (Baggio et al., 2021). Numerous environmental and human-driven factors influence water availability, including climatic variability, pollution, land-use change, population growth, and economic development (e.g., Ravinandrasana, and Franzke, 2025). Regions with less than approximately 1,000 m^3 of renewable freshwater per capita annually are considered under chronic water scarcity, while values below 500 m^3 per capita signify absolute water scarcity (Ding and Ghosh, 2017). These shortages are distinct from temporary droughts, which represent short to medium term meteorological anomalies resulting from prolonged rainfall deficits (Tsakiris et al., 2013). Drought phenomena can result in the reduction of river flows, soil moisture, and groundwater recharge, whereas aridity phenomena reflect the long-term climatic dryness typical of desert and semi-desert environments (Tsakiris et al., 2013).

The impacts of climate change are projected to intensify water scarcity globally by altering hydrological cycles and increasing the frequency and severity of extreme events (Alehu and Bitana, 2023; De Filippi and Sappa, 2024; Kourtis et al., 2025; Roukounis and Tsihrintzis, 2022; Stamou et al., 2024). Such challenges are central to the United Nations' Sustainable Development Goal (SDG) 6, which aims to ensure sustainable water management, reduce water stress, and enhance water-use efficiency across sectors. Monitoring progress toward these objectives requires robust, transparent, and consistent indicators that capture both the physical availability of water and the pressures exerted upon it.

Research on measuring and assessment of water scarcity phenomena has evolved substantially over the last years, with increasing recognition that scarcity is not solely a function of hydrological availability but also of environmental, socioeconomic, and governance dimensions. Hussain et al. (2022) reviewed twelve commonly used indices, comparing their structural assumptions, spatial and temporal applicability, data requirements, and ability to incorporate factors such as environmental flows, water quality, and green water. Their findings emphasized that while traditional withdrawal-to-availability ratios remain prevalent due to their simplicity, they may risk oversimplification by excluding ecological thresholds and alternative water resources. Pedro-Monzonís et al. (2015) reviewed several water scarcity and drought indicators. They categorized the aforementioned indices according to hydrological behavior, basin characteristics, and decision-making context. They concluded that the performance of the indicators reviewed depended on the scale, the climatic regime, and the monitoring capacity of the system. In addition, they noted that decision makers often select indicators based on data availability. This can lead to misinterpretation of the water scarcity severity and as a result inadequate policy responses. Vanham et al. (2018) focuses specifically on the indicator(s) used to monitor SDG 6.4.2, commonly referred to as the “level of water stress”. They identified conceptual and methodological gaps in the current formulation of the indicator, including failure to distinguish gross from net abstractions, exclusion of green water, inadequate representation of environmental flow requirements, and limited temporal resolution. The authors proposed seven essential components for more robust water scarcity metrics, arguing that improvements are necessary to ensure that SDG reporting reflects true resource pressure and supports meaningful international comparison.

Overall, indices play a critical role in assessing water scarcity by merging different types of datasets into one interpretable quantitative measure attributed to a single value. They also allow comparison across different regions and time scales, help identify vulnerability hotspots, and support decision-making for water resources management. Over the past decades, numerous indices have been proposed, each reflecting different theoretical perspectives, data requirements, and management objectives. The present work tries to provide a brief review of twenty key water scarcity indices.

2. REVIEW OF WATER SCARCITY INDICES

The Normalized Difference Vegetation Index (NDVI) quantifies the water status of the vegetation through the spectral response of the vegetation cover using satellite-derived reflectance in the red and near-infrared bands. Since photosynthetic activity responds to water availability, NDVI serves as a proxy for vegetation moisture stress. Values of the NDVI range from –1 to 1, with higher values reflecting greener, healthier vegetation. While NDVI is widely used for drought monitoring as it used to detect vegetation health, it can offer a simple proxy but only indirect proxy for water scarcity detection.

Falkenmark (1989) developed the Water Stress Index (WSI) one of the most widely used indicators for water scarcity assessment. The WSI evaluates water scarcity based on annual renewable water resources per capita, using a threshold of 1,700 m^3/year to define the onset of regular water stress. Availability below 1,000 m^3 is classified as chronic scarcity that hinders economic development and health, while levels below 500 m^3 represent an absolute constraint to life.

The water stress index developed by Gleick (1996) is often used to assess the scarcity of a country’s renewable water supply to meet all water requirements for human needs in terms of drinking and hygienic services. This index expresses renewable freshwater availability per capita and classifies scarcity using well-known thresholds (e.g., <1700 m^3 per capita per year = stress). Simplicity and interpretability are major strengths; however, averages can mask sub-regional variability and do not account for infrastructure, economic capacity, or variability in sectoral water use.

The Water Resources Vulnerability Index (WRVI) was suggested by Raskin et al. (1997) as a ratio of the total annual withdrawals of water to the total available water resources expressed as a percentage. WRVI categorizes water scarcity when withdrawals exceed 20–40%. Additional socio-economic indicators can be incorporated, allowing for a broader vulnerability perspective.

Loucks (1997) proposed the Sustainability Index (SI) is defined to assess sustainability quantitatively. The SI aggregates multiple indicators of water system performance -such as reliability, resilience, and vulnerability- into a single metric. It requires consistent time-referenced data and aims to evaluate how well resource use aligns with sustainable management objectives.

Virtual Water (VW) has been defined by Allan (1998). VW represents the hidden flow of water embedded in traded goods. The concept of VW helps to illustrate how countries offset local scarcity by importing water-intensive products. While the index can be useful for trade analysis, it does not directly quantify hydrological scarcity.

Alcamo et al. (2003) proposed the Critical Ratio (CR), which is the ratio of water use to water availability, for regional water stress assessment. The CR compares total withdrawals to renewable supplies and identifies scarcity at similar thresholds to WRVI. The index is simple but does not capture adaptation mechanisms, environmental requirements, or non-conventional water sources such as desalination.

The Water Poverty Index (WPI) was developed by Sullivan et al. (2003) to assess whether individuals are water secure at the household and community level. WPI integrates physical, socio-economic, and environmental dimensions of water conditions at household or community levels. Although comprehensive, it requires substantial data and subjective weighting.

The Water Footprint (WF) represents an indicator that measures both the direct and indirect amounts of freshwater used to produce goods or services by an individual, community, organization, or nation. WF was introduced in 2002. It accounts for actual water consumption and related pollution, revealing the often-unseen connection between human activities and water utilization (Vanham and Bidoglio, 2013). It is widely used but may oversimplify spatial and temporal variability when aggregated.

The concept of Water Dependency (WD) originates from the water footprint approach and reflects the extent to which a country relies on water resources from abroad (Rodríguez et al. 2008). It is calculated as the ratio between the external water footprint (WFE), representing the virtual water imported through goods and services, and the total national WF. This ratio measures the share of virtual water imported relative to a nation’s total water footprint. High dependency indicates vulnerability to external supply chains.

Water Exploitation Index (WEI) has been introduced by the Water Scarcity and Drought Expert Group of the European Commission (Casadei et al., 2020). WEI expresses total freshwater abstractions relative to renewable resources on an annual basis. It is intuitive but may underrepresent seasonal and regional pressures.

The WEI is normalized to represent the total available water resources prior to any abstraction. The normalized Water Exploitation Index (nWEI) is calculated monthly and on the sub-basin scale. nWEI calculates exploitation relative to total available resources before abstraction, accounting for outflows and return flows at monthly basin scales.

The Water Exploitation Index Plus (WEI+) expresses total water consumption as a percentage of the renewable freshwater resources available within a specific area and timeframe. WEI+ improves upon WEI by incorporating return flows and measuring actual water consumption rather than withdrawals. It can be calculated at various temporal and spatial scales.

The Water Consumption Index (WEI+c) focuses on net water consumption, considering abstractions minus return flows. WEI+c focuses exclusively on net consumption, aligning closely with ecological flow considerations.

The Ecological Stress Indicator for rivers (ESIr) is designed to assess potential ecological stress resulting from water abstraction activities (CIRCABC 2012). ESIr evaluates ecological pressure by comparing river outflows to total available water. It may become unstable when outflows approach zero and may overlook localized impacts from withdrawals.

Table 1 provides a comparative summary of the water scarcity indices reviewed in this study, including their data requirements, thresholds, and main advantages and disadvantages.

Table 1. Water scarcity indices

a/a	Index	Data Required	Threshold(s)	Main Advantages	Main Disadvantages
1	NDVI	Satellite reflectance, precipitation, temperature	No fixed threshold, values –1 to 1	Good for vegetation stress, broad spatial coverage	Indirect measure, not a true water scarcity index
2	WSI (Falkenmark)	Population, renewable resources	1700, 1000, 500 m^3/capita/year	Easy to understand; widely used	Ignores infrastructure, spatial variability
3	WRVI	Withdrawals, renewable water, GDP, storage, precipitation	>20% scarcity, >40% severe	Captures supply–demand balance	Sensitive to data quality, coarse
4	SI	Multiple performance indicators, weights	0–100 scale	Integrates sustainability dimensions	Subjective weighting, high data needs
5	VW	Production volumes, crop/industry water requirements	None	Highlights trade and hidden flows	Not a scarcity measure on its own
6	CR	Withdrawals, renewable water	20–40% scarcity, >40% severe	Simple, sector-neutral	Excludes adaptation, quality, returns
7	WPI	Physical, social, economic, environmental data	0–100 scale	Holistic, community-scale	Extremely data-intensive
8	WF	Green, blue, grey water data, production stats	None	Detailed consumption + pollution insight	Aggregation issues, spatial complexity
9	WD	External and national water footprint	Higher % = more dependent	Shows import vulnerability	Does not show physical scarcity
10	WEI	Annual withdrawals, renewable water	>20% scarcity	Simple national indicator	Weak on seasonality and returns
11	nWEI	Abstractions, outflows, returns	Context-specific	Captures full resource baseline	Data-heavy, complex
12	WEI+	Withdrawals, returns, renewable water	20% scarcity, 40% severe	Considers consumption, higher accuracy	Needs detailed return-flow data
13	WEI+c	Net consumption, outflows	Context-specific	Focuses on actual consumption	Uncertainty in return-flow estimates
14	ESIr	Outflows, abstractions, returns	High ESIr = low stress	Ecological emphasis	Unstable with low flows
15	Efficiency Indicators	Flows, supply, demand, sectoral reliability	Class-based	Diagnostic for system performance	Requires extensive modelling
16	WAI	Monthly supply and demand	Sectoral thresholds	Good operational tool	Not a pure scarcity metric
17	Water scarcity index considering both water quantity and quality	Withdrawals, grey WF, water quality	Blue >0.4, Grey >1	Integrates pollution & quantity	Complex, not a single value
18	EWR	Hydrology, land cover, infrastructure, demand, reliability	Model-specific	Captures realistic exploitable resources	Requires simulation models and expertise
19	W-ScaRI	Drought indices, demand, exposure, vulnerability, GDP, quality	0–1 range	Risk-based, multidimensional	High complexity and data needs
20	eWPI	Physical access, quality, environment, socio-economic data	0–100 scale	Community development focus	Highly subjective, heavy data load

Martín-Carrasco et al. (2013) introduced four indices for the detection and evaluation of water scarcity at the river basin scale. These indices evaluate demand satisfaction, reliability, environmental sustainability, and management potential at basin level. They can be used as detailed diagnostic tools, but they may require substantial modeling and data.

The Water Allocation Index (WAI), introduced by Milano et al. (2013), expresses the ratio of supply to demand for domestic, agricultural, and environmental uses. Sector-specific thresholds help classify severity. It is primarily a reliability metric. Milano et al. (2013) developed a framework for modeling and evaluating both present and future water resources in the Ebro basin, Spain. The water uses assessed were the following: domestic, agricultural, and environmental flow. Water scarcity in the basin was assessed by employing the WAI. WAI combines blue water scarcity (withdrawals vs. resources) with grey water scarcity (pollution load vs. capacity).

Zheng et al. (2013) introduced a new index accounting for both water quality and quantity to assess water scarcity. The index is data intensive and was also presented as a 2-dimensional result rather than a single value, making it difficult to interpret.

Pedro-Monzonís et al. (2015) proposed a framework for accounting for the Exploitable Water Resources (EWR) in the basin level. Exploitable water resources refer to water that is available under specific economic, technical and environmental conditions. EWR represents the maximum demand that can be met while satisfying legal reliability constraints. It requires detailed hydrological and infrastructure modelling and includes both physical and operational factors.

Thomaz et al. (2023) recently proposed a new index called Water Scarcity Risk Index (W-ScaRI). W-ScaRI is based on the risk framework with the water scarcity risk assessed as a functional relationship of hazard, vulnerability, and exposure. The index is highly comprehensive but data demanding and reliant on subjective weighting.

Sullivan et al. (2003) introduced the Water Poverty Index (WPI), aiming to serve as a water scarcity index at the household and/or community level combining physical, social, economic and environmental information. eWPI refines WPI for community-scale development contexts, integrating environmental, social, economic, and physical access dimensions. Its complexity and large data burden are major limitations.

3. DISCUSSION

Water scarcity indices have evolved from simple threshold-based metrics to diverse, purpose-specific tools serving complementary rather than competing roles in water resources assessment. Studies identified various and different essential components for comprehensive assessment of water scarcity.

The reviewed indices demonstrated a broad spectrum of conceptual approaches to evaluating water scarcity. Traditional indices such as the Falkenmark Indicator, WRVI, and the CR index focuses on the balance between renewable resources and withdrawals. They are widely used due to their simplicity and the minimal data requirements, making them suitable for global or national assessments. However, these indices often overlook spatial heterogeneity, seasonal variation, infrastructure, and the role of non-conventional water sources.

More recent indices such as WEI+, nWEI, and WEI+c attempt to resolve these limitations by incorporating return flows, monthly time steps, and environmentally relevant outflows. These improvements provide a more accurate depiction of water scarcity, particularly in basins where withdrawals and returns are substantial; however, their data needs are augmented, which may limit their applicability in data scarce regions.

Composite and multidimensional indices such as the WPI, eWPI, SI, and W-ScaRI, reflect the growing recognition that water scarcity is not exclusively a physical phenomenon but also a socio-economic one. These indices integrate vulnerability, exposure, adaptive capacity, governance, and environmental flows. While they offer richer insights for holistic water resource management, their reliance on subjective weighting and heterogeneous datasets can compromise comparability and reproducibility.

Quality-oriented indices such as the index proposed by Zheng et al. (2013) highlight the critical role of pollution, which can effectively reduce usable resources even where physical water availability appears sufficient.

Overall, no single index can capture all dimensions of water scarcity. The optimal choice depends on scale, data availability, management objectives, and whether the emphasis is on physical availability, risk, sustainability, or socio-economic impacts. A combined approach, using complementary indices/data, is often more effective for operational decision-making. A new index is needed that could account for: environmental flow, temporal scale, renewable surface water and groundwater resources, alternative water resources and water storage in reservoirs. Environmental flow requirements must be incorporated to ensure ecosystem sustainability. In addition, finer spatial and temporal scales are needed in order to improve accuracy and assess the phenomenon in intra- and inter-annual variability rather than relying solely on annual averages. Surface water and groundwater resources must be accounted for along with alternative water resources (e.g., desalinated water). Finally, water storage in reservoirs, recycled water and managed aquifer recharge can represent important elements that should be accounted for in the assessment of water scarcity.

REFERENCES

Alcamo, J., Henrichs, T., & Rösch, T., 2000. World water in 2025: Global modeling and scenario analysis for the World Commission on Water for the 21st Century. Center for Environmental Systems Research, University of Kassel.

Alehu, B.A. and Bitana, S.G., 2023. Assessment of climate change impact on water balance of Lake Hawassa Catchment. Environmental Processes, 10(1): 14.

Allan, J.A., 1998. Virtual water: a strategic resource, global solutions to regional deficits. Groundwater 36 (4) : 545–546.

Baggio, G., Qadir, M. and Smakhtin, V., 2021. Freshwater availability status across countries for human and ecosystem needs. Science of the Total Environment, 792: 148230.

Casadei, S., Peppoloni, F., & Pierleoni, A., 2020. A revised approach for calculating the WEI+. Water, 12(11): 3227.

CIRCABC, 2012. Informal meeting of Water and Marine Directors of the European Union, Candidate and EFTA Countries. Copenhagen, 4–5 June 2012. Synthesis, Communication and Information Resource Centre for Administrations, Businesses and Citizens.

De Filippi, F.M. and Sappa, G., 2024. The simulation of Bracciano Lake (Central Italy) levels based on hydrogeological water budget: A tool for lake water management when climate change and anthropogenic impacts occur. Environmental Processes, 11(1): 8.

Ding, G.K.C. and Ghosh, S., 2017. Sustainable water management-A strategy for maintaining future water resources. Encyclopedia of sustainable technologies.

Falkenmark, M., Lundqvist, J., & Widstrand, C., 1989. Macro-scale water scarcity and micro-scale approaches. Natural Resources Forum, 13: 258-267.

Gleick, P. H., & Cooley, H., 2021. Freshwater scarcity. Annual Review of Environment and Resources, 46: 319–348.

Hussain, Z., Wang, Z., Wang, J., Yang, H., Arfan, M., Hassan, D., Wang, W., Azam, M.I. and Faisal, M., 2022. A comparative appraisal of classical and holistic water scarcity indicators. Water Resources Management, 36(3): 931-950.

Jacque, H., Mozafari, B., Dereli, R.K. and Cotterill, S., 2024. Implications of water conservation measures on urban water cycle: A review. Sustainable Production and Consumption, 50: 571-586.

Kourtis, I.M., Papadopoulou, C.A., Trabucco, A., Peano, D., Sangelantoni, L., Mellios, N., Laspidou, C., Papadopoulou, M.P. and Tsihrintzis, V.A., 2025. Methodological framework for the evaluation of climate change impacts on rural basins using the GR2M model. Environmental Processes, 12(1): 1-26.

Loucks, D.P., 1997. Quantifying trends in system sustainability. Hydrological Sciences Journal, 42 (4): 513–530.

Martin-Carrasco, F., Garrote, L., Iglesias, A. and Mediero, L., 2013. Diagnosing causes of water scarcity in complex water resources systems and identifying risk management actions. Water resources management, 27(6): 1693-1705.

Milano, M., Ruelland, D., Dezetter, A., Fabre, J., Ardoin-Bardin, S. and Servat, E., 2013. Modeling the current and future capacity of water resources to meet water demands in the Ebro basin. Journal of Hydrology, 500: 114-126.

Pedro-Monzonís, M., Ferrer, J., Solera, A., Estrela, T. and Paredes-Arquiola, J., 2015. Key issues for determining the exploitable water resources in a Mediterranean river basin. Science of the Total Environment, 503: 319-328.

Raskin, P. et al., 1997. Water Futures. Stockholm Environment Institute.

Ravinandrasana, V.P. and Franzke, C.L., 2025. The first emergence of unprecedented global water scarcity in the Anthropocene. Nature Communications, 16(1): 8281.

Rodríguez, R., Garrido, A., Llamas, M.R., Varela, C., 2008. La huella hidrológica de la agricultura española. Papeles de Agua Virtual No 2. Fundación Marcelino Botín. Santander.

Roukounis, C.N. and Tsihrintzis, V.A., 2022. Indices of coastal vulnerability to climate change: a review. Environmental Processes, 9(2): 29.

Stamou, A., Mitsopoulos, G. and Koutroulis, A., 2024. Proposed methodology for climate change adaptation of water infrastructures in the Mediterranean Region. Environmental Processes, 11(1) : 12.

Sullivan, C. A., Meigh, J.R. and Giacomello, A.M., 2003. The Water Poverty Index: Development and application at the community scale. Natural Resources Forum, 27: 189–199.

Thomaz, F.R., Miguez, M.G., de Souza Ribeiro de Sá, J.G., de Moura Alberto, G.W. and Fontes, J.P.M., 2023. Water scarcity risk index: A tool for strategic drought risk management. Water, 15(2): 255.

Tsakiris, G., Nalbantis, I., Vangelis, H., Verbeiren, B., Huysmans, M., Tychon, B., Jacquemin, I., Canters, F., Vanderhaegen, S., Engelen, G. and Poelmans, L., 2013. A system-based paradigm of drought analysis for operational management. Water resources management, 27(15): 5281-5297.

Vanham, D., & Bidoglio, G. (2013). Review of the water footprint indicator for the EU28. Ecological Indicators, 26: 61–75.

Vanham, D., Hoekstra, A.Y., Wada, Y., Bouraoui, F., de Roo, A., Mekonnen, M.M., Van De Bund, W.J., Batelaan, O., Pavelic, P., Bastiaanssen, W.G. and Kummu, M., 2018. Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4. 2 "Level of water stress". Science of the total environment, 613: 218-232.

Zeng, Z., Liu, J., Savenije, H., 2013. A simple approach to assess water scarcity integrating water quantity and quality. Ecol. Indicat. 34: 441–449.