

A diagnostic dashboard to evaluate country water security

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Abstract

While water security is widely regarded as an issue of global significance and concern, there is not yet a consensus on a methodology for evaluating it. The difficulty in operationalizing the concept comes from its various interpretations and characteristics at different spatial and temporal scales. In this paper, we generate a dashboard comprised of 52 indicators to facilitate a rapid assessment of a country's water security and to focus the first step of a more comprehensive water security diagnostic assessment. We design the dashboard around a conceptualization of water security that builds upon existing framings and metrics. To illustrate its usefulness, we apply the dashboard to a case study of Pakistan and a regional cross-country comparative analysis. The dashboard provides a rapid view of the water security status, trends, strengths, and challenges for Pakistan. The cross-country comparative analysis tentatively identifies relationships between indicators such as water stress and the transboundary dependency ratio, with countries exhibiting high values in both variables being especially vulnerable to transboundary water risk. Overall, this dashboard (1) provides quantitative information on key water-related variables at the country level in a consistent manner and (2) helps to design and focus more in-depth water security diagnostic studies.

Keywords: Country comparisons; Dashboard; Data monitoring and reporting; Diagnostic; Indicators; Water security

Highlights

- A diagnostic methodology is generated to operationalize a comprehensive framing of water security to capture the current water security situation in a given country.
- A dashboard tool is created to visualize the first step in the diagnostic method.
- The dashboard format offers a streamlined dissemination of information across five key categories of information that are crucial to the understanding of water security.

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- This dashboard is unique as it incorporates trends and is based on a harmonized set of national indicators that allow for cross-country comparisons.
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1. Introduction

Water security has emerged in international policy and academic debate as an overarching concept to encompass the multiple dimensions of water. Water security, like any other form of security, evokes varied meanings. A definition that attempts to capture all of these connotations is a ‘tolerable level of water-related risk to society’ (Grey *et al.*, 2013). This broad definition does not specify a spatial or temporal scale. It applies to a city such as New York or the entirety of China. It refers to water-related risk today and in the future. This definition does not elaborate on the types of water risk. It could refer to risks that arise from natural hazards such as flooding, drought, storm surge, or tsunamis. It could refer to people’s access to safe drinking water supplies, such as a general lack of access, poor quality, or supply system unreliability and unaffordability. It could also refer to threats to water resources, such as groundwater overuse or transboundary conflicts. Given the breadth of scale and types of risk, it is understandable that there is no consensus on an evaluation methodology.

There have been multiple attempts to operationalize the concept of water security (Lautze & Manthrilake, 2012; Norman *et al.*, 2013; Gain *et al.*, 2016; van Ginkel *et al.*, 2018). Zeitoun *et al.* (2016) criticize previous approaches that use risk to attempt to quantify water security. Instead, they suggest that the concept would benefit from a more holistic evaluation process that allows for case-specific understandings along with the ability to incorporate the overlap of water security with additional security concerns (Zeitoun *et al.*, 2016). Yet, they do not lay out a methodological approach to achieve this. In this paper, we are alert to the critique of reductionism, so adopt a broad and holistic understanding of water security. Nonetheless, we argue that there needs to be some standardization and measurement involved if we are to track progress and compare different situations and contexts.

There are several options available for communicating complex concepts with multiple data dimensions, such as visualization software and the use of composite indices. Dashboard tools are one such option and offer a way to communicate and visualize an array of socio-economic and environmental indicators, such as monitoring biodiversity (Han *et al.*, 2014). By monitoring data that are relevant to water security and placing them in a dashboard, one can approach some comparable process of data reporting (van Ginkel *et al.*, 2018). Dashboards can also help countries comprehend their water security progress, aid in policymaking, help with monitoring water security (Han *et al.*, 2014), and are increasingly being promoted in the context of the 2030 Agenda (UNDP, 2017). This also allows for the possibility of comparisons across countries.

Given that the concept of water security has proved to be so challenging to conceptualize and evaluate, its usefulness has been questioned (Pahl-Wostl *et al.*, 2016). However, it is widely used in policy circles both within governments, NGOs, and multilateral development organizations to draw attention to water-related issues and challenges (Staddon & Scott, 2018). Given this wide uptake, it is important for researchers to engage with the concept, even if this proves to be conceptually and operationally challenging. This paper proposes, describes, and applies a diagnostic dashboard for policymakers and water management practitioners to quickly and efficiently attain a picture of a country’s water security.

This dashboard contributes to the literature by structuring diverse data relevant to water security into a single page. We focus on the country level due to the availability of data and to support country-level decisions by governments and international agencies. This perspective also allows for cross-country comparisons.

The paper starts by taking stock of past conceptualizations and empirical studies of water security. Next, we lay out our methodology that consists of three parts: (1) a water security framing built from previous conceptualizations, (2) a diagnostic methodology, and (3) a conceptual dashboard that can be used as an aid in the first step of the diagnostic method. Then, we focus on the dashboard and use a case study of Pakistan to test its accuracy and usefulness, along with a regional cross-country comparison. Finally, the results are discussed, along with concluding remarks.

2. Current approaches to water security

2.1. Framings

The term water security was first used in the early 1990s amid growing concerns that water scarcity could be a threat to national security (Clarke, 1991; Starr, 1991, 1992). By the latter half of the decade, the concept expanded beyond water availability and became part of the broader academic and global agenda with the Ministerial Declaration of The Hague on Water Security in the 21st Century at the 2nd World Water Forum in 2000. The declaration called for the provision of water security and to ensure

‘that freshwater, coastal and related ecosystems are protected and improved; that sustainable development and political stability are promoted, that every person has access to enough safe water at an affordable cost to lead a healthy and productive life and that the vulnerable are protected from the risks of water-related hazards’ (United Nations, 2000).

This multi-dimensional framing was the first to recognize the need to protect against water-related risks and viewed water security as a ‘goal’ of water resources management (United Nations, 2000). This 2000 framing is one of many. There are numerous conceptualizations of water security, generating the need for several periodic reviews of the literature (Cook & Bakker, 2012; Garrick & Hall, 2014; Gerlak et al., 2018).

A long-standing problem in the field of water security is what to include in its conceptual framing, i.e. focus on specific water-related issues or try to cover all possible dimensions. Studies have focused solely on water security and economic growth (Brown & Lall, 2006), drinking water (Hope & Rouse, 2013), and institutional capacity (Bakker & Morinville, 2013). The advantages of these studies are in-depth analyses of a specific aspect of water security that provide vital information to policy-makers. However, they do not cover the full scope of a concept that is widely regarded as being multi-dimensional (Gerlak et al., 2018). Furthermore, water security intersects with broader inter-related assessment frameworks, including assessments of ecosystem services (Russi et al., 2013; GWP, 2016) and of adaptive capacity (Lemos et al., 2016).

Briscoe (2009) created one of the earliest multi-dimensional framings. He designed his framing around what types of information a country ‘water tsar’ would need to achieve water security. This framing focused on four types of information: (1) historical and cultural context, (2) exogenous drivers, (3)

endogenous tools, and (4) outcomes concerning people, economy, and the environment (Briscoe, 2009). Briscoe (2009) emphasized the need for ‘information’ rather than specific indicators. This allows for his framing to be applied across a range of situations. This framing was only laid out in theory and not operationalized within the scope of the 2009 paper, but additional studies by Briscoe and co-researchers provide applied examples (Briscoe & Qamar, 2006). Scholars have continued to propose multi-dimensional framings of water security (Mason & Calow, 2012; Romero-Lankao & Gnatz, 2016; James & Shafiee-Jood, 2017; Srinivasan *et al.*, 2017). Nonetheless, a consistent multi-dimensional framework has proved to be elusive. The fundamental question of how to go about measuring or gathering the consistent information needed and then generating a useful recommendation from it still stands.

2.2. Evaluations

There are several water security evaluations, and they range from the local to the global scale. Local studies tend to focus on stakeholder engagement and attempt to tie research insights to local policies. One example of this is the study conducted by Norman *et al.* (2013) in a small town in British Columbia. They focus on stakeholder engagement in their indicator formation with the intent to inform policy decisions (Norman *et al.*, 2013). On the city scale, a recent study evaluated ten cities using pressure-state-impact-response (PSIR) to create a dashboard of 56 different indicators (van Ginkel *et al.*, 2018). It also develops a single index value of water security for each city. This study is one of the most comprehensive to date as it accounts for various climate and socio-economic drivers, system state variables, outcomes, and adds in the additional response indicators that essentially capture government effectiveness (van Ginkel *et al.*, 2018). Nonetheless, the study is limited in that data to quantify some of the proposed indicators are not readily available, and it does not incorporate trends.

At the country scale, several studies have been conducted specifically in Asia and the Pacific. The first being by Lautze & Manthritilake (2012), who look at water security in terms of ‘basic needs, agriculture production, the environment, risk management, and independence’ for 46 countries. This study was for a single year, and only 27 of the 46 countries had data in all five components. The Asian Development Bank (ADB) (2013, 2016) continued with this focus by releasing two water security reports for 49 countries in Asia and the Pacific. The ADB (2013, 2016) studies are comprehensive, covering five areas of water security: household, economic, urban, environment, and resilience to water-related disasters. They also generate a single index value of water security for each country (ADB, 2013, 2016).

On a global scale, Gain *et al.* (2016) created a map of water security by aggregating data from a 0.5° spatial resolution, country-level data, as well as river basin data. This aggregate value of water security was based on a multi-criteria analysis that included ‘water availability, accessibility to services, safety and quality, and management’ (Gain *et al.*, 2016). Finally, Sadoff *et al.* (2015) evaluated water security across scales: cities, river basins, and aquifers. In addition, the study reported on several indicators based on country information: costs of water insecurity, floods, access to water and sanitation, and ecosystem impacts (Sadoff *et al.*, 2015).

The majority of these studies only focus on a snapshot of data from 1 year. The ADB (2013, 2016) is beginning to formulate a time series with their two separate reports, and the GWP/OECD report (Sadoff *et al.*, 2015) used time series data for several of their water security indicators. One can see that each of the above analyses focus on somewhat similar issues, but they measure water security with different indicators. For example, they measure some form of accessibility to water and environmental degradation. However, when focusing specifically on adaptability to water security, there were multiple

approaches, such as risk management (Lautze & Manthrilake, 2012), resilience (ADB, 2013, 2016), or management (Gain et al., 2016). Zeitoun et al.'s (2016) argument of reductionism is relevant for some of these studies, as they have tended to reduce the complexity of water security to a single indicator (e.g. ADB's National Water Security Index Score). However, this has begun to be addressed both through a focus on context and pathways (Sadoff et al., 2015), but also through the implementation of diagnostic studies (Garrick et al., 2013; Hydrosystems Research Group, 2017; World Bank, 2017, 2018; Young et al., 2019). This study builds upon this line of work to develop a water security diagnostic approach and applies the approach to construct a dashboard to evaluate country water security.

3. Methodology

3.1. Water security framing

An overall framing of water security is presented before proceeding to develop a diagnostic methodology since 'a framework provides the basic vocabulary of concepts and terms that may be used to construct the kinds of causal explanations expected of a theory' (McGinnis & Ostrom, 2014). We focus on the framing by Briscoe (2009) and expand upon it. We chose Briscoe's framing due to its comprehensive nature, its focus on both qualitative and quantitative data, its recognition of the subjectivity of water security, and its ability to allow for an iterative decision-making process. Based on this framing, we propose seven types of information needed to assess and understand water security. These information categories are (1) drivers, (2) historical and cultural context, (3) the water resource system, (4) system performance, (5) outcomes, (6) actions, and (7) trends. The majority of these criteria are reminiscent of the four laid out by Briscoe (2009), with the main difference being (3), (4), and (7). Having a separate category for the water resource system and understanding its performance was alluded to by Briscoe, but never explicit in his framework. The trends category was added because it helps to interpret the future state of water security, which is naturally the focus of water management actions. The reasoning behind each of these information categories is summarized below, with several categories being compared to Ostrom's (2007) theoretical framing of social-ecological systems (SES) as it is a widely accepted framework to understand complex systems.

1. *Drivers* are factors that may contribute to changing the status of water security. Drivers appear in different forms in Briscoe's (2009) framing and Ostrom (2007). In Briscoe's (2009) framing, drivers are exogenous factors that are influencing the water resource system and its governance. For example, an increase in population could increase the pressure on the resource and change usage patterns. Meanwhile, Ostrom (2007) referred to these factors as social, economic, and political settings plus the related ecosystems, as well as mentioning the technological environment. Ostrom (2007) acknowledges that the SES can be influenced as well as influence these factors. In this line, we separate our drives into five categories: social, economic, political, technological, and environmental.
2. As well as acknowledging exogenous influences, Briscoe (2009) also emphasizes the importance of *historical and cultural context*, which is more endogenous in nature, recognizing how this can affect the types of institutions and policies that could be put in place to manage water. For example, people's coping mechanisms to floods can evolve due to changing social or cultural norms. These attributes are more aligned with the cultural representations of water discussed in Veronica Strang's book (2015), in which she points to several well-known cases of historical significance. This includes the Nile in Egypt, where water's place in society has evolved over

the centuries (Strang, 2015). Historical and cultural context will be predominantly qualitative, highly case-specific and, like many aspects of water security, may vary over different spatial and temporal scales.

3. The *water resource system* incorporates the variables that describe the state of water resources, recognizing that the system is, for the most part, modified by human activity. So, understanding the status of the system must include the water endowment and how water is allocated. Thus, this set of state variables includes (1) how much water is available, (2) how the water is allocated, and (3) the infrastructure and institutions that are in place to manage the previous two elements. While these are not explicit categories of Briscoe's (2009) framing, he does express the need for a 'broad, integrated conceptual understanding of the water challenge'. Briscoe (2009) also references the importance of measuring drivers as they have the ability to determine the 'quantity and quality of water available'. Our water resource system category overlaps with three of the primary components of Ostrom's (2007) overall framing of an SES. The water endowment roughly maps onto Ostrom's (2007) characterization of the resource system. This endowment component captures surface and groundwater, how much of this water originates within the country, and unconventional supplies such as desalination and recycled water. Our usage component picks up on the users in Ostrom's (2007) framing and can be broken down further into different usage types such as agricultural, industrial, and municipal. The infrastructure and institutions currently in place are included here because they have alignment with Ostrom's (2007) governance system, and as managed systems, they are difficult to separate from the previous two components. For example, hard infrastructure such as dams affects the quantity of the water endowment (by changing the amount of water that is evaporated), the timing of its availability, and where it is located. Soft infrastructure such as wetlands also influence processes such as evapotranspiration and groundwater recharge. Institutional policies can affect the allocation of the resource as well as the operation of the infrastructure.
4. *System performance* indicators report on how the water resource system is operating as far as users of water are concerned, where this also includes environmental users. The system performance category is also an addition to Briscoe (2009). Briscoe (2009) does discuss how technological advancement can improve the performance of infrastructure. Thus, alluding to the monitoring of performance metrics. In this case, system performance incorporates the overall quality of the water available, the stress on the resource, and whether the resource is being used productively and efficiently. It also includes the performance of infrastructure and institutions. These system performance indicators represent an intermediate step between the system state variables in (3) and the outcomes in (5), which are the values that are associated with and aggregated over system performances. For example, water quality affects the social, economic, and environmental outcomes of the system.
5. *Outcomes* are the attributes of a system that are valued by people and decision-makers (Hall & Borgomeo, 2013). Outcomes appear in Briscoe's (2009) framing, although Briscoe uses the term interchangeably with impacts. In keeping with the 'triple bottom line' definition of sustainability, Briscoe (2009) breaks this information category into social, economic, and environmental outcomes. SES theory also includes outcomes, and they are subdivided into social, ecological, and additional SES externalities (Ostrom, 2007). These two interpretations illustrate the need for subfields within this category, and we choose to use those set out by Briscoe because they align with other risk-based water security framings that focus on outcomes (Sadoff et al., 2015; ADB, 2016).
6. *Actions* are the interventions at the disposal of stakeholders in the system, which may change the state of the water resource system and, hence, its performance and outcomes. This may include policy and operational reforms or investments in infrastructure and technology. Thus, this encompasses a broad decision space. Briscoe (2009) refers to these items as 'endogenous tools' and references the following: institutions, infrastructure, and technology. These actions differ from the infrastructure and institutions that are already a part of the water resource system mentioned above, as they have yet to be implemented. These actions vary across an array of decision-makers from the farmer deciding whether to add drip irrigation to a river basin manager trying to implement water quality regulations. These actions also vary across temporal scales. If we take the example of the farmer, his/her decisions may be implemented from one growing season to the next, while some

strategies, such as increased storage capacity, may take longer to implement, given their high cost and construction timeline.

7. *Trends* in all of the above indicators provide information on the evolution of water security, which informs future management actions. Trends are an addition to Briscoe (2009), but Briscoe does reference the need to acknowledge changes that may occur in the future due to climate change or technological advancement. Trends in any of the above categories may be informative, although data on some (e.g. population drivers) are much easier to obtain than others (e.g. water quality or outcomes for aquatic organisms). Few water security trend analyses have been conducted, mainly due to a lack of data.

3.2. Diagnostic method

To demonstrate the framing of water security described in Section 3.1, we set out a diagnostic approach to evaluate the multiple dimensions of water security. Figure 1 shows a method for diagnosing water security, inspired by an analogy from the medical diagnostic approach (Graber, 2015). The diagnostic process starts by gathering high-level information about water security as a whole, assessing the data, and then generating an initial diagnosis. This initial diagnosis would highlight the main water challenges and opportunities within a country. Once this initial diagnosis is reached, Step 2 involves gathering additional information and running further tests, such as looking at a specific species decline or assessing flood risk. Once all available information is gathered and has been assessed, a final diagnosis is reached. Based on this diagnosis, a treatment plan can be constructed. Step 4 in the process is labeled as ‘treatment’, given the medical analogy of the term ‘diagnostic’. Treatment includes the

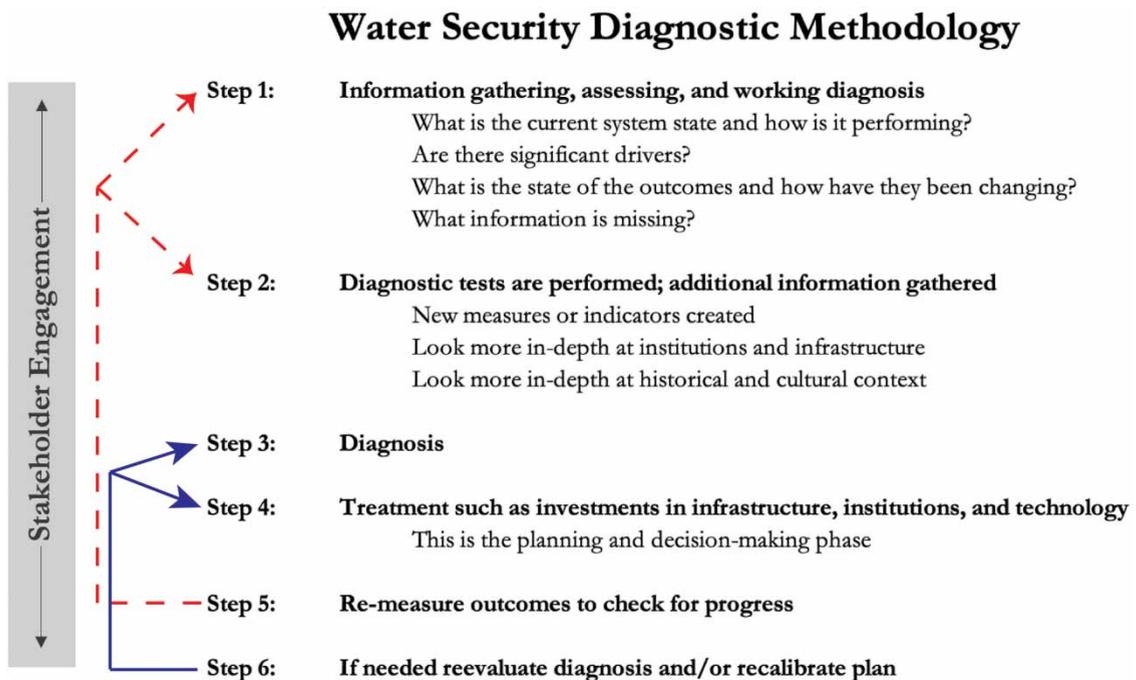


Fig. 1. Water security diagnostic methodology based on a medical diagnosis process (Graber, 2015). Please refer to the online version of this paper to see this figure in color: <https://doi.org/10.2166/wp.2020.235>.

planning and decision-making phase, and examples could be generating a policy to regulate pollution discharge or enhancing the financial stability of urban water utilities. After the treatment stage, there is a need for periodic reviews of the outcomes of the treatment. This is illustrated through the red arrows (dotted line) in Figure 1. Based on this evaluation, one should determine if the treatment was successful or not, and if the diagnosis or treatment needs to be re-assessed. This is illustrated through the blue arrows in Figure 1. Finally, this is an iterative method that takes into account stakeholder feedback during each step of the process.

3.3. Water security dashboard: a tool for initial diagnosis

The dashboard that we have created facilitates a rapid approach to Step 1 of the diagnostic methodology and thereby assists the process of reaching a working or initial diagnosis. The dashboard is generated based on the framework set out above. Thus, it seeks to look at a variety of indicators in order to highlight multiple water security challenges. A single-page dashboard helps to focus on the analysis and visualize the current status and trends of relevant information. It also helps to identify potential connections between indicators and dimensions to understand how water-related risks may arise. Although water security may be assessed at many scales, we have focused on the national scale. By using globally and publicly available data at this scale, the dashboard tool can be used for cross-country comparisons and enable ranking of performance across countries.

Even though the framework above was used as a basis for the dashboard, two categories were not compatible with a dashboard format: (2) historical and cultural context and (6) actions. Historical and cultural context typically are found in a narrative format. However, diagrammatic timelines have been used to highlight historical events relating to water (Sadoff *et al.*, 2015). General context is reported at the beginning of the Results section, although this does not provide a complete historical and cultural analysis. Data on the ‘actions’ category are also not included, as these relate to the ‘treatment’ step in the diagnostic process and require creative input from decision-makers. Ultimately, 52 variables were selected for the dashboard (Table 1). This represents a pragmatic choice of data that are available for most countries. In the discussion below, we note limitations with these datasets.

Based on this data, we can make an initial diagnosis and recommend items to be pursued in Step 2, such as additional data to be gathered and tests to run. This format also lends itself to cross-country comparative analysis. However, this is only the first step in the overall diagnostic methodology. Even though a standardized set of variables are used to create a working diagnosis, Steps 2–6 of the method allow for tailoring and stakeholder engagement.

Socio-demographic drivers include population, urbanization, net migration, the human development index (HDI), the Gini coefficient, the gender gap in wages, and the percentage of employment in agriculture. Population and the urbanization rate provide basic demographic context. The net migration value is a sum of the total emigration and immigration within the country. The HDI is a multi-dimensional indicator and incorporates life expectancy, education level, and gross national income (GNI) per capita (United Nations, 2019b). GNI includes all income for citizens regardless if it was earned abroad, whereas GDP only includes revenue from production within the country’s boundaries (World Bank Databank, 2019). The Gini coefficient is a measure of economic distribution within society measuring equality on a scale of (0–100), with 0 being total equality and 100 being absolute inequality (World Bank Databank, 2019). We incorporate the gender gap in wages (United Nations, 2019a). This is the gap in average wages across all income categories with a value of 1 indicating equality in wages and

Table 1. Items included in the dashboard along with unit, timescale analyzed, and data source.

Variable name	Unit	Timescale	Source
Drivers			
<i>Social</i>			
Population	–	1990–2017	World Bank Databank (2019) and projections United Nations (2017)
Urban population	% of population		World Bank Databank (2019) and projections United Nations (2017)
Net migration		1990–2017	World Bank Databank (2019)
Human Development Index	0–1 (0 worse)	1990–2017	United Nations (2019b)
Gini coefficient	0–100 (100 worse)	1990–2017	World Bank Databank (2019)
Gender gap in wages	0–1.5 (1 is equality)	2000–2016	United Nations (2019a)
Employment in agriculture	–	1990–2017	World Bank Databank (2019)
<i>Economic</i>			
Gross domestic product (GDP)	2010 USD	1990–2017	World Bank Databank (2019) and projections from IMF (2019)
GDP per capita	2010 USD/person	1990–2017	World Bank Databank (2019)
Agriculture value added	% of GDP	1990–2017	World Bank Databank (2019)
Industry value added	% of GDP	1990–2017	World Bank Databank (2019)
Services value added	% of GDP	1990–2017	World Bank Databank (2019)
<i>Political</i>			
Fragile states index (FSI)	0–120 (120 worse)	2006–2018	The Fund for Peace (2019)
<i>Technological</i>			
Technology Development	Number of water-related patents	2000–2016	OECD (2020)
<i>Environmental</i>			
Average yearly temperature	°C	1990–2017	Harris <i>et al.</i> (2014) and projections World Bank CCKP (2019)
Interannual temperature variability (CV)	–	1990–2017	Calculated: Harris <i>et al.</i> (2014)
Total yearly precipitation	mm	1990–2017	Harris <i>et al.</i> (2014) and projections World Bank CCKP (2019)
Interannual precipitation variability (CV)	–	1990–2017	Calculated: Harris <i>et al.</i> (2014)
The Water Resource System			
<i>Conventional Water Endowment</i>			
Total renewable freshwater	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
Renewable groundwater	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
Renewable surface water	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
Transboundary dependency ratio	%	1990–2017	FAO Aquastat (2019)
Water availability per capita	m ³ /inhab	1990–2017	Calculated: FAO Aquastat (2019) and World Bank Databank (2019)
<i>Unconventional Water Endowment</i>			
Desalinated water produced	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
Direct use of treated wastewater	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
Net virtual water imports	10 ⁹ m ³	1996–2005	Mekonnen & Hoekstra (2011)
<i>Usage</i>			

(Continued.)

Table 1. (Continued.)

Variable name	Unit	Timescale	Source
Agriculture	10 ⁹ m ³	1990–2017	FAO Aquastat (2019) and Liu <i>et al.</i> (2016)
Industry	10 ⁹ m ³	1990–2017	FAO Aquastat (2019) and Liu <i>et al.</i> (2016)
Municipal	10 ⁹ m ³	1990–2017	FAO Aquastat (2019) and Liu <i>et al.</i> (2016)
Environmental	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
Renewable groundwater	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
Renewable surface water	10 ⁹ m ³	1990–2017	FAO Aquastat (2019)
<i>Infrastructure</i>			
Cultivated land equipped for irrigation	%	1990–2017	FAO Aquastat (2019)
Treated wastewater	%	2018	Wendling <i>et al.</i> (2018)
Total storage capacity	10 ³ m ³	1990–2017	FAO Aquastat (2019)
<i>Institutions</i>			
Government institutions	–	At present	FAO (2019)
International freshwater treaties	–	As of 2007	Oregon State University (2007)
System Performance			
Number of recorded droughts	–	1990–2017	EM-DAT (2019)
Number of recorded floods	–	1990–2017	EM-DAT (2019)
Water stress	%	1990–2017	SDG 6.4.2 calculated from FAO Aquastat (2019) and Liu <i>et al.</i> (2016)
Water productivity	2010 USD/m ³	1990–2017	SDG 6.4.1 calculated from FAO Aquastat (2019) and Liu <i>et al.</i> (2016)
Water quality index – pollution	0–1 (1 worse)	2014	Sadoff <i>et al.</i> (2015)
Continuity of Service	0–24 h	1995–2019	IB-NET (2020)
Degree of IWRM implementation	0–100 (0 worse)	2018	SDG 6.5.1 from UN Environment (2018)
Outcomes			
<i>Social</i>			
Access to improved water	%	2000–2017	WHO/UNICEF JMP (2019) (by service level)
Access to improved sanitation	%	2000–2017	WHO/UNICEF JMP (2019) (by service level)
Deaths from flood	–	1990–2018	EM-DAT (2019)
<i>Economic</i>			
Agriculture value added	2017 USD	1990–2017	World Bank Databank (2019)
Total cost of flood damage	2017 USD	1990–2017	EM-DAT (2019)
Total cost of drought damage	2017 USD	1990–2017	EM-DAT (2019)
<i>Environmental</i>			
Biodiversity index	0–1 (1 worse)	2014	Sadoff <i>et al.</i> (2015)
Environ flow violations index	0–1 (1 worse)	2014	Sadoff <i>et al.</i> (2015)
Maps for Dashboard Tool			
Country and admin level shapefiles	–	Current	Natural Earth (2019)
World's major rivers	–	Current	Natural Earth (2019)
HydroSHEDS basin rivers	–	2013	Lehner & Grill (2013)
World cities	–	2019	ArcGIS Hub (2019)

a value less than one indicating that males are earning more than females (United Nation, 2019a). The indicator is currently only available for Pakistan and not the additional four countries used in our cross-country comparison analysis. Finally, we include the percentage of employment in the agricultural sector, as this could indicate the percentage of the workforce relying on water-intensive activities. While this is not an exhaustive list of demographic or equity-based indicators, they give us a general idea as to changing population dynamics and socio-economic status through time.

Variables for economic drivers include GDP per capita and a breakdown of a country's economic makeup in terms of the overall GDP as well as agriculture, industry, and service sectors. Knowing whether a country has transitioned or is in the process of transitioning to a manufacturing or service-based economy can help to understand how water withdrawals could change in the future, i.e. in some countries, such as the United States, agricultural water withdrawals have decreased following industrialization (Siddiqi & Anadon, 2011). To quantify political stability within a country, we use the Fragile States Index (FSI). This indicator measures state vulnerability across 12 different dimensions, making it a comprehensive index of overall country stability (The Fund for Peace, 2019). Ostrom (2007) recognized that the technological, along with the social, economic, and political, environment are important factors that contribute to outcomes. The technological environment is expressed through the OECD's (2020) technology development indicator. In this case, this indicator is comprised of the number of water-related patents developed or partially developed (indicated by a fraction) by a given country between 2000 and 2016, which includes water pollution abatement and water adaptation technologies (OECD, 2020). Technology development is used as one of the OECD's indicators on Green Growth and gives some indication to the value placed on innovation within the country (Hašičič & Migotto, 2015). Finally, information on climate drivers includes temperature and precipitation data. The coefficient of variation (CV) for temperature and precipitation represents the interannual hydroclimatic variability, which is associated with more challenging conditions for water management as it means that rainfall is not predictable from one year to the next (Hall et al., 2014).

The water resource system is broken down into the water endowment, water usage, infrastructure, and institutions. The water endowment is further separated into the conventional endowment and unconventional endowments. The conventional endowment includes renewable groundwater and surface water, as well as data on the transboundary dependency ratio and total renewable freshwater is put in relative terms by reporting on the water availability per capita. The conventional water endowment only considers renewable freshwater, so it would benefit from the additional information on slow-recharge aquifers. The data were acquired from FAO Aquastat (2019), but there are some limitations since country renewable freshwater remains constant from 1958 to 2017. Also, groundwater and surface water may not sum to the total renewable freshwater, as FAO Aquastat's (2019) total renewable freshwater includes values that could be considered both groundwater and surface water. We also highlight a country's dependency ratio, which refers to the amount of renewable freshwater that originates outside the country's borders. A low dependency ratio (0%) indicates that all of a country's water is generated within the country, whereas a high dependency ratio of (100%) would suggest that all of the country's water is generated elsewhere and flowing into the country. We recognize the importance of green water in a country's water endowment; however, given the lack of country-level data on green water, we excluded it for now. Unconventional endowments include net virtual water imports, the amount of desalinated water produced, and the direct use of treated municipal wastewater. If we think of the water endowment as the water available for different uses, then the virtual water imported is water that effectively becomes available to use (e.g. in the form of the imported agricultural products). Thus, importing

water effectively expands a country's resource endowment. Desalinated water and recycled wastewater are also ways in which countries can effectively enhance their resource base.

FAO Aquastat (2019) database is the primary resource on country-level water withdrawals. However, data are reported in 5-year windows. A value can be reported for each country for any of the years within these 5-year windows, and there are frequent data gaps. Liu *et al.* (2016) attempted to fill in FAO Aquastat data gaps through interpolation and inverse distance weighting. The result was a complete country-level dataset for water withdrawals on a 5-year time step from 1973 to 2013 (Liu *et al.*, 2016). For this analysis, we use Liu *et al.*'s (2016) dataset and update it based on current FAO data. The environmental usage is based on the environmental flow requirements found in FAO Aquastat (2019). We additionally report on the amount of surface water and groundwater withdrawn, as we try to capture the importance groundwater plays in water security (Gleeson *et al.*, 2012). These data come from the FAO Aquastat (2019) database and may not directly align with sectoral water withdrawal data.

Several relevant indicators are used to characterize the current infrastructure and institutions. The cultivated land area equipped for irrigation, the amount of wastewater treated, and storage capacity are used to measure the scale of water infrastructure (Gaupp *et al.*, 2015). Elaborating on the current status of water-related institutions is more challenging, as the type of institutions, along with their roles and capacity, are highly context specific. Currently, the FAO reports (FAO, 2019) on the number of water-related governmental institutions, and Oregon State University (2007) reports on international freshwater treaties every country is a party. These are not perfect indicators, but sometimes the 'mere presence of governance instruments' is all that is available (Woodhouse & Muller, 2017). We recognize that these available indicators give limited perspective on infrastructure and institutional complexity within a country, but unfortunately, are amongst the only indicators for which data are available for cross-country comparisons. We believe that they represent a reasonable starting point at the initial diagnostic phase of a water security assessment.

Water system performance includes how well the system is operating, i.e. if it is being sustainably managed. First, the recorded number of floods and droughts are listed as these values provide knowledge on how the overall hydrological regime is performing. Water stress is calculated based on the water withdrawals versus the total renewable freshwater (including environmental flow needs), using the equation for UN SDG 6.4.2 (FAO, 2018b). Water productivity is a metric that captures the amount of money gained from a unit of water used and is calculated based on the UN SDG 6.4.1 indicator for water use efficiency (FAO, 2018a; Doeffinger & Hall, 2020). The calculation excludes the proportion of rainfed agriculture from the equation and does not include green water (FAO, 2018a). Also, the agricultural gross value added for this calculation includes forestry and fisheries, as these items are typically included as part of the agricultural sector (FAO, 2018a). Both of these system performance metrics were calculated with the water withdrawal data discussed above and come with limitations inherent in these data. Water quality is a crucial system performance attribute which can affect each of the outcomes. For example, poor water quality can affect the health of both people and the environment (Damania *et al.*, 2019). Due to the lack of information on country-level water quality, we use the country-level pollution indicator from the GWP/OECD report (Sadoff *et al.*, 2015). This indicator has no time series, so we are not able to quantify how water quality has changed over time. In terms of infrastructure performance, we include information on the reliability of water service delivery in terms of the continuity of service (IB-NET, 2020). We also include new data from SDG indicator 6.5.1, 'degree of integrated water resource management implementation' (UN Environment, 2018),

which is a qualitative measurement. Ideally, an indicator for the affordability of water services would be included, but it is not currently reported on in a consistent way across countries and, as Hoque & Hope (2019) point out, is a challenging metric to measure effectively.

Outcomes are reported with indicators for social, economic, and environmental impacts. Social outcomes include access to improved water and sanitation as well as flood-related deaths. For economic outcomes, we focus on the value of agriculture as well as flood and drought costs. The agricultural sector GVA is used to help understand the scale of economic dependence on water. This value also provides insight into the implications of changes in agricultural production. Flood and drought costs were originally given in US dollars in the year the event occurred, so the values were adjusted to 2017 US dollars using the US Inflation Calculator (2019). In regards to determining the outcomes of drought, these outcomes are much more challenging to account for than those of flooding (Hall & Leng, 2019). The EM-DAT (2019) dataset is based on reporting by governments and NGOs, so the criteria for including floods and droughts are variable. In addition to the variation in the qualification of a drought, measuring the direct human and economic impacts can be challenging (Van Loon *et al.*, 2016). Finally, for environmental outcomes, we look at the biodiversity index and environmental flow violation index. Data for both of these indicators are taken from Sadoff *et al.* (2015). The biodiversity index represents the strength of the area's biodiversity, while the environmental flow violation index relays if enough water is flowing through a country's waterways.

3.3.1. Generating the dashboard. The dashboard was generated to communicate and act as a visualization for the 52 variables in a single place and within one sheet of paper to streamline the process of water security diagnostics. We highlight trends in the indicators for which a time series is available. We focused on an overall period of 1990 to the present for trend detection, since the majority of the data was available for this time period. The data are also more robust during this time period, i.e. not as many interruptions in datasets. For exact date ranges used for each indicator, see Table 1. The direction of the arrows in the dashboard signifies an increasing or decreasing trend, while a horizontal line indicates no positive or negative trend over the time period. Trends were calculated using ordinary least-squared (OLS) regression. Additionally, the average annual rate of growth was calculated for each indicator for which a time series was available. This is indicated based on the size of the trend arrow in the dashboard. Finally, future projections were available for population, GDP, annual precipitation, and average temperature.

In addition, we ranked the majority of the 52 indicators across countries. The overall water endowment and the number of current institutions were not ranked since they are intended to provide context. The majority of the indicators were ranked from highest to lowest. However, several were ranked from lowest to highest: the HDI, GDP per capita, total GDP, technology development, total precipitation, water availability per capita, net virtual water imports, cultivated land equipped for irrigation, treated wastewater, water productivity, continuity of service, degree of IWRM implementation, and access to improved water and sanitation. These specific indicators were ranked from lowest to highest, as a lower score is of more cause for concern. Highlighted indicators within the dashboard are those that fall in the top 75th percentile of the aforementioned ranking scheme. These rankings provide a simple mechanism to highlight potential water security challenges, particularly when looking across the system performance and outcome categories.

3.3.2. Case study selection. To test the validity of this dashboard, we use Pakistan as a case study because its water security has been examined in several studies (Lautze & Manthrilake, 2012; ADB, 2013, 2016; Young et al., 2019). This literature gives us a way to validate our findings and test whether or not the dashboard is capable of correctly and accurately indicating key water security challenges. Four further case studies were conducted, and their dashboard printouts are detailed in the Supplementary Material. The countries studied were Afghanistan, Turkmenistan, Uzbekistan, and Tajikistan. We selected these countries due to their geographical proximity to Pakistan to allow for regional cross-country comparisons.

4. Results

4.1. Pakistan case study

Management of the waters of the Indus Valley in what is now Pakistan has been a challenge for civilization since ancient times. Some attribute the fall of the Harappan civilization in around 1500 BC, which had ‘a highly sophisticated system of water management and sanitation’ (Strang, 2015), to a decrease in precipitation (Giosan et al., 2012). By the 19th century, ‘the Indus irrigation system became the largest contiguous irrigation system in the world’ (Briscoe & Qamar, 2006). Management of this irrigation scheme was complicated when Pakistan was partitioned from India in 1947 (Briscoe & Qamar, 2006). The Indus Water Treaty, signed in 1960, made great strides in the joint cooperation of the Indus (Briscoe & Qamar, 2006). However, there are continuing political tensions between the countries that threaten this cooperation (Ranjan, 2016; Williams, 2019). Over the years, there has been continued expansion of storage and channel infrastructure (Briscoe & Qamar, 2006). Large flooding still occurs along the Indus, with the 2010 floods claiming approximately 1,985 lives and causing 9.5 billion USD in economic damages (EM-DAT, 2019). Some future projections suggest that around 11 million people are expected to be at risk from fluvial flooding by 2044 (Willner et al., 2018).

Following the concise summary to provide context, a dashboard was generated based on the methodology described above. The result can be seen in Figure 2. The country has data available for the 50 out of 52 variables. Data were not reported for the amount of desalinated water produced or water reuse in terms of the direct use of treated wastewater. Also, no data is available for Pakistan’s GDP projections (IMF, 2019). This dashboard, coupled with the brief historical summary above, is used to generate an initial or working diagnosis of water security for Pakistan. If trends are available, they are shown to the right of the related indicator. The highlighted indicators are in the 75th percentile based on the ranking system described above.

The dashboard in Figure 2 highlights several of Pakistan’s water-related issues. First, looking at the Water Resource System section, we see that 78% of the country’s water comes from outside the country. This transboundary dependency ratio is a substantial proportion of the country’s water, with the majority flowing into Pakistan from India. However, the Indus Water Treaty is in place and thus reduces the transboundary risk. The water stress in the country is 103%, signaling that Pakistan is either relying on non-renewable groundwater (since the amount is over 100%) or not leaving enough water for environmental flows. The latter is illustrated in the Outcomes section, with the high incidence of both biodiversity threats and environmental flow violations.

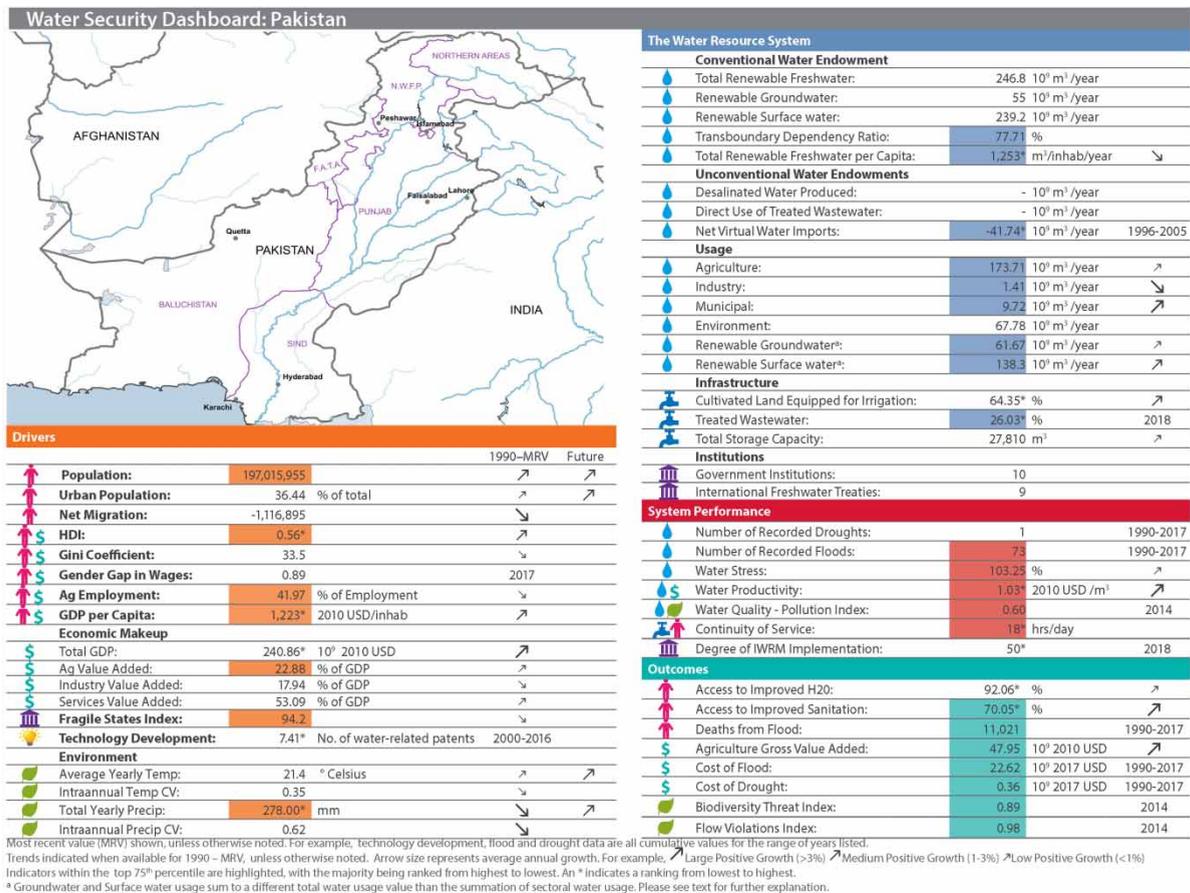


Fig. 2. Water security dashboard for Pakistan. Please refer to the online version of this paper to see this figure in color: <https://doi.org/10.2166/wp.2020.235>.

By looking at the socio-economic drivers, we can see that the country has a large GDP and is expected to see an increase in population despite the large negative net migration rate. The urban population is expected to increase from 36% to over 50% by 2050 (UN, 2017). The municipal withdrawals have seen a rapid upward trend, which corresponds to the increase in population. The country’s service sector has been growing. However, the industrial sector has shown a decline, and the agriculture sector still accounts for around 23% of the GDP and has remained relatively constant over the last 30 years. This signals an overall rise in economic output from agriculture since the percent of GDP from agriculture has remained relatively constant, but the GDP has grown. There has also been a steady rise in agriculture water withdrawals, with the most recent estimate being 94% of all withdrawals. On top of this, the country’s total water productivity is extremely low, albeit improving. However, this improvement in total water productivity could be associated more with the large increase in GDP rather than water efficiency improvements. Finally, the agriculture sector accounts for 42% of employment within the country, but this has declined slightly since 1990.

Yearly precipitation has been declining over the last 30 years, while the annual mean temperature has been increasing. When looking from 1901 to 2017, the temperature has exhibited an increasing trend

and is expected to continue rising (World Bank CCKP, 2019). However, looking over this longer time period, precipitation has actually increased slightly and is expected to continue to increase, although projections have high uncertainty. Regardless, by looking at current values, the country is trending toward an increase in water stress. Alone this is a cause for concern, but since water productivity is also low, it could be seen as an opportunity to strengthen productivity and efficiency improvements, such as in the agricultural sector.

There are two additional issues: access to sanitation and flooding. The country has comparatively low sanitation rates even though access has been improving over the last 17 years. Couple this with the low installed wastewater treatment (only 26% as of 2016), and the sanitation sector emerges as a key priority area for improvement. Yet, the country does have a higher rate of access to an improved drinking water source at 92%. In addition to sanitation issues, the country also has seasonal precipitation fluctuations and yearly flooding, with 73 floods occurring between 1990 and 2017. These floods have cost the economy around 20 billion USD over the last 30 years, with thousands of lives lost.

Finally, the dashboard is useful to not only highlight challenges but also opportunities and strengths. As mentioned above, one opportunity for improvement is through increasing agricultural efficiency and/or productivity. As far as strengths, the country appears to be performing poorly across the majority of outcome and system performance indicators. However, when taking into consideration the country's status as a Fragile State, Pakistan appears to be doing an acceptable job of water management in terms of their degree of IWRM implementation (when comparing to other countries).

4.2. Cross-country comparisons

The country dashboard also allows for cross-country comparisons. Four additional dashboard print-outs for Afghanistan, Tajikistan, Turkmenistan, and Uzbekistan can be found in the Supplementary Material. Overall, the regional comparisons (Figure 3) show that these five countries have similar water security issues, but with varying intensities. All countries have high levels of water stress, with the majority of water going toward the agricultural sector. The highest water stress occurs in Turkmenistan at 199%. Turkmenistan also has the highest dependency ratio at 97%. Countries with a high dependency ratio and high water stress are particularly vulnerable to the joint management of trans-boundary water bodies. Turkmenistan and Uzbekistan have the lowest scores on the FSI in the region, and both of these countries have the highest rates of access to improved drinking water and sanitation sources. Afghanistan has the highest FSI score out of the five countries, and the lowest rates of access to improved drinking water and sanitation services. The variations in these indicators across the five countries, as well as a world average, can be found in Figure 3.

The countries all face high seasonal variations in precipitation and have seen an increase in average yearly temperature since 1990. The rise in temperature is expected to continue. However, the degree of future change in the region's precipitation is uncertain. Given this high hydrological variability, most countries have issues with floods and droughts. Only Turkmenistan has no record of drought, based on the broad definition laid out by the EM-DAT (2019) database: 'an extended period of extremely low precipitation...'. Turkmenistan also only has one recorded flood since 1990, and Uzbekistan has only experienced one flood and one drought in the same time frame. In addition, all countries have a biodiversity index over 0.6 (on a scale from 0 to 1), indicating an elevated threat to the countries' biodiversity.

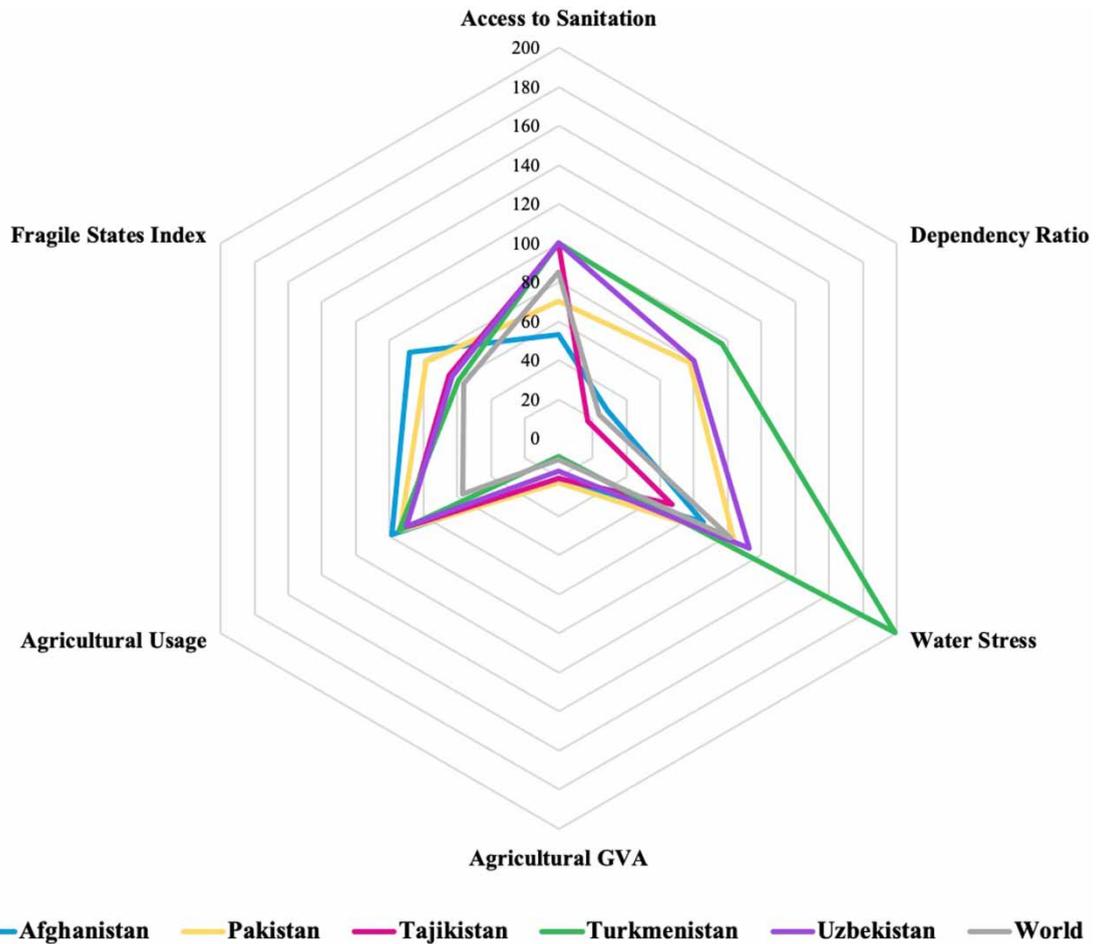


Fig. 3. Variation of key water security indicators by country: access to sanitation refers to access to an improved sanitation source, FSI stands for Fragile States Index, water stress is calculated based on SDG 6.4.1, the dependency ratio refers to the percentage of renewable freshwater originating outside the country, Ag GVA stands for the agricultural gross value added, and Ag Usage stands for agricultural water usage. All indicators are in percentage. The FSI is taken as the percentage of the observed value out of the possible total score of 120. Please refer to the online version of this paper to see this figure in color: <https://doi.org/10.2166/wp.2020.235>.

5. Discussion

The Pakistan water security dashboard highlights the status, trends, and water challenges and strengths within the country. These findings correspond to the issues found in a recent World Bank report on the water security of Pakistan (Young *et al.*, 2019), but the report goes into much more depth including institutional and management structures, expands upon each of the challenges faced in Pakistan, and includes recommendations for enhancing water security. This dashboard could serve as a first step in the evaluation of a country's water security and potentially help to structure and direct a more comprehensive analytical study. The dashboard picks up on several additional items

that other indicator-based assessments of water security have not exposed. Lautze & Manthritilake (2012) do not include items, such as water quality or economic outcomes. The ADB (2016) had similar findings but did not specifically report on the water stress within a country. This is an essential piece of information that needs to be emphasized since the country's water stress is over 100%. The ADB (2016) also rates the water security of specific economic sectors on a scale from 1 to 5, with 5 being the best possible score. Pakistan receives a 3 in the agricultural economic category, equating to essentially average economic water security in the agricultural sector (ADB, 2016). The ADB (2016) agricultural score 'describes the degree to which water is secured to enable agriculture in the country' and includes 'water productivity in agriculture and self-sufficiency of agricultural production'. When looking at the individual sector productivity calculated within our database for 2013, agricultural productivity was extremely low at \$0.25/m³ and ranking 132nd out of 141 countries. It is hard to compare these values since we are comparing a categorical value with a specific value, but it is interesting that the ADB (2016) scores Pakistan as average in agricultural water security when we find the country to have such low agricultural water productivity.

This dashboard differs from previous analyses of water security for two key reasons. First, it provides a quick assessment of water security that can be applied to all countries of the world based on a harmonized dataset. For example, a World Bank (2017) report is centered around the Middle East. The ADB (2013, 2016) studies focus on Southeast Asia. Second, two key global studies on water security do not incorporate all of the categories of information shown in the dashboard (Vörösmarty et al., 2010; Gain et al., 2016). For example, Gain et al. (2016) do not incorporate environmental uses of water or several potential drivers of water insecurity, such as population growth, climate change, and economic shifts. Whereas Vörösmarty et al. (2010) do not incorporate economic outcomes. Third, this work expands upon a previous water security dashboard (van Ginkel et al., 2018), as we incorporate trends. Thus, our study incorporates additional information that is vital in understanding the totality of water security challenges and opportunities and can be applied across countries.

The dashboard is only the first step of the overall diagnostic methodology, and we are only able to arrive at a working diagnosis. From here, additional information would need to be gathered, and tests run to reach a final diagnosis by which to begin prescribing solutions. Based on the findings for Pakistan, we would recommend the following possible actions in the next diagnostic step. First, the inclusion of studies on the climate regime and how it will change in the future, including glacial melt in the Himalayas (e.g. Jury et al., 2020). Second, we recommend additional analysis of country water usage as well as a better understanding of the water balance, especially the significant surface-groundwater interactions (e.g. Foster & MacDonald, 2014). FAO Aquastat (2019) estimates that in 2012, approximately 60 billion cubic meters of groundwater were withdrawn compared to the 55 billion cubic meters of renewable groundwater available. Much of the groundwater withdrawal is canal irrigation recharge, complicating the water balance (Young et al., 2019). A discussion around these issues, as well as a basin and provincial groundwater balances, can be found in Young et al. (2019). We also find that the agricultural sector accounts for 23% of the GVA and uses around 174 billion cubic meters of water per year, but a recent report shows that 58% of the agricultural GDP derives from livestock, which requires less blue water than crops (Young et al., 2019). We also report a wastewater treatment rate of 26% (Wendling et al., 2018), which appears to be higher than other estimates (Young et al., 2019). This difference could be due to the reported value in the dashboard being normalized by data on connectivity rates (Wendling et al. 2018). Also, there is no information reported on the reuse of treated wastewater. These items would need to be studied more in-depth to gain a better understanding of water usage

impacts and productivity. In addition, the country has several hotspots of potential water insecurity that are only expected to be exacerbated by climate change. The Indus delta is experiencing rapid biodiversity loss (Young *et al.*, 2019), and Karachi, one of the country's most populated cities, is at risk from rising sea levels (Dasgupta *et al.*, 2011). Finally, anyone evaluating water security will need a thorough understanding of the political system and the institutional frameworks within the country, such as water service delivery and resource management (Mustafa, 2001). These items are by no means an exhaustive list, but they illustrate potential further steps in the diagnostic process.

The cross-country comparisons can help policymakers learn lessons from other countries while recognizing the differences that exist. They can also allow us to begin to recognize regional patterns like the ones seen above. For example, three out of five of the countries have a declining contribution of the agricultural sector to overall GDP. However, this is not fully reflected in their water withdrawals, with over 90% of withdrawals in these countries going toward their agricultural sector, compared to a world average is 57% (Liu *et al.*, 2016; FAO Aquastat, 2019). Like the example above, some patterns are more noticeable and highlight areas of concern, whereas other observations are more hypothetical in nature. For instance, we can observe that the fragile countries are exhibiting lower rates of access to improved sanitation.

5.1. Limitations

Given our focus on datasets that cover most countries, there are inevitable limitations. The first is the overall quality of the data available. There are obvious issues such as a country's renewable freshwater remaining constant since 1958, according to FAO Aquastat (2019). Thus, the dashboard has the potential to be improved by an increasing amount of new data being generated, such as data on water quality (Damania *et al.*, 2019). Information on affordability of water services is vital to the understanding of the ability of a country to meet its citizens' needs. This indicator is currently unavailable across the majority of countries, but an affordability indicator is under development (WHO/UNICEF, 2019). In addition, these specific indicators may or may not be useful for each country. For example, indicators on drought may be more useful for Pakistan than Turkmenistan. Finally, the database underlying this dashboard is static, i.e. it is not linked to online databases such as FAO Aquastat (2019) or the World Bank Databank (2019). This means that the database does not capture the periodic updates of information from these sources. We also are unable to determine whether needs are truly met based on the current data. The drinking water use category outlined by Molle & Mollinga (2003) could be incorporated in future iterations of the dashboard as more disaggregated data become available on municipal usage. As we are unable to capture water needs in this version of the dashboard, we are also unable to distinguish between water needs versus water demands (Feitelson, 2012).

Whilst we include metrics on institutions and their performance, we recognize that these are rather crude metrics of the quality of water governance, which is recognized as being fundamental to the sustainable management of water resources. The number of government institutions only provides basic context, but SDG Indicator 6.5.1, that specifically looks at the level of implementation of IWRM within a country, is a useful performance indicator. Once more data are collected on this indicator, trends could be included. We would also wish to include metrics for information availability, as good system monitoring is an essential prerequisite for good governance.

At this stage, the dashboard does not take into consideration any sub-national heterogeneity. This means that it does not pick up on any hotspots of water insecurity within a country. This is primarily due to the lack of data at smaller spatial scales, and the differences in reporting mechanisms and

indicators across countries. This is an important area of future research as a multiscale analysis would offer a more accurate picture of a country's water security.

Finally, the current version of the dashboard does not show relationships between the indicators, whether they be casual or in the form of a feedback mechanism. The dashboard also does not include two out of the seven information categories of the framing in Section 3.1 (e.g. historical and cultural context and actions). Thus, these two categories will have to be included in additional steps of the diagnostic methodology. Historical and cultural context is excluded due to its narrative format and country specificity. We do try and incorporate this information category through a brief historical and cultural narrative for the Pakistan case study, but acknowledge that this is not a full analysis. In the future, a more robust historical analysis could be conducted in Step 2 of the diagnostic methodology. The action's category represents the actions available to a decision-maker. These actions, whether they are an investment in information gathering or the investment in a new storage facility, represent a broad decision space, so this category does not lend itself to the dashboard format. This information would become available in the treatment stage of the methodology or Step 4.

6. Conclusion

Combined with a general understanding of the water resources system within a country, the dashboard that we have proposed highlights key water security challenges and opportunities. We have found that the dashboard format can act as an initial diagnostic tool for the status and trends of water security in a country. The ability to rapidly generate the dashboard printout and evaluate it quickly also increases the usefulness of the tool. By conducting a case study in Pakistan, we were able to compare our dashboard to several other water security evaluations of the country. This allowed us to provide some validation of the robustness of the dashboard and its ability to provide information on country water security. It also allowed us to show its added value in terms of its comprehensiveness and its global replicability. By adding in trends, we can begin to understand how water security indicators have changed in relation to one another and could potentially change in the future. The comparative analysis across five countries also highlights several potential relationships that could be studied further. Additional comparative analyses have the potential to identify new patterns.

The application of the dashboard needs to be followed by additional data collection and analysis. Nonetheless, this dashboard could serve as the first step or an introductory overview of country-level water security. The dashboard was generated at the country level and, due to a harmonized dataset, allows for cross-country comparisons. There is the potential for this dashboard to be applied at other scales, such as the city or district level. Yet, the actual indicators used may vary by scale as data and monitoring of drivers, the water resource system, system performance, and outcomes will vary by scale. For example, data on outcomes may be available at a smaller scale, but there could be issues with the downscaling of drivers or water resource system data.

The dashboard is designed for policymakers and water management practitioners and provides a quick and efficient way to rapidly assess and communicate a country's water security. We envision a version of this dashboard being incorporated into a global online database. This type of uptake would also improve the dashboard by linking the underlying database to the original data sources as well as allowing some level of interaction by the user. It could also help in structuring more in-depth

analyses of a country's water security and could encourage early stakeholder engagement around water security issues.

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Data availability statement

Data cannot be made publicly available; readers should contact the corresponding author for details.

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