

Water Policy

Exploring water indices and associated parameters: a case study approach

--Manuscript Draft--

Manuscript Number:	WPOL-D-14-00022R2
Full Title:	Exploring water indices and associated parameters: a case study approach
Article Type:	Review
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Abstract:	<p>In the past twenty 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 has highlighted missing parameters, inadequate consideration of complex relationships among 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.</p>
Additional Information:	
Question	Response
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38 human-water systems within the frameworks of water scarcity, water poverty, water
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40 vulnerability, and water security. This study compares existing water indices in Bangladesh and
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42 Sri Lanka to better understand which parameters (or lack thereof) contribute to the usefulness of
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48 inadequate consideration of complex relationships among parameters, and inconsistencies in
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50 index nomenclature and units. This study reveals both the benefits and shortcomings of water
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54 selecting indices to assess and support their water policy goals.
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Keywords: Water scarcity, water poverty, water security, water vulnerability, water indices,
Bangladesh, Sri Lanka

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”).

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).

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4 In the past twenty years, over 50 indices have been created to measure human
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6 interactions with water (Plummer et al., 2012). These indices facilitate program evaluation,
7
8 support environmental monitoring, and serve as tools for managers of human-water systems
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10 (Chenoweth, 2008). Indices vary in both comprehensiveness and focus, reflecting the expanding
11
12 scope of the frameworks (Rijsberman, 2006). Literature reviews of existing water indices have
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14 been conducted by various authors (Chenoweth, 2008; Brown & Matlock, 2011; Cook & Bakker,
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16 2012; and Plummer et al., 2012). However, little attention has been given to which parameters
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18 (or lack thereof) contribute to the usefulness of water indices. Therefore, we use a case study
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20 approach to assess existing water indices and parameters for two countries in South Asia, a
21
22 region exposed to extreme seasonal and spatial variation in rainfall, among other water-related
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24 stressors (Rijsberman, 2006; Grey & Sadoff, 2007; ADB, 2013a). Since the scale and scope of
25
26 water indices vary greatly, we limit our analysis to national water indices that are flexible enough
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28 to employ at subnational scales. Our aim is not to review these two countries' water policies but
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30 rather to systematically evaluate tools often used in policy settings. We conclude with
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32 recommendations for researchers and water managers to consider prior to selecting and applying
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34 indices to achieve their particular national water goals.
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45 **2. Methods**

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47 In this study, an “index” is computed from multiple parameters and a “parameter” is
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49 defined as a value that is measured or observed. Some parameters are also computed using
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51 multiple values; additional information regarding these parameters is presented in the following
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53 sections. The various parameters relate to different aspects of water resources issues. For
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55 example, river flows and groundwater volumes can be taken as measures of water availability
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4 whereas availability of piped water and proximity of households to wells can be taken as
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6 measures of access. We group like parameters together and refer to the groups as “components.”
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10 **2.1 Index Descriptions**

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12 Multiple water indices in the current literature were reviewed. Only national indices for
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14 Sri Lanka and Bangladesh that have already been developed or could be developed given readily
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16 available information were included in the analysis (for descriptions of the two countries, see
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18 Appendix). Indices were grouped under frameworks based primarily on their nomenclature. The
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20 indices included in this study are: the Falkenmark Indicator (Falkenmark, 1989), Social Water
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22 Scarcity Index (Appelgren & Klohn, 1999), Water Poverty Index (Lawrence, Meigh, & Sullivan,
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24 2002), Rural Water Livelihoods Index (Sullivan et al., 2009), Index of Drinking Water
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26 Adequacy-2 (Kallidaikurichi & Rao, 2009), National Water Security Index (ADB, 2013a), Water
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28 Security Index (Lautze & Manthrilake, 2012), Water Resources Vulnerability Index (Raskin et
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30 al., 1997), and Composite Water Vulnerability Index (Paladini, 2012).
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37 ***Water Scarcity***

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39 The Falkenmark Indicator identifies regions as being under “water stress” when less than
40
41 1,700 cubic meters (m³) of water are available per capita per year; regions are “water scarce”
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43 when only 1,000 m³ of water is available per capita per year (Falkenmark, 1989). The
44
45 Falkenmark Indicator is unique because it is an index containing only a single parameter; the
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47 index is defined simply as water resources per capita. This traditional definition of water scarcity
48
49 is based on physical resources (i.e., total water resources available to a country and its population
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51 size) and gives no consideration to the societal response capacity of a nation to adjust the scarcity
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53 situation. In response to these criticisms, Appelgren & Klohn (1999) attempted to account for
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55 this societal capacity by dividing the Falkenmark Indicator by the Human Development Index
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4 (HDI), a composite index that is composed of national parameters for education, health, and
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6 income (UNDP, 2013a). They argued that this new index, called the Social Water Scarcity Index,
7
8 reflected the social and institutional capacity of a country to respond to water stress.
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10 11 ***Water Poverty***

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14 “Water poverty” links physical estimates of water availability to socioeconomic variables
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16 that reflect conditions of poverty (Lawrence, Meigh, & Sullivan, 2002; Sullivan, 2002; Feitelson
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18 & Chenoweth, 2002; Sullivan & Meigh, 2003; Sullivan et al., 2003). Water poverty indices
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20 account for the fact that many countries with adequate physical water resources lack the political
21
22 and financial resources necessary to make these resources available (Seckler et al., 1998;
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24 Rijsberman, 2006; Molden, 2007; Molle & Mollinga, 2003). The most commonly used index in
25
26 this framework is the Water Poverty Index. This index includes five components of water
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28 poverty: resources, access, capacity, use, and environment (Lawrence, Meigh, & Sullivan, 2002;
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30 Sullivan, 2002). The Water Poverty Index encompasses not only water and income parameters
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32 but also parameters regarding ecosystem productivity and human health (Lawrence, Meigh, &
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34 Sullivan, 2002; Sullivan, 2002; Brown & Matlock, 2011).
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41 In 2009, Sullivan et al. (2009) introduced a version of the Water Poverty Index for rural
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43 communities called the Rural Water Livelihoods Index, which distinguishes between urban and
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45 rural human-water systems. The Rural Water Livelihoods Index includes components
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47 accounting for access to water and sanitation, crop and livestock water security, clean and
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49 healthy environments, as well as secure and equitable water entitlements. This index also
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51 utilizes parameters measuring local corruption, agricultural holdings, and water quality (total
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53 nitrogen consumed on cultivated land) (Sullivan et al., 2009).
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4 Biswas & Seetharam (2008) simplified the WPI to create an Index of Drinking Water
5 Adequacy (IDWA). The first version of IDWA, IDWA-1, is an aggregate of internal renewable
6 fresh water resources, access to improved water sources, national capacity to purchase water
7 (represented by nominal gross domestic product), domestic water use, and water quality
8 (represented by diarrheal deaths) parameters. Kallidaikurichi & Rao (2009) updated this index
9 and created the Index of Drinking Water Adequacy-2 by changing access from all improved
10 water sources to only households with piped connections. The authors argued that the revised
11 access parameter accounted for opportunity costs of time lost collecting water (Kallidaikurichi &
12 Rao, 2009).

13 ***Water Vulnerability***

14 Vulnerability is broadly defined by Kelly & Adger (2000) as “the ability or inability of
15 individuals and social groupings to respond to, in the sense of cope with, recover from or adapt
16 to, any external stress placed on their livelihoods and well-being” (Kelly & Adger, 2000, p. 328).
17 External stresses on water systems include natural hazards such as floods, droughts, and storm
18 surges as well as runoff changes from climate change (Gain, Giupponi, & Renaud, 2012).

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

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11 Lautze & Manthritilake (2012) developed a Water Security Index for 46 countries in
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13 Asia that includes five components: basic household needs, food production, environmental
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15 flows, risk management, and water independence. They concluded that the Water Security Index
16
17 was strongly correlated with the economic development of the 46 nations they studied. The
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19 Asian Development Bank’s National Water Security Index also has five components: household
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21 water security, urban water security, environmental water security, economic water security, and
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23 resilience to water-related disasters (ADB, 2013a). Despite the inclusiveness of this framework,
24
25 water security indices rarely account for seasonal water-related shocks.
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32 **2.2 Parameter and Component Descriptions**

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34 A comprehensive list of parameters comprising the indices listed above was compiled.
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36 Following Lawrence, Meigh, & Sullivan (2002), the parameters were organized into five
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38 components: resources, access, use, capacity, and environment. Where appropriate, the results
39
40 and tables are organized using these component classifications. The resource component
41
42 represents the amount of water physically available to a region. The access component represents
43
44 accessibility to improved water and sanitation resources within one kilometer. Improved water
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46 sources include household connections, public standpipes, boreholes, protected dug wells,
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48 protected springs, and rainwater collection; improved sanitation facilities include connection to a
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50 public sewer, septic system, pour-flush latrine, simple pit latrine, or a ventilated improved pit
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52 latrine (WHO & UNICEF, 2012).
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4 The water use component represents the amount of water used in the nation, either in sum
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6 or partitioned across different sectors (e.g., agricultural, domestic, and industrial). “Water use”
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8 can refer to either water withdrawal or water consumption; a portion of withdrawn water is
9
10 returned to a water source, while consumed water is lost to mechanisms such as evaporation and
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12 is thus no longer available to meet human or environmental needs. The capacity component is
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14 divided into two subcomponents: soft capacity and hard capacity. Soft capacity refers to non-
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16 engineered solutions to water management such as education and institutional capacity, while
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18 hard capacity refers to built infrastructure such as dams and wastewater treatment plants (Brown
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20 & Lall, 2006; Gleick, 2003). The environment component represents the interactions between
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22 water resources and the ecosystem, which plays a significant role in protecting the quality and
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24 quantity of water.
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32 **2.3 Overview of Analysis**

34 Water indices for Bangladesh and Sri Lanka were compared to determine the relative
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36 rankings of these countries. The Falkenmark Indicator and the Social Water Scarcity Index for
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38 Bangladesh and Sri Lanka were calculated based on the most recent Food and Agriculture
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40 Organization (FAO) and UN Development Programme data (FAO, 2013; UNDP, 2013a). The
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42 remaining indices were compiled from the original publications. Although the data used to
43
44 develop indices are from different years, it is assumed that the relative placement of Bangladesh
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46 and Sri Lanka has not changed over time.
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51 After compiling a comprehensive list of parameters comprising the water indices, the
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53 parameters were organized into the five components. When possible, the most recent parameter
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55 values were obtained from FAO and other resources. Otherwise, original publication data was
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57 used. Drawing on knowledge about human-water interactions in Bangladesh and Sri Lanka,
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4 missing parameters as well as inconsistencies in the quantification of included parameters were
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6 identified within each of these components. Information is noted when there is no readily
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8 available information for missing parameters.
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10 11 12 13 **3. Results**

14 15 16 17 **3.1 Indices**

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20 Water indices for Bangladesh and Sri Lanka have been shaded in Table 2 to indicate the
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22 country with a more favorable ranking. Bangladesh has more physical water resources than Sri
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24 Lanka at the national level (i.e., Falkenmark Indicator and Social Water Scarcity Index). Water
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26 poverty indices (i.e., Water Poverty Index, Rural Water Livelihoods Index, and Index of
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28 Drinking Water Adequacy-2) suggest that Sri Lanka's political and financial resources are
29
30 sufficient to compensate for its fewer physical water resources. The water vulnerability indices
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32 give a mixed message; the Water Resources Vulnerability Index suggests that Sri Lanka is more
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34 stressed, while the Composite Water Vulnerability Index suggests that Sri Lanka is more
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36 resilient. Overall, however, Sri Lanka ranks more favorably in water security indices (i.e.,
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38 National Water Security Index and Water Security Index) than Bangladesh.
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45 46 **3.2 Parameter Values**

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48 Resource parameters include long-term annual water resource averages (either total or
49
50 based on source of water (i.e., within or outside country borders)), a measure of the inter-annual
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52 variability in precipitation, and extreme weather indicators. Although Bangladesh has more total
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54 water per capita than Sri Lanka, Sri Lanka has more internal water resources per capita than
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56 Bangladesh, due to Sri Lanka's lack of dependence on external sources (Table 3). As measured
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58 by the coefficient of variation in precipitation, inter-annual variability in precipitation is greater
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4 in Sri Lanka than Bangladesh. According to the National Water Security Index, Bangladesh is
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6 more prone than Sri Lanka to floods, windstorms, droughts, and storm surges (ADB, 2013a).
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8 Neither the Water Resources Vulnerability Index nor the Composite Water Vulnerability Index
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10 contained any parameters measuring extreme weather.
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14 Access parameters measure the percentage of the population with access to improved
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16 water sources (either total or only as household connections) and sanitation. Some of the indices
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18 also distinguished between access parameters for urban and rural populations. Each country's
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20 urban population has greater access to water than its rural population. Bangladeshi urban and
21
22 rural populations have equal access to sanitation while Sri Lanka's rural population has higher
23
24 access to sanitation than the country's urban population. Sri Lanka's urban and rural populations
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26 each have greater access to improved water sources and sanitation than the corresponding
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31 Bangladeshi populations (Table 3).
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33 Most indices in Table 2 include water withdrawal values, although some of the
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35 parameters are labeled generally as "use" (Table 3). The indices listed in Table 2 quantify water
36
37 withdrawals as either a volumetric measurement per capita or as a percentage of total renewable
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39 water resources; because normalized data better reflect quality-of-life, all data presented in Table
40
41 3 have been normalized by total water resources. Some indices consider total withdrawal values
42
43 while others prioritize certain sectors over others. For example, Index of Drinking Water
44
45 Adequacy-2 prioritizes domestic use by focusing specifically on drinking water while the Water
46
47 Security Index only considers agricultural use of water. The Composite Water Vulnerability
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49 Index includes volumetric inputs for both total withdrawals and water use by the industrial and
50
51 domestic sectors, but does not consider agricultural use (Paladini, 2012). Of the indices listed in
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53 Table 2, only the Water Poverty Index explicitly includes a water consumption parameter that
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4 captures the percentage of a country's land that is under severe water stress (i.e., where the water
5 consumption is greater than 40% of its available water) (Lawrence, Meigh, & Sullivan, 2002;
6 YCELP & CIESIN, 2005). A greater amount of water is being withdrawn (both per capita and as
7 a percentage of total available water) in Sri Lanka than in Bangladesh in each of the three sectors
8 (Table 3). Because most agricultural water use is consumptive (Vaux, 2012), a higher proportion
9 of Sri Lankan land is stressed than Bangladeshi land (YCELP & CIESIN, 2005).
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19 Soft capacity parameters include metrics of national education, health, income, and
20 corruption. Education, health, and income parameters are commonly used to assess the level of a
21 nation's development. The HDI is a composite index commonly used as a measure of a nation's
22 soft capacity. Some of the water indices include HDI as a parameter (e.g., Social Water Scarcity
23 Index) while others explicitly include individual metrics for education, health, and income. The
24 Water Poverty Index, for example, uses HDI parameters for education and income, but replaces
25 the health parameter of life expectancy with child mortality rate because the authors argue that
26 the latter is more closely related to access to clean water (Lawrence, Meigh, & Sullivan, 2002).
27
28 Sri Lankans are more educated than Bangladeshis, both in terms of years of schooling and
29 literacy rate. Sri Lankans are also healthier on average, with a greater life expectancy at birth and
30 a lower child mortality rate. Bangladesh has a lower percentage of undernourished people than
31 Sri Lanka. Sri Lanka has higher income per capita (both GNI and GDP) and a higher GDP
32 growth rate. However, Sri Lanka also has a higher GINI coefficient, indicating greater inequality
33 in income distribution within the country. Corruption was only addressed by one index
34 evaluated, the Rural Water Livelihoods Index. The corruption perception parameter used in this
35 index suggests that Sri Lanka is significantly less corrupt than Bangladesh. Overall, Sri Lanka
36 has higher soft capacity than Bangladesh (Table 3).
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4 In the indices reviewed, hard capacity is seldom evaluated but has been operationalized
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6 as the presence of major infrastructure, such as large reservoirs and wastewater treatment plants.
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8 Both Bangladesh and Sri Lanka have approximately the same amount of large storage capacity
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10 (Table 3). The Water Security Index includes a risk management parameter that measures the
11
12 extent to which countries are buffered from rainfall variability (as measured by the coefficient of
13
14 variation of precipitation) through large dam storage (Lautze & Manthrilake, 2012); nations
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16 with higher inter- and intra-annual variability in rainfall require more infrastructure than nations
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18 with little variability in rainfall. Because Sri Lanka's higher inter-annual variability is balanced
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20 by its greater upstream storage capacity (Table 3), both Bangladesh and Sri Lanka received the
21
22 same value for the risk management parameter in the Water Security Index (Lautze &
23
24 Manthrilake, 2012). In addition, Sri Lanka currently treats more of its wastewater than
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26 Bangladesh (ADB, 2013a).
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33 Ecosystems are extremely complex and are not often addressed in water indices. When
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35 ecosystems are considered, they are often assessed using proxies such as environmental flows
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37 and land cover. The indices reviewed include few consistent parameters that address the
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39 environment. Parameters grouped under the environment component are either water-specific or
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41 general measures of ecosystem health. Environmental flows, or the amount of water unclaimed
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43 for human use and thus available to ecosystems, are greater in Bangladesh than Sri Lanka (Table
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45 3). Water quality impacts are measured with either human health or chemical pollution
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47 indicators. A common human health indicator is the prevalence of "waterborne" diarrheal
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49 diseases; Bangladesh has more diarrheal incidents per 100,000 people than Sri Lanka (ADB,
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51 2013b). Chemical pollution indicators are either agriculture-specific (i.e., Water Poverty Index)
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53 or industry-specific (i.e., Composite Water Vulnerability Index). Sri Lanka consumes more
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4 fertilizers and pesticides per hectare of arable land than does Bangladesh. Biochemical oxygen
5 demand (BOD), a related metric to dissolved oxygen, reflects the amount of dissolved oxygen
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7 needed by aerobic organisms to break down organic material in water (Penn, Pauer, & Mihelcic,
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9 2006); Bangladesh has a much higher industrial BOD than Sri Lanka (Paladini, 2012).
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14 Biodiversity and a composite River Health Indicator are the two general measures of
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16 ecosystem health included in the Water Poverty Index and the National Water Security Index,
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18 respectively. Biodiversity is measured as the percentage of threatened mammals and birds in the
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20 country; biodiversity is greater in Sri Lanka than Bangladesh (Lawrence, Meigh, & Sullivan,
21
22 2002; YCELP & CIESIN, 2005). The River Health Indicator values in the National Water
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24 Security Index were developed using GIS tools to measure pressures and threats to river systems
25
26 from watershed disturbance and pollution activities (such as livestock density) and the
27
28 vulnerability of the river systems to alterations in natural flows by infrastructure development
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30 and biological factors (such as river network fragmentation and nonnative species) (ADB,
31
32 2013a). Although information regarding soil salinization and nonnative species were not
33
34 provided, the Asian Development Bank reports that both countries' rivers are very poor in health
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36 with Sri Lanka's rivers being marginally healthier than Bangladesh's rivers (ADB, 2013a).
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44 **3.3 Missing Parameters**

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46 During the analysis, numerous missing parameters that could contribute to a
47
48 comprehensive understanding of the human-water systems of Bangladesh and Sri Lanka were
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50 identified (Table 4). Parameters for total, internal, and external water resources are based on
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52 long-term annual averages, which may mask seasonal variations in water availability (Brown &
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54 Lall, 2006; Rijsberman, 2006). Due to their monsoonal climate, Bangladesh and Sri Lanka both
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56 experience high intra-annual variability in rainfall (Brown & Lall, 2006), which is not accounted
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4 for in any of the indices listed in Table 2. Additionally, none of the indices contained any
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6 information regarding the distribution of water resources among surface and groundwater
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8 resources. The distinction between surface and groundwater sources in quantifying water
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10 resources is critical since the two resources have significantly different recharge rates
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12 (Hornberger et al., 1998). Sri Lanka has more groundwater per capita than Bangladesh (FAO,
13
14 2013). While groundwater usage information is available for Bangladesh, no such information
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16 for Sri Lanka is available (Table 4). Villholth & Rajasooriyar (2010) approximate that 60% of
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18 Sri Lanka's total population is currently dependent on groundwater for domestic use.
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24 Although the indices presented in Table 2 include valuable access information (such as
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26 distinctions between urban and rural populations), parameters of other intra-group differences
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28 were excluded, notably between men and women. Women have been shown to be
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30 disproportionately affected by lack of water access because they are predominantly responsible
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32 for household water collection, especially in poor households (UNDP, 2006; Sultana, 2007;
33
34 Sullivan et al., 2009). Men and women fare more equally in Sri Lanka than in Bangladesh (Table
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36 4; Gender Inequality Index values closer to zero indicate men and women fare equally).
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41 Kaufmann (2005) identifies six key aspects of governance: voice and accountability,
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43 political stability, government effectiveness, regulatory quality, rule of law, and control of
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45 corruption. Of these parameters, only corruption has been included in one of the index
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47 calculations. According to the World Bank's 2012 Worldwide Governance Indicators, Sri
48
49 Lanka's government is more stable and effective, and has a greater ability to formulate and
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51 implement sound policies, than Bangladesh's government, but the latter's population ranks
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53 higher for voice and accountability (World Bank, 2013a).
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4 Dams are not the only built infrastructure present in Bangladesh and Sri Lanka. Both
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6 reservoirs and tanks play a large role in stabilizing food production in Sri Lanka (see Appendix
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8 for additional details). Tanks cover almost 25% of the total surface water storage area in the
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10 country (Mawilmada et al., 2010). Similarly, small-scale surface irrigation schemes account for
11
12 16% of national irrigation coverage in Bangladesh (FAO, 2012).
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16 While nutrient pollution is relevant for both countries, none of the indices include metrics
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18 for water quality issues of significant concern in Bangladesh and Sri Lanka such as toxic metal
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20 pollution, fecal coliforms, and salinization. Additionally, although deforestation, including the
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22 conversion of forests to agricultural land, continues to threaten Asia, no information on forest
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24 cover or the amount of protected land has been incorporated into any of the indices. Currently, a
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26 higher percentage of Sri Lanka's lands are covered by forests, and more Sri Lankan lands are
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28 protected than Bangladeshi lands (ADB, 2013c; WRI, 2013). Annual deforestation rates,
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30 however, are higher in Sri Lanka than in Bangladesh (ADB, 2013b).
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38 **4. Discussion**

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41 While water indices can facilitate program evaluation and serve as tools for water
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43 managers, as stated in Section 3.1, the findings from water indices can be ambiguous. Unlike
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45 parameter level comparisons, index level comparisons offer limited insight at small geographic
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47 scales. Our parameter level analysis has shown specific metrics (e.g., education and income) that
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49 contribute to Sri Lanka's improved indices. Water index parameters, however, have limitations
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51 as outlined below.
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56 The most notable issue uncovered during the analysis was the absence of key parameters
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58 that could greatly impact overall water indices (Table 4). While no single index can capture all of
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4 the complex interactions implicit in human-water systems, the omission or inclusion of key
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6 parameters can alter the conclusions drawn from an index (Grey & Sadoff, 2007). For example,
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8 parts of both Bangladesh's and Sri Lanka's populations rely predominantly on groundwater
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10 resources, which has resulted in aquifer depletion in both countries (Shah et al., 2003; Brown &
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12 Lall, 2006; Senaratne, 1996; ADB, 2013a). Furthermore, declining groundwater levels in
13
14 Bangladesh are affecting water quality, causing adverse effects to soils and limiting crop growth
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16 (FAO, 2012). However, groundwater resource or usage data for both countries are glaringly
17
18 absent from all evaluated indices. This absence is in part due to lack of available information, so
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20 policymakers and water managers should ensure that groundwater resource and usage data are
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22 being collected to help develop a comprehensive understanding of the current state of their water
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24 resources.
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31 Similarly absent in the indices are water-specific information regarding capacity and
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33 water quality parameters. It should be noted that while general governance information is
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35 valuable, it gives little insight into the specific structure and management of water infrastructure.
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37 The general World Bank Governance Indicator for government effectiveness, for example, does
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39 not seem to adequately represent the concerns arising from limited coordination between Sri
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41 Lanka's water agencies (for additional details, see Appendix: Country Descriptions). Education
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43 metrics (e.g., literacy rate) also provide little information regarding awareness of basic
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45 hydrological concepts such as the water cycle and how to limit contamination of water supplies.
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47 Future research should assess how information on water-specific governance and education can
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49 be collected and measured. While not a comprehensive list, Table 4 lists additional parameters
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51 that should be evaluated for inclusion in water indices. Until this data becomes available, the
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53 rationale for using certain proxies should be explicitly stated in analyses.
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4 Few of the evaluated indices considered the complex relationships between the
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6 components. The Water Security Index was one of the few indices to include a risk management
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8 parameter to measure the extent to which a nation was buffered from rainfall variability through
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10 large dam storage. Similarly, the presence of water agreements with neighboring countries
11
12 suggests that a country's external water resources should not be ignored. Most of the evaluated
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14 indices, however, give equal weight to the parameters listed in Table 3, rather than examining
15
16 these complex relationships when developing indices. Since the indices typically have more
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18 parameters reflecting social conditions than physical conditions, Sri Lanka has more favorable
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20 water indices despite having a third of Bangladesh's total water resources available per capita
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22 (Tables 2 and 3). Equal weighting of all parameters also causes valuable information to be lost.
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24 For example, in addition to having greater income per capita, Sri Lanka also has higher income
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26 inequality (as indicated by the GINI coefficient and percentage of undernourished people) than
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28 Bangladesh.
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36 The indices evaluated did not always reflect the framework implied in their
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38 nomenclature. For example, the Water Resources Vulnerability Index has no parameters
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40 measuring natural hazards but the National Water Security Index does. In addition, the Water
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42 Poverty Index includes parameters measuring agricultural water quality, which are not present in
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44 any other indices. Inconsistencies in parameter units were also present. For example, some of the
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46 indices only use per capita volumetric measurements, while the percentage of water used relative
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48 to total water resources is a better indicator of the stress on a nation's water resources. Some
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50 indices also had issues with double counting; the Composite Water Vulnerability Index, for
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52 example, had a parameter representing total water use as well as additional parameters for water
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54 use by the industrial and domestic sectors (Paladini, 2012).
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4 **5. Conclusion**
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7 This analysis demonstrates that policy makers, water managers, and academics should
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9 use water indices with caution. Human-water systems are extremely complex, and all of their
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11 parameters cannot be encompassed by any one index. Therefore, researchers and water managers
12
13 should be cautious when selecting and applying an index to monitor progress towards their
14
15 national goals. Particular attention should be given to the selection of parameters relevant to
16
17 national priorities. When possible, parameters that reflect complex hydrological characteristics
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19 and contain water-specific metrics should be used. Regardless of the shortcomings outlined here,
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21 water indices are a valuable method to integrate physical and social factors influencing human-
22
23 water systems. Following these recommendations will improve the likelihood of these indices
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25 providing a comprehensive representation of the most critical aspects of a nation’s water
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27 resource issues.
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35 **Acknowledgements:** This material is based upon work supported by the Office of Naval
36
37 Research through Grant No N00014-11-1-0683 and the National Science Foundation Graduate
38
39 Research Fellowship Program under Grant No DGE-0909667 and by WSC program Grant No
40
41 NSF-EAR 1204685. We would like to thank George Hornberger and Jonathan Gilligan for their
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43 feedback.
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Appendix: Country Descriptions

Bangladesh

Bangladesh, a least developed country, is one of the most densely populated countries in the world (Table 1) (UNCTAD, 2011; FAO, 2012). Bangladesh is a riverine country with 7% of the total country's land area covered by rivers, notably the Ganges, Brahmaputra, and Meghna (FAO, 2012). More than 90% of Bangladesh's surface water originates in other countries (Chowdhury, 2010). The majority of rain falls during the annual monsoon, from June to September, when 80% of annual precipitation occurs (Chowdhury, 2010). The country receives an annual average of 2,320 millimeters (mm) of rain but there is significant spatial variation in the amount of rainfall received, with an annual average of 1,110 mm of rainfall in the west to over 5,000 mm in the northeast (FAO, 2012; FAO, 2013). Water is the primary transportation medium and water-intensive industries such as agriculture, fisheries, forestry, and aquaculture are significant contributors to Bangladesh's economy. Currently, groundwater is the primary water source in Bangladesh, comprising 79% of total water use in 2008 (FAO, 2012). The agricultural sector, particularly paddy cultivation, is the biggest water user, accounting for 88% of the country's total water withdrawals in 2008 (Chowdhury, 2010; FAO, 2013).

Bangladesh is extremely vulnerable to frequent floods, cyclones, droughts, and storm surges. Due to its flat and low-lying topography, sea level rise is also of concern (Chowdhury, 2010). Although the country has plentiful water during the monsoon season, there is insufficient storage throughout the country to meet the needs of people and agriculture during the dry season (FAO, 2012). Furthermore, water quality has been adversely impacted by agricultural runoff, fecal contamination due to inadequate sanitation, saltwater intrusion, and pollution from industrial sources. To address contamination of surface waters, in the 1970s, the Bangladesh

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4 government initiated a nationwide program to provide shallow groundwater tube wells to many
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6 rural residents. This provided a dependable alternative drinking water supply until arsenic
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8 contamination was discovered in 1994 (Biswas & Adank, 2004). Today, an estimated one
9
10 million tube wells are contaminated with arsenic, exposing over 30 million people to its toxic
11
12 effects (Chowdhury, 2010; FAO, 2013). Increased salinity in surface waters has occurred
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14 because of decreased flows, and saltwater intrusion in the coastal areas is evident in groundwater
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16 drinking wells (Chowdhury, 2010; FAO, 2013).
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21 In Bangladesh, the Ministry of Water Resources (MoWR) is responsible for planning,
22
23 implementation, and operation of all water resource activities in Bangladesh. Two of the major
24
25 institutions under MoWR are the Bangladesh Water Development Board (BWDB) and the Water
26
27 Resources Planning Organization (WARPO). WARPO has national and regional water planning
28
29 responsibilities, and BWDB is charged with the execution of over 400 water projects. The
30
31 National Water Resources Council (NWRC) is the national body responsible for water policy in
32
33 Bangladesh. WARPO has a mandate to coordinate with all relevant ministries through the
34
35 NWRC (Chowdhury, 2010). Delivery of water and sewerage services in the larger cities is the
36
37 responsibility of the Water and Sanitation Authorities, whereas local governments implement
38
39 water supply projects in smaller municipalities. The Department of Public Health Engineering is
40
41 the national agency responsible for water and sanitation facilities in rural areas (Chowdhury,
42
43 2010). Nongovernment organizations are primarily responsible for implementing or extending
44
45 water service in the country, either directly or indirectly through microfinance assistance (Biswas
46
47 & Adank, 2004). Bangladesh has reached an agreement with India regarding equitable use of the
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49 Ganges in 1996, but no such agreements have been made for the other transborder rivers (FAO,
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51 2012). Water rights in the country are linked to land ownership rights, but over 45% of the rural
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4 population in the country is either landless or “functionally landless,” owning less than 200
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6 square meters of land (World Bank, 2013).
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9 10 *Sri Lanka*

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12 Sri Lanka, an island nation, is divided into three climatic zones determined by rainfall
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14 patterns: the wet zone, the intermediate zone, and the dry zone. Sri Lanka receives rain from two
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16 monsoons, the northeast monsoon and the southwest monsoon. The wet zone receives rain
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18 during both the northeast and southwest monsoon, while the dry zone, which covers three-
19
20 quarters of the island, receives rain only during the northeast monsoon. Like Bangladesh, there is
21
22 high spatial variation in the rainfall patterns, with an average annual rainfall of less than 1,000
23
24 mm in the northwest and over 5,000 mm in the central highlands of the country (Gunatilaka,
25
26 2008). Both floods and droughts are issues of particular concern in parts of the island (FAO,
27
28 2012). Because Sri Lanka is an island nation, it has no transborder water resources. Water quality
29
30 issues include agricultural pollution, fecal contamination, and saltwater intrusion, notably in the
31
32 coastal areas (Villholth & Rajasooriyar, 2010).
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40 As in Bangladesh, agriculture (predominantly paddy cultivation) plays a large role in the
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42 local Sri Lankan economy. In Sri Lanka, irrigation schemes are classified as minor, medium, and
43
44 major depending on the size of the area that can be irrigated by the scheme. Small artificial lakes
45
46 and ponds, known locally as tanks, dominate the minor irrigation systems (Marambe,
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48 Pushpakumara, & Silva, 2012). Due to overcrowding in other parts of the country, the Sri
49
50 Lankan government initiated the Mahaweli Development Programme in the 1970s which
51
52 oversaw the construction of medium and major irrigation systems in the dry zone.
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57 There are approximately 40 institutions and 40 legislative acts related to water in Sri
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59 Lanka (Manthrithilake & Liyanagama, 2012). Small-scale irrigation schemes are under the
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4 purview of the Department of Agrarian Development and are primarily managed by the farmers
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6 themselves. Medium and large irrigation schemes in the dry zone are managed collaboratively by
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8 the Mahaweli Authority of Sri Lanka and the Irrigation Department with priorities given to
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10 drinking and irrigation water over electricity generation (Manthrithilake & Liyanagama, 2012).
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12 Unlike Bangladesh, there is little coordination in managing general water resources in the
13
14 country; for example, the Meteorological Department and the Irrigation Department both collect
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16 rainfall data but neither shares their data with the other agency (FAO, 2012; Thuraisingham,
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18 2013). Overlap, gaps, and conflicting jurisdictions arise from Sri Lankan water laws being
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20 administered at the agency-level rather than being coordinated under a single Ministry (FAO,
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22 2012). Water rights in Sri Lanka are linked to land ownership so landowners have full authority
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24 over the use of surface and groundwater resources accessible on their land (FAO, 2012).
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26 Nevertheless, land fragmentation, landlessness, and encroachment in Sri Lanka generate
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28 inequality in access to water rights (Azmi, 2007). To date, no comprehensive groundwater
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30 management or planning systems have been implemented in the country (FAO, 2012).
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Table 1: Bangladesh and Sri Lanka Country Profiles

	Bangladesh	Sri Lanka	Source
Land area (km ²)	144,000	25,332	FAO, 2012
Population (x1000)	150,494	21,025	FAO, 2013
Population density (inhabitants/km ²)	1,045	321	FAO, 2013
Population growth rate (%)	1.3	0.7	ADB, 2013b
Mean annual temperature (°C)	25°C	27°C in the lowlands, 15°C in the central highlands	FAO, 2012
Total cultivable land area (hectares per capita)	0.06	0.10	FAO, 2013
Gross domestic product, PPP (\$US 2012 per capita)	1,943	6,040	ADB, 2013b

Table 2. 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, Meigh, & Sullivan, 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 & Manthritilake, 2012

^aShaded indices indicate country with a more favorable ranking.

Table 3: 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
		Urban	20%	67%		NWSI, IDWA-2
		Rural	0.23%	3.76%		IDWA-2
	Population with access to sanitation	Total	55%	91%	UN, 2013b	WPI, NWSI
		Urban	55%	83%		
		Rural	55%	93%		RWLI
Use	Water withdrawals (% of total water resources)	Total	2.9%	24.5%	FAO, 2013	WRVI, RWLI, CWVI
		Domestic/Municipal	0.3%	1.5%		WPI, CWVI, IDWA-2
		Agricultural	2.6%	21.4%		WPI, WSI
		Industrial	0.1%	1.6%		WPI, CWVI
	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 1000 births)	59	12	ADB, 2013b	WPI
		Percentage of undernourished people	17	24	ADB, 2013b	RWLI
	Income: GNI per capita	GNI per capita, PPP (2013 \$ International) ^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

		Parameters	Bangladesh ^a	Sri Lanka ^a	Source	Indices using parameters ^b
		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
Environment		Environmental flows (water available for environmental purposes)	Very Good	Poor	Lautze & Manthrilake, 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	

^aShaded values indicate country with a more favorable ranking.

^bFI: 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.

^cRWLI uses inter-annual variation in cattle holdings and cereal production as a proxy for the coefficient of variation in precipitation.

^dSome indices use the Human Development Index, which is 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 (2012\$). The current HDI for Bangladesh and Sri Lanka are 0.515 and 0.715 respectively (UNDP, 2013a).

Table 4: 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	

^aShaded values indicate country with a more favorable ranking.

^bDue to lack of data, surface area instead of volume of water stored in small-scale irrigation schemes is listed.