




A comparative Appraisal of Classical and Holistic Water Scarcity Indicators

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Abstract

Precise measurement of water scarcity is a prerequisite to effective resource management. Researchers have developed a range of water scarcity indicators. However, no single indicator grasping all dimensions is available. In this paper, we compared 12 indicators for their sensitivity to blue and green waters, quality-induced water scarcity, environmental flows, data requirements, spatial scale, and adaptive capacity. Also, an analysis was carried out based on previous studies to identify hotspots and show the dissimilarity in the results yielded by different indicators. We found four classical indicators considered in this study deficient in accuracy given their insensitivity to green water, quality-induced water scarcity, environmental flow requirement, seasonality, virtual water, and so on. Whereas, seven holistic indicators face the challenges of data scarcity, validation, and lack of wide-spread application. None of these indicators is inclusive enough to provide a broad-gauge assessment. Finally, we provided a profound discussion on the limitations and needs of creativity in indicators and the data challenges. We concluded that water scarcity measurement in a country or region should not be based on a single indicator. A country-specific selection of multiple indicators should be made to cover the maximum parameters in view of spatial scale and data requirements.

Keywords Water scarcity · Indicators · Quality-induced water scarcity · Water Poverty Index · SGD6

Abbreviations

CR	Criticality Ratio
CTA	Consumption to Availability Ratio
EFR	Environmental Flow Requirement
FI	Falkenmark's Indicator
LCA	Life Cycle Assessment
MENA	Middle East & North Africa
VWT	Virtual Water Trade

Extended author information available on the last page of the article

WF	Water Footprint
WEI	Water Exploitation Index
WPI	Water Poverty Index
WTA	Withdrawal to Availability Ratio

1 Introduction

Water scarcity, defined as a condition when available water resources fail to satisfy demand, is one of the defining challenges of the 21st century (Pearce 2019). The World Economic Forum 2019 identified water scarcity as one of the largest global risks that could impact the world over the next decade (World Economic Forum 2019). The Food and Agriculture Organization (FAO) of the United Nation (UN) estimated that around 4 billion people experience water scarcity during at least one month annually, in addition, more than half a billion live under severe water scarcity permanently (Mekonnen and Hoekstra 2016). Ever increasing water consumption owing to population growth has put the resource base under immense pressure.

Given the dynamic nature of water resources, accurate measurement of water scarcity is a challenging task. It is a complex phenomenon that appears in various forms. Physical scarcity is essentially a resource scarcity when there is insufficient available water to meet demand. Economic scarcity corresponds to a condition when water is available physically, but the lack of financial or human resources creates a supply-demand gap (Chen et al. 2018). Institutional scarcity occurs when a society fails to provide responsive institutional and technological interventions to address supply-demand gaps. Political scarcity arises when political subordination stops a group of people from accessing available water resources.

In addition to the type of water scarcity, what makes the assessment complex is the type of water itself. Blue water i.e. the water present in surface and groundwater reservoirs (Gain and Wada 2014), green water i.e., rainwater stored in the upper layers of the soil (Lee and Bae 2015), and grey water i.e. water required to assimilate the pollutants to keep the overall quality within usable limits (Yin and Xu 2020). Unlike blue water, green water is difficult to measure accurately as the transfer of water vapors from non-croplands to the atmosphere is not calculated while measuring evapotranspiration. The grey water requirement is calculated against the level of pollution.

Water scarcity indicators are essential to assess the extent of the problem. A thorough understanding of water scarcity helps formulate local, national, regional, and global policies aimed at effective management. Water scarcity indicators serve this need by pointing out the type and severity of water scarcity and identifying the areas to be addressed. These indicators are supposed to assess the supply-demand gap and management plans are framed based on these assessments. Hence, they serve as a bridge between science and policy and enable decision-makers to make information-based decisions.

The literature reveals that none of the 150+ water scarcity indicators developed so far, based on various approaches is holistic enough to encompass all facets of water scarcity (UNESCO World Water Assessment Programme (WWAP) 2003; Vörösmarty et al. 2005). The indicators based on resource availability ignore socioeconomic aspects, while those based on human water requirements overlook the quality-induced water scarcity. Some do not add green and grey water to the equation, while some ignore EFR defined as the quan-

tity, quality and timing of flows required for sustaining river ecosystems and human livelihoods. The measurements made by different indicators can present contradicting results and mislead public opinion and decision-making by creating a false sense of security or insecurity. Therefore, water scarcity indicators were termed “deception of numbers” in the literature (Savenije 2000).

Previous reviews of water scarcity indicators can be classified into three categories: (i) comprised of critiques pointing out basic flaws in indicators. Previous studies identified several inconsistencies related to the application and meaningfulness of the water scarcity indicators (Savenije 2000; Chenoweth 2008; Serrano et al. 2016; Damkjaer and Taylor 2017); (2) one specific class of indicators has been reviewed. For example, Schyns et al. (2015) reviewed green water scarcity indicators, Molle and Mollinga (2003) analyzed water poverty indicators, and Hoekstra (2017) appraised water footprint assessments; (3) indicators have been selected from various classes and reviews have been carried out for their strengths, shortcomings, and usage (Plummer et al. 2012; Norman et al. 2013; De Grosbois and Plummer 2015; Pedro-Monzonis et al. 2015; Haak and Pagilla 2020).

In this article, we have compared 12 water scarcity indicators against 7 parameters of comparison, showing how these indicators miss certain areas and how they can be used collectively to supplement their deficiencies. Out of 12 indicators, 5 are the most widely used classical and 7 are promising holistic indicators. Some water scarcity hotspots have also been identified to show how different indicators yield different results.

2 Water Scarcity Indicators

2.1 Classical Indicators

Classical water scarcity indicators were developed soon after water scarcity became a pervasive concern in the 1980s. Most of these indicators have addressed one or more aspects of water scarcity with a sectoral approach.

2.1.1 Falkenmark's Indicator

Falkenmark Indicator was the first indicator used on a national scale where requisite data is readily available (Brown et al. 2011). This index measures blue water availability and quantifies annual per capita water requirements. Its key strength, making it the most commonly used measure of water resources, is its ability to differentiate between climate-induced and anthropogenic water scarcity (Vörösmarty et al. 2005).

This indicator calculates water availability with the view that resources are fixed while the population is growing and draws a neo-Malthusian picture (Chenoweth 2008). A key limitation is its inability to take into account the water distribution and usage patterns of countries while overlooking the adaptive capacities of societies. For example, many Middle Eastern countries have managed to ensure food security by importing food from the global market amid acute in-house water scarcity (Allan 1997). Hence, the idea of the existence of a strong linkage between water resource availability and food security (Falkenmark et al. 1989) has been questioned. Also, it is insensitive to green water, quality-induced water scarcity, and EFR. Fig. 1 shows world map of water scarcity as per the Falkenmark Indicator.

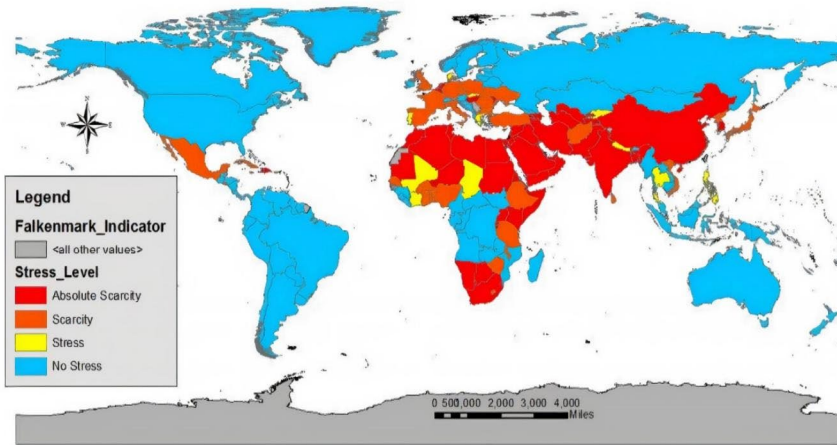


Fig. 1 World Map of Water Scarcity as per the Falkenmark Indicator. (Source: University of Texas)

2.1.2 Criticality Ratio

The Criticality Ratio assesses water scarcity as a ratio of annual water use to total water resource availability (Perveen and James 2010). If the ratio is found to be between 20 and 40%, the country is considered water-scarce. A threshold of 40% represents the percentage of water withdrawn from the available resources. The term “water use” was later interpreted by the researchers both as “water consumption” (the amount of water actually used which does not return to the source) and “water withdrawal” (the total amount of water removed from the sources, of which a fraction is consumed and the remaining water returns to the source). As water consumption is significantly less than water withdrawal, the use of either figure yields different results. A majority of the studies based on CR used the withdrawal to

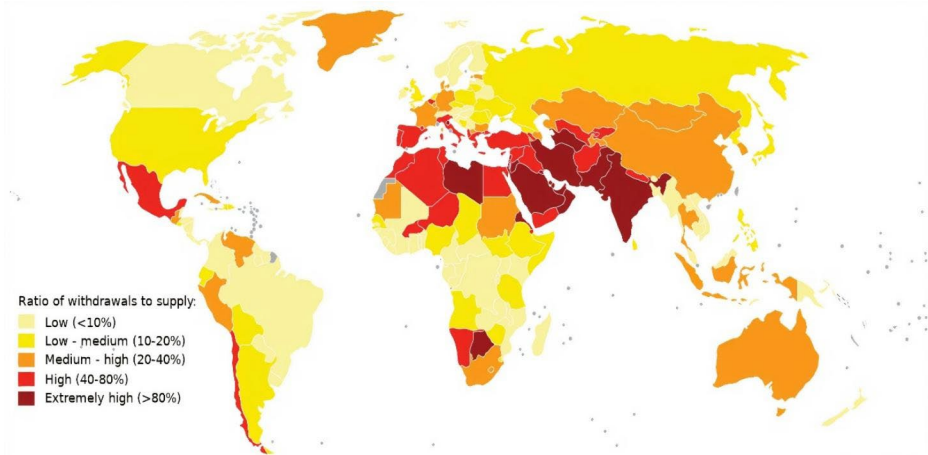


Fig. 2 World Map of Water Scarcity as per Withdrawal to Availability Ratio. (Source: World Resources Institute)

availability ratio (WTA) (Wada et al. 2011). Some studies have considered WTA as maximum and CTA as minimum water scarcity (Munia et al. 2016). However, there is still the possibility of misrepresentation of water scarcity. Although CR is sensitive to demand variations, it overlooks several technological and social interventions like desalination, recycling, reuse of withdrawn water, and adaptive capacity. Also, it does not consider green water and quality-induced scarcity. Moreover, the threshold of 40% is based on the assumption that a country can store nearly one-third of river flows in its reservoirs (Hanasaki et al. 2018). Over time, this threshold has become debatable as many countries have increased storage capacity far beyond 1/3. Fig. 2 shows world map of water scarcity as per withdrawal to availability ratio.

2.1.3 International Water Management Institute (IWMI) Indicator

IWMI Indicator differentiates between physical and economic water scarcity (Molden 2007). Physical scarcity cannot be overcome by investing in infrastructure, while economic scarcity can be cured by building adequate infrastructure (Seckler et al. 1998). A country with more than 75% of its river flows withdrawn is considered physically scarce (Brown and Matlock 2011), whereas a country withdrawing less than 25% and showing symptoms of water scarcity, is identified as economically scarce (Rijsberman 2006). Figure 3 shows a global overview in 2008. The IWMI indicator is wide-ranging compared to the FI and is sensitive to adaptive capacity at the macro level. However, it is complex to calculate and is indifferent to the adaptive capacity of individual users. For example, the micro-scale infrastructure like the High-Efficiency Irrigation System adopted by progressive farmers can make a visible difference by reducing water consumption (Peterson 2005).

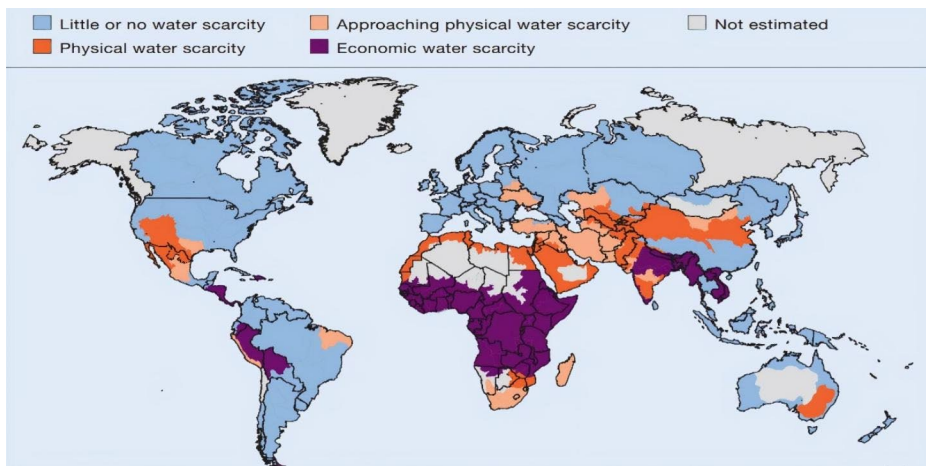


Fig. 3 World Map of Water Scarcity as per the IWMI Indicator. (Source: IWMI)

2.1.4 Water Poverty Index

WPI is calculated using five key components: (1) water availability; (2) population access in terms of time and distance from a water source; (3) institutional capacity to ensure efficient water management and the ability of the population to afford water-saving technologies; (4) use of water for agricultural, industrial, municipal, and environmental purposes; and (5) environment (Sullivan et al. 2003). As per the weighted multiplicative function, the components of WPI may be aggregated as under:

$$WPI = (w_r * R + w_a * A + w_c * C + w_u * U + w_e * E) / (w_r + w_a + w_c + w_u + w_e) \quad (1)$$

Where WPI means Water Poverty Index, R denotes resources, A depicts access, C shows capacity, U means the use of water, E represents environmental flows, and w_r, w_a, w_c, w_u, w_e are the weighting factors of respective components, i.e., R, A, C, U, and E.

Originally considered suitable for usage at the community level, WPI's implementation later expanded to larger areas (Sullivan et al. 2006; Shalamzari and Zhang 2018). Though not as simple and straightforward as FI and CR, WPI can help make rational decisions and monitor water scarcity in interdisciplinary areas. On the flip side, it has huge data requirements and complex calculations. WPI considers blue water and EFR but is insensitive to green water and quality-induced scarcity.

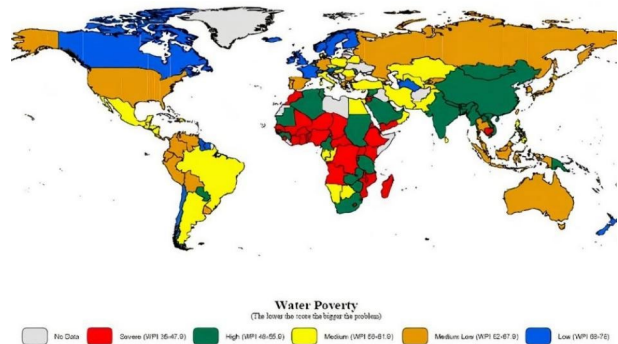
2.1.5 SDG6 Indicator (Water Stress)

Sustainable Development Goal 6 aims to ensure the sustainable development of water resources and ecosystems for providing clean drinking water and sanitation to all (Berger et al. 2021). To track the progress on SDG6, 11 indicators have been framed, of which the indicator 6.4.2 relates to the "Level of Water Stress" and is expressed as:

$$WS (\%) = \frac{TFWW}{TRWR - EFR} * 100 \quad (2)$$

Where WS stands for water stress, TFWW for total freshwater withdrawn, TRWR for total renewable water resources, and EFR for environmental flow requirement (Vanham et al. 2018). This is primarily a blue water stress indicator that does not distinguish between

Fig. 4 World Map of Water Poverty (Source: The Centre for Ecology & Hydrology of the UK)



water withdrawal and water consumption. It does not take into account green water, quality-induced water scarcity, adaptive capacity, and seasonality. However, the indicators 6.3.1 and 6.3.2 of the SDG6 framework, which relate to wastewater treatment and water quality, can indirectly give a picture of quality-induced scarcity.

2.2 Holistic Indicators

Holistic indicators, covering multiple aspects of water scarcity, are further categorized into two classes: (1) based on water accounting and (2) sensitive to quality induced water scarcity.

Water accounting aims at providing policy-centric information in a comprehensive, comparable, and consistent manner (Hazelton 2015). Indicators based on accounting follow the water balance approach (i.e. water inputs should be equal to water output in addition to any change in storage) (Van Dijk et al. 2014).

Quality-induced scarcity can considerably influence the overall availability of water resources. Water quality is deteriorated by a range of pollutants, and water quality standards vary for drinking, irrigation, and municipal water. Hence, data collection, parameter selection, and development of an aggregate indicator are uphill tasks. Some promising accounting-based and quality-sensitive indicators have been reviewed.

2.2.1 The System for Environmental-Economic Accounting of Water (SEEAW)

The System for Environmental-Economic Accounting (SEEA), developed by the UN Statistics Division, provides a conceptual framework for better organization of information related to economics and the environment (United Nations 2012). It describes the relationship between water and the economy and aims at standardization of water accounting as a decision support tool for water allocations and management.

As of 2020, 89 countries employed SEEA at different stages and coverage. A total of 62 countries, identified at Stage-III, regularly published at least one of many accounts on this platform. 11 countries existed at Stage-II that published their accounts on an ad-hoc basis. The remaining 16 countries at Stage-I were in the process of compiling the data. A total of 27 countries were planning data compilation. The UN set a target of 100 countries with ongoing, well-resourced SEEA programs, out of which 50 would be using it as a decision support tool by 2020. SEEAW is inevitably data-intensive, complex, and especially challenging at large basin scales. It is sensitive to seasonality, transboundary waters, and inter-annual variability.

2.2.2 Water Exploitation Index

WEI is the percentage of the mean annual total demand against mean annual freshwater resources in the long term (Casadei et al. 2020). Results are categorized as (European Environment Agency 2013):

WEI < 20% = no water scarcity.

WEI ranges 21–40% = water scarcity.

WEI > 40% = extreme water scarcity.

On the flip side, its calculations, based on annual averages, do not represent the monthly variability (Pedro-Monzonís et al. 2015). Its complex environment may produce unreliable results if demands and resources are not correctly calculated.

To overcome these limitations, the modified Water Exploitation Index+ was introduced. The WEI+ can be expressed as:

$$WEI+ = \frac{(Abstractions - Returns)}{RenewableWaterResources} \quad (3)$$

Where, Abstraction means total water withdrawn, Returns means the amount of water not used consumptively and rejoins the environment, and Renewable Water Resources refer to the blue water that can be replenished by precipitation and recharging.

WEI+ can be defined on the various time scales and, hence, addresses the seasonality issue. The WEI+ application has mostly been limited to Europe, where the European Environmental Agency (EEA) has adopted it and assessments are available from 1990 to 2017 (European Environment Agency 2021).

2.2.3 Water Footprint and Virtual Water

The concept of virtual water was first presented by Allan (1997) as a possible means to mitigate the impacts of water scarcity. The virtual water trade between the land-rich-water-poor countries and water-rich-land-poor countries has exacerbated the problem for water-poor countries (Kumar and Singh 2005).

The Water Footprint approach, introduced by Hoekstra et al. (2011), takes into account all links in the supply chain and measures the freshwater used for the production of goods and services utilized by the end consumer. It can differentiate between blue, green, and grey waters and is sensitive to the virtual water trade (Aldaya et al. 2010).

The dependency ratio, used to assess the share of virtual water in total water consumed, is calculated as under:

$$WD (\%) = \frac{WFE}{WF} \cdot 100 \quad (4)$$

Where WD means water dependency ratio, WFE means external water footprint, and WF means national water footprint.

The data requirements for WF assessment are huge, whereas, available studies at the basin level are rare. Moreover, the amount of water consumed during the production of particular products may vary from region to region, leading to data inconsistency issues. Another drawback is the assumption of an EFR of 80%, which is way too high for many river basins. This figure is a presumptive standard based on the Sustainability Boundary Approach, suggested by Richtler (2009) for basins with no or little scientific calculation of EFR. This overestimation of EFR can lead to the overestimation of water scarcity (Pastor et al. 2014). Fig. 5 shows the world map of virtual water trade.

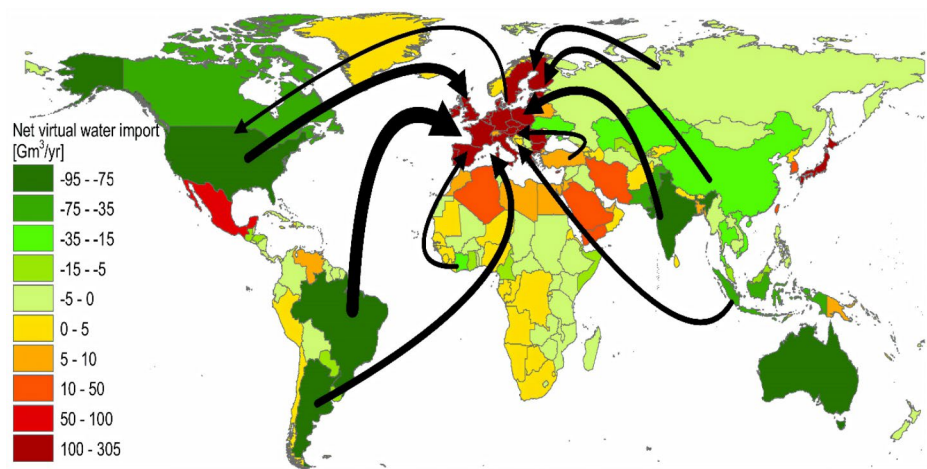


Fig. 5 World Map of Virtual Water Trade. (Source: Hoekstra A.Y. et al.)

2.2.4 Green-Blue Scarcity Indicator

An accurate measurement is impossible without accounting for green water, which irrigates 80% of global cropland (Rost et al. 2008) and produces 60% of total food (Lundquist 1997). To integrate both waters into one indicator, (Rockström et al. 2009) proposed the green-blue indicator. This indicator compares to the global average of 1300 m³/capita/day of green-blue water required to produce food carrying 3000 kilocalories/capita/day. A country falling short of this threshold is considered water-scarce. However, the amount of water required to produce the same amount of food varies among countries. It is the lowest in Western Europe and a major portion of North America (<650 m³ /capita/day), moderate in South America, Southern parts of North America and larger parts of Asia (650–1300 m³ /capita/day), and the highest in the African continent (>1300 m³/capita/day) (Kummu et al. 2014). Gerten et al. (2011) have investigated to make this indicator country-specific. This indicator assumes 30% EFR, though not based on some scientific findings. Data inconsistency issues limit its widespread use. The indicator does not account for the evapotranspiration from non-croplands.

2.2.5 LCA Based Indicators

The Life Cycle Assessment methodology assesses environmental impacts along the life cycle of a product. This methodology was employed to gauge water scarcity and related environmental impacts by Frischknecht et al. (2009) and Pfister et al. (2009). Later on, Berger et al. (2014) developed the Water Accounting and Vulnerability Evaluation (WAVE) model that considers atmospheric evaporation recycling within the basins that can save up to 32% of water. WAVE focuses on freshwater depletion in basins as a result of consumption using the Water Depletion Index based on physical blue scarcity (Pfister et al. 2009). LCA-based water scarcity indicators can be categorized as midpoint indicators (that take water scarcity as a resource problem), and endpoint indicators (that focus on ecological and health-related impacts). Water scarcity is addressed by LCA at the midpoint level. Both

types of LCA-based indicators are applicable at a watershed scale (Berger et al. 2014). These indicators consider blue and green water as well as quality-induced water scarcity. On the downside, LCAs are operation-specific and hard to transpose to other operations. The data requirements are huge and sometimes estimates have to be used for lack of precise data (Kounina et al. 2013).

2.2.6 Zeng’s Quantity-Quality Indicator (QQ)

Zeng et al. (2013) came up with a simple yet novel approach to include quality-induced scarcity in water measurement. This index assesses water quality by the amount of water required to assimilate the pollutants and dilute them to acceptable water quality standards. The index is presented as:

$$I = I_{blue} + I_{grey} \tag{5}$$

Where I denotes Zeng’s QQ indicator, I_{blue} represents quantity oriented water scarcity based on criticality ratio whereas I_{grey} denotes quality-induced water scarcity that considers the amount of water required for dilution of pollutants to an acceptable level. If $I_{blue} > 0.4$, the region is facing serious water scarcity from a quantity standpoint. $I_{grey} \geq 1$ represents quality-induced water scarcity. Zeng’s indicator is simple and has low data demand. It has successfully been used in Beijing city and major river basins of China. On the downside, this indicator does not consider green water and EFR. Socioeconomic aspects fall beyond the scope of this indicator as it primarily focuses on physical water scarcity (Zeng et al. 2013).

2.2.7 Quantity-Quality-EFR Indicator (QQE)

Zeng’s QQ indicator was taken up by Liu et al. (2016) for the inclusion of EFR as:

$$S_{qqe} = S_{quantity}(P) | S_{quality} \tag{6}$$

$$S_{quantity} = \frac{BWF}{BWA} = \frac{W * R}{BWR - EFR} \tag{7}$$

$$S_{quality} = \frac{GWF}{BWR} \tag{8}$$

$$EFR = \sum_{i=1}^{12} e_{ij} \tag{9}$$

$$e_{ij} = 3600 * 24 * n_i * Q_i * P_{ij} \tag{10}$$

$$GWF = L / (C_{max} - C_{nat}) \tag{11}$$

Where S_{qqc} means overall water scarcity, $S_{quantity}$ is quantitative scarcity, $S_{quality}$ is quality-induced water scarcity, and P is the percentage of EFR in total blue water resources, Where BWF means blue water footprint, BWA represents blue water availability, W is blue water withdrawal, R is the water consumption ratio, BWR is total blue water resources, GWF is grey water footprint, e_{ij} is the EFR in the month under consideration (i) for the desired habitat quality level (j), n_i shows the number of days in the month (i), Q_i shows mean daily flow in in the month (i), P_{ij} is the percentage of mean annual flow during the month (i) at habitat quality level of j. L is the pollutant load, C_{max} is the maximum acceptable concentration of water quality and C_{nat} is the natural pollutant concentration in the concerned water body.

The indicator was first used in the Huangqihai river basin of China and yielded values of $S_{quantity}$, EFR and $S_{quality}$ to be 1.3, 26% and 14.2, respectively. The threshold of both $S_{quantity}$ and $S_{quality}$ is 1 (Hoekstra et al. 2011). Therefore, the basin faces both quantity-induced and quality-induced scarcity. The startlingly high value of $S_{quality}$ (14.2) shows acute pollution. The value of P indicates that 26% of total blue water resources should be spared as EFR. This indicator has many upsides, e.g., a single indicator amalgamating quantity, quality, and ecological aspects; low data requirements; and applicability to other regions and scales. The key limitations are insensitivity to green water and complex results requiring professional understanding (Liu et al. 2016).

Table 1 Areas of Water Scarcity Covered by Various Indicators

Sr	Indicator	Coverage*					Suitable Spatial Scale	Data Requirement	
		BW	GW	WQ	EFR	Adaptive Capacity			
1-5	Classical indicators	FI	✓					Country	Low
		CR	✓			✓		Country	Low
		IWMI Indicator	✓				✓	Country	Medium
		WPI	✓			✓	✓	Community	High
		SDG6 indicator 6.4.2	✓			✓		Country	Low
6-8	Holistic indicators	SEEAW	✓		✓	✓	✓	Country	High
		WEI+	✓			✓		Country	High
		Water Footprint and Virtual Water	✓	✓		✓	✓**	Country	High
9		Green-Blue Scarcity Indicator	✓	✓		✓		Country	High
10		LCA	✓	✓	✓			Watershed	High
11		Q-Q Indicator	✓		✓			Region/ River Basin	Low
12		QQE Indicator	✓		✓	✓		Region/ River Basin	Medium

*Inspired from (Liu et al. 2017)

** Flow of virtual water can be used/checked to adapt to the situations

3 Water scarcity Indicators Comparison

3.1 Comparison criteria

Table 1 compares all 12 indicators reviewed in this study against the parameters listed below. No indicator covers all these parameters simultaneously. Therefore, adoption of single indicator is not an option and a selection has to be made of multiple indicators so as to make a reasonably inclusive and realistic assessment of water scarcity.

- i. Blue water (BW).
- ii. Green water (GW).
- iii. Water quality-induced water scarcity (WQ).
- iv. EFR.
- v. The adaptive capacity of nations.
- vi. The spatial scale at which the indicator is suitably applicable.
- vii. Data requirements..

3.2 Water Scarcity Hotspots

The maps used in this study were utilized to identify three water scarcity hotspots i.e., MENA, South Asia, and Africa, and to show how different indicators produce different results. For this purpose, the thresholds of FI, CR, IWMI indicator, WPI, and VWT & WF were reduced to three categories, as shown in Table 2, depicting no or little scarcity, moderate scarcity, and severe scarcity.

MENA was found to be the most affected region. FI and WTA respectively identified 20 and 19 MENA countries in the severe water scarcity category, while the IWMI indicator testified to the physical nature of scarcity in 18 countries. WPI categorized five nations as middle-scoring and 16 as high-scoring. Since WPI considers socioeconomic conditions, the oil-rich Middle Eastern countries might have performed better on this indicator despite severe physical scarcity. Water Footprint and Virtual Trade (WFVT) showed that 12 nations in this region are water-importing while 9 are neutral. No country in this region can afford to export water. Despite facing physical scarcity, the adaptive capacity of these nations has enabled them to ensure food security through imports.

Water scarcity worries South Asia as well (Vinke et al. 2017), the home to over 24% of the world's population (Mukherjee 2018). FI and WTA, respectively, identify 3 and 5 nations in this region as being severely water-scarce. India, Pakistan, and Bangladesh face severe water scarcity, followed by Afghanistan and Sri Lanka. Nepal and the Kingdom of Bhutan were relatively in better positions. The IWMI indicator classified Pakistan as physically water-scarce while more than half of the Indian Territory was economically water scarce. WFVT shows that both Pakistan and India are water exporters (Zhang et al. 2016).

Africa, except for its northern belt discussed above, represents another interesting case. FI and WTA recognize many African countries to be water scarce (McNally et al. 2019), whereas the IWMI indicator shows that the majority of these countries are economically water scarce. Two-thirds of the world's most economically water-scarce croplands exist in Sub-Saharan Africa (Rosa et al. 2020), calling for financial assistance to the water sector in Africa (Nick et al. 2015). Compromised socioeconomic conditions, particularly in Sub-

Table 2 Indicator-Wise Status of Water Scarcity in the Most Affected Regions

Indicator	Severity Level	MENA	South Asia	Africa
FI	No Scarcity	0	3	26
	Scarcity	0	2	14
	Absolute Scarcity	21	3	13
WTA	No Stress	0	3	44
	Mild Stress	1	0	3
	Severe Stress	20	5	6
IWMI Indicator	Little or No Scarcity	2	2	10
	Existing/Approaching Physical Scarcity	18	2	7
	Economic Scarcity	1	4	37
WPI	Low Scoring	0	0	0
	Middle Scoring	5	2	4
	High Scoring	16	6	49
VWT	Importing	12	1	0
	Exporting	0	2	4
	Neutral	9	5	49

Saharan Africa (Jemmali 2017), make these nations score high on the Water Poverty Index and 49 out of 53 are extremely water-poor despite having an abundance of water resources available, showing the impact of socioeconomic factors on the gravity of water scarcity.

4 Water Scarcity Indicators Discussion

Water scarcity, once considered a myth, now stands established as a grim reality (Falkenmark 2013). Growing water-related issues prompted the world leaders to set a stand-alone goal on water i.e. SDG 6. Specific to water scarcity issues, Target 6.4 requires that “By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity“(UN Water 2021).

Ever since the water management challenges surfaced during the latter half of the 20th century, researchers have attempted the development of water scarcity indicators for simple and easily understandable indications of water scarcity. These indicators can be categorized as: (1) classical indicators (mostly developed before the year 2000) and (2) holistic indicators (mostly developed after the year 2000). Classical indicators provided the foundations for water scarcity measurement. Since these indicators grasp limited aspects of water scarcity, the researchers came up with the indicators sensitive to economic and social aspects of water scarcity e.g. WF, LCA, WEI, WPI, and Social Water Stress Index based on broader sets of water scarcity features. Further research pointed out more missing areas including the new realities like climate change.

4.1 Limitations of the Indicators

Integrity The multiple facets and interconnections of water scarcity with food, energy, ecology, socioeconomics, and governance (Veldkamp et al. 2015) require integration of these

critical areas to make water scarcity measurement as accurate as possible. The research evolution from classical to holistic indicators marks the efforts to bring more integrity to water scarcity measurement. Classical indicators are generally based on a sectoral approach and consider an incomplete set of factors. Given the multidisciplinary nature of water scarcity, expecting the accuracy and reliability of projections without integrating all spheres and types of water scarcity with the socioeconomic conditions of a region is not a rational expectation. In terms of integrity, holistic indicators have a visible advantage over classical indicators due to their sensitivity to a relatively wider range of factors.

Objectivity The multidisciplinary nature of water scarcity brings another problem: where to draw the line. While integrating the factors belonging to the allied areas of food, energy, socioeconomics, and ecology, etc., there exists dissension about which factors should be included or excluded. Economic and social factors, for example, cover a wide range of topics, from income to education, health status to housing (distance from a water source), and so on (Walker et al. 2015). Some of the socioeconomic factors can be related to water scarcity in one location and unrelated in another. Many of these factors are so closely associated with each other that any decision regarding their inclusion has certain consequences in terms of the accuracy of the results. Therefore, drawing the line between the factors to be included and dropped decides the objectivity of the indicators. This problem is more prominent in the case of holistic indicators that consider social and economic factors.

Simplicity Water scarcity indicators are relevant to policymakers and the general public as well. These stakeholders need the measurement of water scarcity in a simple, easily interpretable, and straightforward form. Simplicity is one of the reasons for the widespread adoption of classical indicators (Chenoweth 2008). Holistic indicators have limited application because they involve the integration of multiple factors, diverse data, and complex interpretation. As an added advantage, simple indicators have low data requirements. Ensuring simplicity along with integrity and objectivity is a challenging task. Therefore, future research on the development of holistic indicators needs to focus on the representation of the complexity of this subject in a manner comprehensible for all stakeholders. As much as possible, efforts to make the indicators holistic should add value to water scarcity measurement in terms of accuracy and simplicity.

Applicability It refers to the ease with which an indicator can be applied in different physical conditions and at different time steps. Water scarcity exhibits spatiotemporal variations that need to be grasped by the indicators to make precise measurements of the problem. The majority of indicators have shortcomings in this respect. Classical indicators are not easily tractable at different time steps, and holistic indicators have application limitations in varying physical conditions due to lack of validation and data scarcity. The most commonly used spatial scale of the grid by hydrologists is not of particular interest to policymakers, as they are more concerned about their geographical boundaries. Some research studies have focused on the extendibility question. For example, WPI, which was originally developed for community-level usage, has been extended to province and country levels. More research on this aspect is needed.

Reliability The question of reliability is of vital importance as no single indicator is available so far to address all the needs of policymakers. Classical indicators offer a simple representation of water scarcity that proves unrealistic in many cases. Holistic indicators promise increased integrity, but their huge data requirements, validation issues, and conceptual shortcomings limit their reliability as well. Classical indicators based on population growth draw a neo-Malthusian picture of water scarcity that can lead to the adoption of overstretched measures, or sometimes otherwise, resulting in inefficient use of resources and even aggravation of the problem.

4.2 Need for Multidimensional Indicators

The literature reveals that all indicators have certain limitations, either conceptual, operational, or both. None of the indicators cover simultaneously all the necessary areas, i.e., blue water, green water, EFR, water quality, etc. However, the major shortcoming occurs when some vital aspects are not included in the account. For example, virtual water trade accounts for a sizeable portion of water usage in all countries. Accounting for virtual water is especially important for countries that rely heavily on agricultural trade. For a country already struggling with physical security, any measurement of water scarcity without accounting for the export of virtual water will yield unreliable results. This is not limited to virtual water only. Every country has a unique scenario of water availability, spatiotemporal distribution, water quality concerns, EFR, and desalination capacity. Some Middle Eastern countries, for instance, have developed a sizeable capacity for water desalination (Nair and Kumar 2013). However, many indicators, particularly classical, are unable to reflect the impact of desalination. Similarly, some indicators are oblivious to EFR while it is quite high in the areas receiving abundant rainfall. Whereas, deteriorated water quality can also reduce the actual availability of water, despite the indicators painting a rosy picture. Hence, it may prudently be suggested that the use of a single indicator, from a planning perspective, cannot yield reliable results. It not only gives a false sense of security but sometimes unnecessarily presents a bleak scenario. Therefore, a set of indicators should be carefully created to make a measurement befitting the unique realities and needs of every region or country.

4.3 Data Challenges

One of the major problems influencing the adoption of indicators, causing shortcomings and restricting research and development, is data scarcity, especially in the case of composite and accounting-based indicators. Many holistic indicators have not been extensively utilized because the requisite data is not readily available. Measurement of water scarcity requires a reasonably long time series at the desired time step. Different indicators consider different parameters. Hence, the data required for holistic indicators is huge and diverse. Before the acceptance of water scarcity as a challenge, water sector policies, plans, and strategies were based on a supply-driven approach. Demand-driven approaches have gained currency after water scarcity became more visible (Damkjaer and Taylor 2017). Therefore, water data collection has historically been carried out on supply-driven lines. With the advent of holistic water scarcity indicators, the data needs have considerably changed and increased. In the wake of the Integrated Water Resources Management (IWRM) and the Water-Energy-Food (WEF) Nexus approaches being mulled worldwide, the data requirements may become even

more challenging. Hence, data collection patterns and parameters would need to be amended accordingly. Another dimension of this data challenge is the dearth of socio-economic factors data, particularly in less developed regions. All holistic indicators would consider the interconnection between socioeconomic factors and physical water availability. There exists a consensus that the impacts of physical water scarcity are more severe on the downtrodden and vulnerable (UN Water 2007). Therefore, the data collection patterns and reliability need to be synchronized with diverse data requirements. This challenge is quite pressing for the scientific fraternity and policymakers as both have to undergo twofold change management, i.e., switching from a supply-driven to a demand-driven approach to water management and rearranging data acquisition order and methodology.

5 Conclusions

The goal of this study was to compare 12 water scarcity indicators (5 classical and 7 holistic) in terms of their sensitivity to blue water, green water, quality-induced water scarcity, EFR, data requirement, and suitable spatial scale. In addition, based on previous studies on water scarcity using various indicators, we compiled a global comparison. The main conclusions from this paper are as follows:

- 1) No single indicator, whether classical or holistic, provides a one-size-fits-all solution for water scarcity measurement. Classical indicators overlook a range of important factors like green water, quality-induced water scarcity, spatiotemporal variations, and other factors influencing the occurrence and severity of water scarcity. Holistic indicators are more considerate of return flows, spatiotemporal variations, socioeconomic aspects, and green water. However, they are posed with the challenges of huge data requirements, validation, and conceptual integration of all necessary parameters, particularly quality-induced water scarcity and EFR. Due to a lack of larger scale application, the pros and cons of holistic indicators are largely based on experts' judgment.
- 2) A comparison of water scarcity hotspots shows that different indicators come up with contradicting results. Many African countries ranked by FI and WTA as water-scarce have sufficient water resources and their actual problem is a lack of infrastructure. Similarly, Middle Eastern nations identified as severely water-scarce by FI, face no food security issues due to virtual water imports and adaptive capacity. Water-rich, land-poor Europe imports water from water-poor, land-rich South Asia, East Asia, and Southeast Asia, showing that ignoring these facts can lead to ill-planning of water resources management.
- 3) Therefore, a single indicator-based measurement of water scarcity should not be relied upon; rather, a selection should be made from classical, water accounting-based, and water quality-focusing indicators to develop a reasonably reliable and clearer picture of water scarcity in a region.

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