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Exploring water indices and associated parameters: a case study approach

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Abstract

In the past 20 years, over 50 water indices have been developed to characterize human-water systems within the frameworks of water scarcity, water poverty, water vulnerability, and water security. This study compares existing water indices in Bangladesh and Sri Lanka to better understand which parameters (or lack thereof) contribute to the usefulness of water indices. Drawing on knowledge about human-water interactions in Bangladesh and Sri Lanka, this exploration of indices at the parameter level highlights missing parameters, inadequate consideration of complex relationships between parameters, and inconsistencies in index nomenclature and units. This study reveals both the benefits and shortcomings of water indices and provides recommendations for researchers and water managers to consider when selecting indices to assess and support their water policy goals.

Keywords: Bangladesh; Sri Lanka; Water indices; Water poverty; Water scarcity; Water security; Water vulnerability

1. Introduction

In the past century, rates of water usage have grown twice as rapidly as global population (FAO, 2007; UN, 2013a). Although global renewable freshwater resources are currently sufficient to meet population requirements, uneven distribution of water resources, compounded by pollution and mismanagement, results in severe national and regional disparities in water availability and quality (UN, 2013a). Considering the influence of human management on the distribution of water resources, it is important to study both the physical and human aspects to develop a comprehensive understanding of water systems (hereafter referred to as 'human-water systems').

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Human-water systems were initially viewed through the lens of 'water scarcity', which assessed the amount of water physically available to a nation (Falkenmark, 1989). However, this traditional definition of water scarcity gives no consideration to the capacity of a nation to adjust to limited water resources (Appelgren & Klohn, 1999). Consequently, the framework expanded to 'water poverty', which assesses both the physical and economic capabilities of a nation to meet its water needs. External threats to the human-water system (e.g. extreme weather events) were incorporated into the framework through 'water vulnerability'. Most recently, interactions between humans and water have been viewed comprehensively in terms of 'water security'. UN-Water defines water security as:

> '*the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*' (UN-Water, 2013, p. 1).

In the past 20 years, over 50 indices have been created to measure human interactions with water (Plummer *et al*., 2012). These indices facilitate program evaluation, support environmental monitoring, and serve as tools for managers of human-water systems (Chenoweth, 2008). Indices vary in both comprehensiveness and focus, reflecting the expanding scope of the frameworks (Rijsberman, 2006). Literature reviews of existing water indices have been conducted by various authors (Chenoweth, 2008; Brown & Matlock, 2011; Cook & Bakker, 2012; Plummer *et al*., 2012). However, little attention has been given to which parameters (or lack thereof) contribute to the usefulness of water indices. Therefore, we use a case study approach to assess existing water indices and parameters for two countries in South Asia, a region exposed to extreme seasonal and spatial variation in rainfall, among other water-related stressors (Rijsberman, 2006; Grey & Sadoff, 2007; ADB, 2013a). Since the scale and scope of water indices vary greatly, we limit our analysis to national water indices that are flexible enough to be employed at sub-national scales. Our aim is not to review these two countries' water policies but rather to systematically evaluate tools often used in policy setting. We conclude with recommendations for researchers and water managers to consider prior to selecting and applying indices to achieve their particular national water goals.

2. Methods

In this study, an 'index' is computed from multiple parameters and a 'parameter' is defined as a value that is measured or observed. Some parameters are also computed using multiple values; additional information regarding these parameters is presented in the following sections. The various parameters relate to different aspects of water resources' issues. For example, river flows and groundwater volumes can be taken as measures of water availability whereas the availability of piped water and the proximity of households to wells can be taken as measures of access. We group like parameters together and refer to the groups as 'components'.

2.1. Index descriptions

Multiple water indices in the current literature were reviewed. Only national indices for Sri Lanka and Bangladesh that have already been developed or could be developed given readily available information were included in the analysis (for descriptions of the two countries, see Appendix – available online at http://www.iwaponline.com/wp/017/022.pdf). Indices were grouped under frameworks based primarily on their nomenclature. The indices included in this study are: the Falkenmark indicator (Falkenmark, 1989), the social water scarcity index (Appelgren & Klohn, 1999), the water poverty index (Lawrence *et al.*, 2002), the rural water livelihoods index (Sullivan *et al.*, 2009), the index of drinking water adequacy-2 (IDWA-2) (Kallidaikurichi & Rao, 2009), the national water security index (ADB, 2013a), the water security index (Lautze & Manthrithilake, 2012), the water resources vulnerability index (Raskin *et al.*, 1997), and the composite water vulnerability index (Paladini, 2012).

2.1.1. Water scarcity. The Falkenmark indicator identifies regions as being under 'water stress' when less than 1,700 cubic meters (m^3) of water are available per capita per year; regions are 'water scarce' when only 1,000 m^3 of water are available per capita per year (Falkenmark, 1989). The Falkenmark indicator is unique because it is an index containing only a single parameter; the index is defined simply as water resources per capita. This traditional definition of water scarcity is based on physical resources (i.e. total water resources available to a country and its population size) and gives no consideration to the societal response capacity of a nation to adjust to the scarcity situation. In response to these criticisms, Appelgren & Klohn (1999) attempted to account for this societal capacity by dividing the Falkenmark indicator by the human development index (HDI), a composite index that is composed of national parameters for education, health, and income (UNDP, 2013a). They argued that this new index, called the social water scarcity index, reflected the social and institutional capacity of a country to respond to water stress.

2.1.2. Water poverty. 'Water poverty' links physical estimates of water availability to socio-economic variables that reflect conditions of poverty (Feitelson & Chenoweth, 2002; Lawrencee *et al.*, 2002; Sullivan, 2002; Sullivan & Meigh, 2003; Sullivan *et al.*, 2003). Water poverty indices account for the fact that many countries with adequate physical water resources lack the political and financial resources necessary to make these resources available (Seckler *et al.*, 1998; Molle & Mollinga, 2003; Rijsberman, 2006; Molden, 2007). The most commonly used index in this framework is the water poverty index (WPI). This index includes five components of water poverty: resources, access, capacity, use, and environment (Lawrence *et al.*, 2002; Sullivan, 2002). The water poverty index encompasses not only water and income parameters but also parameters regarding ecosystem productivity and human health (Lawrence *et al.*, 2002; Sullivan, 2002; Brown & Matlock, 2011).

In 2009, Sullivan *et al.* (2009) introduced a version of the WPI for rural communities called the rural water livelihoods index, which distinguishes between urban and rural human-water systems. The rural water livelihoods index includes components accounting for access to water and sanitation, crop and livestock water security, and clean and healthy environments, as well as secure and equitable water entitlements. This index also utilizes parameters measuring local corruption, agricultural holdings, and water quality (total nitrogen consumed on cultivated land) (Sullivan *et al.*, 2009).

Biswas & Seetharam (2008) simplified the WPI to create an index of drinking water adequacy (IDWA). The first version of IDWA, IDWA-1, was an aggregate of internal renewable freshwater resources, access to improved water sources, national capacity to purchase water (represented by nominal gross domestic product (GDP)), domestic water use, and water quality (represented by diarrheal deaths) parameters. Kallidaikurichi & Rao (2009) updated this index and created the IDWA-2 by changing the access from all-improved water sources to only households with piped connections. The authors argued that the revised access parameter accounted for the opportunity costs of time lost collecting water (Kallidaikurichi & Rao, 2009).

2.1.3. Water vulnerability. Vulnerability is broadly defined as 'the ability or inability of individuals and social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being' (Kelly & Adger, 2000, p. 328). External stresses on water systems include natural hazards such as floods, droughts, and storm surges as well as runoff changes from climate change (Gain *et al.*, 2012).

Raskin *et al*. (1997) developed the water resources vulnerability index (WRVI), which is based on water supply and storage parameters, a withdrawal to discharge ratio, and a coping capacity index reflecting the nominal GDP per capita. The WRVI has two variations: WRVI-1 is a composite value of the index components while WRVI-2 is equal to the worst value for any one of the components. Because the components are weighted equally, only WRVI-1, henceforth referred to as WRVI, is considered in the rest of this paper. The composite water vulnerability index, developed by Paladini (2012), has four components: industrial growth rate, level of development, water stress, and water availability. GDP per capita, domestic and industrial water use, electricity production, HDI, and population density are some of the parameters included in this index (Paladini, 2012).

2.1.4. Water security. Lautze & Manthrithilake (2012) developed a water security index for 46 countries in Asia that includes five components: basic household needs, food production, environmental flows, risk management, and water independence. They concluded that the water security index strongly correlated with the economic development of the 46 nations they studied. The Asian Development Bank's national water security index also has five components: household water security, urban water security, environmental water security, economic water security, and resilience to water-related disasters (ADB, 2013a). Despite the inclusiveness of this framework, water security indices rarely account for seasonal water-related shocks.

2.2. Parameter and component descriptions

A comprehensive list of parameters comprising the indices listed above was compiled. Following Lawrence *et al*. (2002), the parameters were organized into five components: resources, access, use, capacity, and environment. Where appropriate, the results and tables are organized using these component classifications. The resource component represents the amount of water physically available to a region. The access component represents accessibility to improved water and sanitation resources within one kilometer. Improved water sources include household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater collection; improved sanitation facilities include connection to a public sewer, septic system, pour-flush latrine, simple pit latrine, and a ventilated improved pit latrine (WHO & UNICEF, 2012).

The water use component represents the amount of water used in the nation, either in sum or partitioned across different sectors (e.g. agricultural, domestic, and industrial). 'Water use' can refer to either water withdrawal or water consumption; a portion of withdrawn water is returned to a water source, while consumed water is lost to mechanisms such as evaporation and is thus no longer available to meet human or environmental needs. The capacity component is divided into two sub-components: soft capacity and hard capacity. Soft capacity refers to non-engineered solutions to water management such as education and institutional capacity, while hard capacity refers to built infrastructure such as dams and wastewater treatment plants (Gleick, 2003; Brown & Lall, 2006). The environment component represents the interactions between the water resources and the ecosystem, which plays a significant role in protecting the quality and quantity of water.

2.3. Overview of analysis

The water indices for Bangladesh and Sri Lanka were compared to determine the relative rankings of these countries. The Falkenmark indicator and the social water scarcity index for Bangladesh and Sri Lanka were calculated based on the most recent Food and Agriculture Organization (FAO) and UN Development Programme data (FAO, 2013; UNDP, 2013a). The remaining indices were compiled from original publications. Although the data used to develop indices are from different years, it is assumed that the relative placement of Bangladesh and Sri Lanka has not changed over time.

After compiling a comprehensive list of parameters comprising the water indices, the parameters were organized into the five components. When possible, the most recent parameter values were obtained from the FAO and other resources. Otherwise, original publication data were used. Drawing on knowledge about human-water interactions in Bangladesh and Sri Lanka, the exploration identified missing parameters as well as inconsistencies in the quantification of included parameters within each of these components. Information is noted when there is no readily available information for missing parameters.

3. Results

3.1. Indices

Water indices for Bangladesh and Sri Lanka have been shaded in Table 1 to indicate the country with a more favorable ranking. Bangladesh has more physical water resources than Sri Lanka at the national level (i.e. the Falkenmark indicator and social water scarcity index). Water poverty indices (i.e. the WPI, rural water livelihoods index, and the IDWA-2) suggest that Sri Lanka's political and financial resources are sufficient to compensate for its fewer physical water resources. The water vulnerability indices give a mixed message: the WRVI suggests that Sri Lanka is more stressed, while the composite water vulnerability index suggests that Sri Lanka is more resilient. Overall, however, Sri Lanka ranks more favorably in water security indices (i.e. the national water security index and the water security index) than Bangladesh.

3.2. Parameter values

Resource parameters include long-term annual water resource averages (either total or based on the source of water, that is, within or outside country borders), a measure of the inter-annual variability in precipitation, and extreme weather indicators. Although Bangladesh has more total water per capita than Sri Lanka, Sri Lanka has more internal water resources per capita than Bangladesh, due to Sri Lanka's

Table 1. Indices for Bangladesh and Sri Lanka.

Index	Bangladesh[a]	Sri Lanka[a]	Source
Falkenmark indicator	8,153 m^3/person/year (No water stress)	2,509 m^3/person/year (No water stress)	Falkenmark (1989); Data: FAO (2013)
Social water scarcity index	2.4 (relative sufficiency)	5.6 (relative sufficiency)	Appelgren & Klohn (1999); Data: FAO (2013); UNDP (2013a)
Water poverty index	58.1 out of 100	58.5 out of 100	Lawrence *et al.* (2002)
Rural water livelihoods index	65.44 out of 100	68.62 out of 100	Sullivan *et al.* (2009)
Index of drinking water adequacy-2	24 out of 100	37 out of 100	Kallidaikurichi & Rao (2009)
Water resources vulnerability index	3 (stress)	4 (high stress)	Raskin *et al.* (1997)
Composite water vulnerability index	0.11 (low resilience)	0.22 (upper-low resilience)	Paladini (2012)
National water security index	1 out of 5	2 out of 5	ADB (2013a)
Water security index	13.5 (poor)	15 (satisfactory)	Lautze & Manthrithilake (2012)

[a]Shaded indices indicate country with a more favorable ranking.

lack of dependence on external sources (Table 2). As measured by the coefficient of variation in precipitation, inter-annual variability in precipitation is greater in Sri Lanka than in Bangladesh. According to the national water security index, Bangladesh is more prone than Sri Lanka to floods, windstorms, droughts, and storm surges (ADB, 2013a). Neither the WRVI nor the composite water vulnerability index contains any parameters measuring extreme weather.

Access parameters measure the percentage of the population with access to improved water sources (either total or only as household connections) and sanitation. Some of the indices also distinguish between access parameters for urban and rural populations. Each country's urban population has greater access to water than its rural population. Bangladeshi urban and rural populations have equal access to sanitation while Sri Lanka's rural population has higher access to sanitation than the country's urban population. Sri Lanka's urban and rural populations each have greater access to improved water sources and sanitation than the corresponding Bangladeshi populations (Table 2).

Most of the indices in Table 1 include water withdrawal values, although some of the parameters are labeled generally as 'use' (Table 2). The indices listed in Table 1 quantify water withdrawals as either a volumetric measurement per capita or as a percentage of total renewable water resources; as normalized data better reflect quality of life, all the data presented in Table 2 have been normalized by total water resources. Some indices consider total withdrawal values while others prioritize certain sectors over others. For example, IDWA-2 prioritizes domestic use by focusing specifically on drinking water while the water security index considers only the agricultural use of water. The composite water vulnerability index includes volumetric inputs for both total withdrawals and water use by the industrial and domestic sectors, but does not consider agricultural use (Paladini, 2012). Of the indices listed in Table 1, only the WPI explicitly includes a water consumption parameter that captures the percentage of a country's land that is under severe water stress (i.e. where the water consumption is greater than 40% of its available water) (Lawrence *et al.*, 2002; YCELP & CIESIN, 2005). A greater amount of water is being withdrawn (both per capita and as a percentage of total available water) in Sri Lanka than in Bangladesh in each of the three sectors (Table 2). Because most agricultural water use is consumptive (Vaux, 2012), a higher proportion of Sri Lankan land is stressed than that of Bangladeshi land (YCELP & CIESIN, 2005).

Table 2. Water index parameter values for Bangladesh and Sri Lanka.

		Parameters		Bangladesh[a]	Sri Lanka[a]	Source	Indices using parameters[b]
Resources		Total renewable water sources (m^3/person/year)		8,153	2,509	FAO (2013)	FI, SWSI, WPI, CWVI
		Total renewable water sources located within a nation's boundaries (m^3/person/year)		698	2,509	FAO (2013)	IDWA-2
		Dependence on external sources		91.4%	0%	FAO (2013)	WSI, WRVI
		Inter-annual variability in precipitation		0.11	0.20	Raskin *et al.* (1997)	WRVI, RWLI[c]
		Flood indicator		0.23	0.44	ADB (2013a)	NWSI
		Drought indicator		0.13	0.51	ADB (2013a)	NWSI
		Coastal indicator		0.20	0.44	ADB (2013a)	NWSI
Access		Population with access to improved water	Total	83%	93%	UN (2013b)	WPI, CWVI, WSI
			Urban	85%	99%		
			Rural	82%	92%		RWLI
		Population with household connections	Total	6%	29%	ADB (2013b); Kallidaikurichi & Rao (2009)	NWSI, IDWA-2 NWSI, IDWA-2 IDWA-2
			Urban	20%	67%		
			Rural	0.23%	3.76%		
		Population with access to sanitation	Total	55%	91%	UN (2013b)	WPI, NWSI, RWLI
			Urban	55%	83%		
			Rural	55%	93%		
Use		Water withdrawals (% of total water resources)	Total	2.9%	24.5%	FAO (2013)	WRVI, RWLI, CWVI, WPI, CWVI, IDWA-2 WPI, WSI, WPI, CWVI
			Domestic/Municipal	0.3%	1.5%		
			Agricultural	2.6%	21.4%		
			Industrial	0.1%	1.6%		
		Water consumption (% of land area that exceeds 40% of total available water)		22.9%	32.9%	YCELP & CIESIN (2005)	WPI
Capacity	Soft	Education	Expected years of schooling[d]	12.7	8.1	UNDP (2013a)	SWSI, CWVI
			Mean years of schooling[d]	4.8	9.3	UNDP (2013a)	SWSI, CWVI
			Literacy rate (% of adults over 15)	56.8%	91.2%	ADB (2013b)	NWSI
		Health	Life expectancy at birth (years)[d]	69.2	75.1	UNDP (2013a)	SWSI, CWVI
			Child mortality (under 5 years) (per 1,000 births)	59	12	ADB (2013b)	WPI
			Percentage of undernourished people	17	24	ADB (2013b)	RWLI
		Income: GNI per capita	GNI per capita, PPP ($International 2013)[d]	2,070	6,120	World Bank (2013b)	SWSI, CWVI
			GDP per capita at purchasing power parity ($US 2012)	1,917	6,247	ADB (2013b)	WPI, IDWA-2, WRVI, CWVI
			Growth rates of real GDP per capita (%)	4.9	5.7	ADB (2013b)	CWVI
			GINI coefficients of income distribution	0.321	0.364	ADB (2013b)	WPI
		Corruption index		144 of 176	40 of 176	Transparency International (2013)	RWLI
	Hard	Storage in large dams (m^3/capita)		43.2	298.0	Raskin *et al.* (1997); FAO (2013)	WSI, WRVI
		Wastewater treatment		17%	32%	ADB (2013a)	NWSI

(*continued*)

Table 2. (*continued*)

		Parameters	Bangladesh[a]	Sri Lanka[a]	Source	Indices using parameters[b]
Environment	Environmental flows (water available for environmental purposes)		very good	poor	Lautze & Manthrithilake (2012)	WSI
	Diarrheal disease (diarrheal incidence per 100,000 people; diarrheal deaths)		1,510	21	ADB (2013b)	NWSI, IDWA-2
	Agricultural water pollution indicators	Dissolved oxygen (mg/L)	7.70	8.13	YCELP & CIESIN (2005)	WPI
		Electrical conductivity (µS/cm)	231.60	722.22		
		Phosphorus (mg/L)	0.29	0.2		
		Total suspended solids (mg/L)	4.08	not available		
		Fertilizer consumption per hectare of arable land (kg)	168	262		
		Pesticide consumption per hectare of arable land (kg)	0.40	0.90		
	Industrial water pollution (biochemical oxygen demand) (kg/day)		273,082	88,943	Paladini (2012)	CWVI
	River health indicator		0.16	0.20	ADB (2013a)	NWSI
	Biodiversity		0.54	0.66	YCELP & CIESIN (2005)	WPI

[a]Shaded values indicate country with a more favorable ranking.
[b]FI: Falkenmark indicator, SWSI: social water scarcity index, WPI: water poverty index, RWLI: rural water livelihoods index, IDWA-2: index of drinking water adequacy-2, NWSI: national water security index, WSI: water security index, WRVI: water resources vulnerability index, and CWVI: composite water vulnerability index.
[c]RWLI uses inter-annual variation in cattle holdings and cereal production as a proxy for the coefficient of variation in precipitation.
[d]Some indices use the human development index, which is a composite of these parameters. HDI represents three dimensions of human development: a long life, as measured by life expectancy at birth; access to knowledge, as measured by mean years of adult education; and standard of living, as measured by gross national income per capita, expressed in a constant purchasing power parity, PPP ($US 2012). The current HDI for Bangladesh and Sri Lanka are 0.515 and 0.715 respectively (UNDP (2013a).

Soft capacity parameters include metrics of national education, health, income, and corruption. Education, health, and income parameters are commonly used to assess the level of a nation's development. The HDI is a composite index commonly used as a measure of a nation's soft capacity. Some of the water indices include HDI as a parameter (e.g. the social water scarcity index) while others explicitly include individual metrics for education, health, and income. The WPI, for example, uses HDI parameters for education and income, but replaces the health parameter of life expectancy with child mortality rate because the authors argue that the latter is more closely related to access to clean water (Lawrence *et al*., 2002). Sri Lankans are more educated than Bangladeshis, both in terms of years of schooling and literacy rates. Sri Lankans are also healthier on average, with a greater life expectancy at birth and a lower child mortality rate. Bangladesh has a lower percentage of undernourished people than Sri Lanka. Sri Lanka has higher income per capita (both GNI (gross national income) and GDP) and a higher GDP growth rate. However, Sri Lanka also has a higher GINI coefficient, indicating greater inequality in income distribution within the country. Corruption is addressed by only one index evaluated – the rural water livelihoods index. The corruption perception parameter used in this index suggests that Sri Lanka is significantly less corrupt than Bangladesh. Overall, Sri Lanka has a higher soft capacity than Bangladesh (Table 2).

In the indices reviewed, hard capacity is seldom evaluated but has been operationalized as the presence of major infrastructure, such as large reservoirs and wastewater treatment plants. Both Bangladesh and Sri Lanka have approximately the same amount of large storage capacity (Table 2). The water security index includes a risk management parameter that measures the extent to which countries are buffered from rainfall variability (as measured by the coefficient of variation of precipitation) through large dam storage (Lautze & Manthrithilake, 2012); nations with higher inter- and intra-annual variability in rainfall require more infrastructure than nations with little variability in rainfall. Because Sri Lanka's higher inter-annual variability is balanced by its greater upstream storage capacity (Table 2), both Bangladesh and Sri Lanka received the same value for the risk management parameter in the water security index (Lautze & Manthrithilake, 2012). In addition, Sri Lanka currently treats more of its wastewater than Bangladesh (ADB, 2013a).

Ecosystems are extremely complex and are not often addressed in water indices. When ecosystems are considered, they are often assessed using proxies such as environmental flows and land cover. The indices reviewed include few consistent parameters that address the environment. Parameters grouped under the environment component are either water-specific or general measures of ecosystem health. Environmental flows, or the amount of water unclaimed for human use and thus available to ecosystems, are greater in Bangladesh than in Sri Lanka (Table 2). Water quality impacts are measured with either human health or chemical pollution indicators. A common human health indicator is the prevalence of 'waterborne' diarrheal diseases; Bangladesh has more diarrheal incidents per 100,000 people than Sri Lanka (ADB, 2013b). Chemical pollution indicators are either agriculture-specific (i.e. the WPI) or industry-specific (i.e. the composite water vulnerability index). Sri Lanka consumes more fertilizers and pesticides per hectare of arable land than does Bangladesh. Biochemical oxygen demand (BOD), a metric related to dissolved oxygen, reflects the amount of dissolved oxygen needed by aerobic organisms to break down organic material in water (Penn *et al.*, 2006); Bangladesh has a much higher industrial BOD than Sri Lanka (Paladini, 2012).

Biodiversity and a composite river health indicator are two general measures of ecosystem health included in the WPI and the national water security index, respectively. Biodiversity is measured as the percentage of threatened mammals and birds in the country; biodiversity is greater in Sri Lanka than in Bangladesh (Lawrence *et al.*, 2002; YCELP & CIESIN, 2005). The river health indicator values in the national water security index were developed using GIS (geographic information system) tools to measure pressures and threats to river systems from watershed disturbance and pollution activities (such as livestock density), and the vulnerability of the river systems to alterations in natural flows from infrastructure development and biological factors (such as river network fragmentation and non-native species) (ADB, 2013a). Although information regarding soil salinization and non-native species was not provided, the Asian Development Bank reports that both countries' rivers are in very poor health, with Sri Lanka's rivers being marginally healthier than Bangladesh's rivers (ADB, 2013a).

3.3. Missing parameters

During the analysis, numerous missing parameters that could contribute to a comprehensive understanding of the human-water systems of Bangladesh and Sri Lanka were identified (Table 3). Parameters for total, internal, and external water resources are based on long-term annual averages, which may mask seasonal variations in water availability (Brown & Lall, 2006; Rijsberman, 2006). Due to their monsoonal climate, Bangladesh and Sri Lanka both experience high intra-annual variability in rainfall (Brown & Lall, 2006), which is not accounted for in any of the indices listed in Table 1. Additionally, none of the indices contains any information regarding the distribution of water resources among surface and groundwater resources. The distinction between surface and groundwater sources in quantifying water resources is critical since the two resources have significantly different recharge rates (Hornberger *et al.*, 1998). Sri Lanka has more groundwater per capita than Bangladesh (FAO, 2013).

Table 3. Missing parameters.

		Parameters	Bangladesh[a]	Sri Lanka[a]	Source
Resources		Groundwater resources (m^3/person/year)	140	371	FAO (2013)
		Intra-annual variability in precipitation	high	low-medium	WRI (2013)
Access		Gender inequality index	0.508	0.402	UNDP (2013b)
Use		Groundwater withdrawal (% of total resources)	79.4%	not available	FAO (2013)
		Water consumption (% of groundwater resources)	not available	not available	
Capacity	Soft	Voice and accountability (percentile rank)	34.1	29.9	World Bank (2013a)
		Political stability (percentile rank)	9.0	22.7	World Bank (2013a)
		Government effectiveness (percentile rank)	22.5	45.9	World Bank (2013a)
		Regulatory quality (percentile rank)	19.6	48.3	World Bank (2013a)
		Rule of laws (percentile rank)	19.4	52.1	World Bank (2013a)
	Hard	Small-scale irrigation schemes (% of surface water coverage)[b]	16%	25%	Mawilmada *et al.* (2010); FAO (2012)
Environment		Toxic metal pollution	not available	not available	
		Fecal coliforms	not available	not available	
		Percentage of coastal resources affected by salinization	not available	not available	
		Percentage of natural vegetation land cover	11.1%	28.8%	ADB (2013c)
		Deforestation rate	0.18%	0.78%	ADB (2013b)

[a]Shaded values indicate country with a more favorable ranking.

[b]Due to lack of data, surface area instead of volume of water stored in small-scale irrigation schemes is listed.

While groundwater usage information is available for Bangladesh, no such information for Sri Lanka is available (Table 3). Villholth & Rajasooriyar (2010) report that approximately 60% of Sri Lanka's total population is currently dependent on groundwater for domestic use.

Although the indices presented in Table 1 include valuable access information (such as distinctions between urban and rural populations), parameters of other intra-group differences are excluded, notably between men and women. Women have been shown to be disproportionally affected by lack of water access because they are predominantly responsible for household water collection, especially in poor households (UNDP, 2006; Sultana, 2007; Sullivan *et al.*, 2009). Men and women fare more equally in Sri Lanka than in Bangladesh (Table 3: gender inequality index values closer to zero indicate that men and women fare equally).

Kaufmann (2005) identifies six key aspects of governance: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. Of these parameters, only corruption has been included in one of the index calculations. According to the World Bank's 2012 Worldwide Governance Indicators, Sri Lanka's government is more stable and effective, and has a greater ability to formulate and implement sound policies than Bangladesh's government, but the latter's population ranks higher for voice and accountability (World Bank, 2013a).

Dams are not the only built infrastructure present in Bangladesh and Sri Lanka. Both reservoirs and tanks play a large role in stabilizing food production in Sri Lanka (see Appendix for additional details – available online at http://www.iwaponline.com/wp/017/022.pdf). Tanks cover almost 25% of the total surface water storage area in the country (Mawilmada *et al*., 2010). Similarly, small-scale surface irrigation schemes account for 16% of national irrigation coverage in Bangladesh (FAO, 2012).

While nutrient pollution is relevant for both countries, none of the indices includes metrics for water quality issues of significant concern in Bangladesh and Sri Lanka, such as toxic metal pollution, fecal coliforms, and salinization. Additionally, although deforestation (including the conversion of forests to agricultural land) continues to threaten Asia, no information on forest cover or the amount of protected land has been incorporated into any of the indices. Currently, a higher percentage of Sri Lanka's land is covered by forests, and more Sri Lankan land is protected than is Bangladeshi land (ADB, 2013c; WRI, 2013). Annual deforestation rates, however, are higher in Sri Lanka than in Bangladesh (ADB, 2013b).

4. Discussion

While water indices can facilitate program evaluation and serve as tools for water managers, as stated in Section 1, the findings from water indices can be ambiguous. Unlike parameter level comparisons, index level comparisons offer limited insight on small geographic scales. Our parameter level analysis has shown specific metrics (e.g. education and income) that contribute to Sri Lanka's improved indices. Water index parameters, however, have limitations as outlined below.

The most notable issue uncovered during the analysis was the absence of key parameters that could greatly impact overall water indices (Table 3). While no single index can capture all of the complex interactions implicit in human-water systems, the omission or inclusion of key parameters can alter the conclusions drawn from an index (Grey & Sadoff, 2007). For example, parts of both Bangladesh's and Sri Lanka's populations rely predominantly on groundwater resources, which has resulted in aquifer depletion in both countries (Senaratne, 1996; Shah *et al*., 2003; Brown & Lall, 2006; ADB, 2013a). Furthermore, declining groundwater levels in Bangladesh are affecting water quality, causing adverse effects on soils, and limiting crop growth (FAO, 2012). However, groundwater resource or usage data for both countries are glaringly absent from all the evaluated indices. This absence is in part due to a lack of available information, so policy makers and water managers should ensure that groundwater resource and usage data are being collected to help develop a comprehensive understanding of the current state of their water resources.

Similarly absent from the indices is water-specific information regarding capacity and water quality parameters. It should be noted that while general governance information is valuable, it gives little insight into the specific structure and management of water infrastructure. The general World Bank Governance Indicator for government effectiveness, for example, does not seem to adequately represent the concerns arising from limited coordination between Sri Lanka's water agencies (for additional details, see Appendix – available online at http://www.iwaponline.com/wp/017/022.pdf). Education metrics (e.g. literacy rate) also provide little information regarding awareness of basic hydrological concepts such as the water cycle and how to limit contamination of water supplies. Future research should assess how information on water-specific governance and education can be collected and measured. While not a comprehensive list, Table 3 lists additional parameters that should be evaluated for inclusion in water indices. Until these data become available, the rationale for using certain proxies should be explicitly stated in analyses.

Few of the evaluated indices consider the complex relationships between the components. The water security index is one of the few indices to include a risk management parameter to measure the extent to which a nation is buffered from rainfall variability through large dam storage. Similarly, the presence of water agreements with neighboring countries suggests that a country's external water resources should not be ignored. Most of the evaluated indices, however, give equal weight to the parameters listed in Table 2, rather than examining these complex relationships when developing indices. Since the indices typically have more parameters reflecting social conditions than physical conditions, Sri Lanka has more favorable water indices despite having a third of Bangladesh's total water resources available per capita (Tables 1 and 2). Equal weighting of all parameters also causes valuable information to be lost. For example, in addition to having greater income per capita, Sri Lanka also has higher income inequality (as indicated by the GINI coefficient and the percentage of undernourished people) than Bangladesh.

The indices evaluated did not always reflect the framework implied in their nomenclature. For example, the WRVI has no parameters measuring natural hazards but the national water security index does. In addition, the WPI includes parameters measuring agricultural water quality, which are not present in any of the other indices. Inconsistencies in parameter units are also present. For example, some of the indices use only per capita volumetric measurements, whereas the percentage of water used relative to total water resources is a better indicator of the stress on a nation's water resources. Some indices also have issues with double counting: the composite water vulnerability index, for example, has a parameter representing total water use as well as additional parameters for water use by the industrial and domestic sectors (Paladini, 2012).

5. Conclusion

This analysis demonstrates that policy makers, water managers, and academics should use water indices with caution. Human-water systems are extremely complex, and not all of their parameters can be encompassed by any one index. Therefore, researchers and water managers should be cautious when selecting and applying an index to monitor progress towards their national goals. Particular attention should be given to the selection of parameters relevant to national priorities. When possible, parameters that reflect complex hydrological characteristics and contain water-specific metrics should be used. Regardless of the shortcomings outlined here, water indices are a valuable method to integrate physical and social factors influencing human-water systems. Following these recommendations will improve the likelihood of these indices providing a comprehensive representation of the most critical aspects of a nation's water resource issues.

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