

Review

# Addressing Water Security: An Overview

Juliana Marcal<sup>1,2</sup>, Blanca Antizar-Ladislao<sup>3,4</sup> and Jan Hofman<sup>1,2,\*</sup> 

<sup>1</sup> Water Innovation and Research Centre (WIRC), Department of Chemical Engineering, University of Bath, Bath BA2 7AY, UK; j.marcal@bath.ac.uk

<sup>2</sup> Water Informatics in Science and Engineering (WISE) Centre for Doctoral Training, University of Bath, Bath BA2 7AY, UK

<sup>3</sup> Isle Utilities Ltd., 2nd Floor, 89 Albert Embankment, Vauxhall, London SE1 7TP, UK; blanca.antizar@isleutilities.com

<sup>4</sup> Department of Civil, Environmental and Geomatic Engineering, University College London, London WC1E 6BT, UK

\* Correspondence: J.A.H.Hofman@bath.ac.uk

**Abstract:** For the last two decades, water security has been in the spotlight as a key concept for sustainable development. However, due to its wide interpretation range, the understanding of what water security is and what it encompasses can change considerably with different perspectives. By means of a review of both academic and grey literature, this paper presents an in-depth global overview of what water security means and how assessment is being carried out. These aspects are put together in the present work with the aim to facilitate access to this complex concept for academics but also policymakers and other stakeholders involved in water management and governance. Aiming to provide a groundwork for water security understanding, we examine definitions, scales of application, frequent approaches and methodologies used to study water security. We also present indicators and aspects being included in water security frameworks. A summary of important actions towards water security improvement is also presented. As a dynamic and multi-faceted concept, water security requires an equally multi-dimensional and flexible interpretation. Understanding and measuring are key to improving water security levels. Bringing attention to how climate change, environmental needs, demographics, economics and governance are linked to water security can boost impact by prompting science, policies and innovation to come together.

**Keywords:** water security; assessment; sustainable development; policymaking; water governance; innovation; climate change



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## 1. Introduction

Water security is about managing too much, too little and/or too polluted water. Water security is about the increasing importance of sustainable management of water resources, drinking water and human well-being and protection of life and property from water-related disasters. Water security is about the health of ecosystems and economic development. Water security and creating a water-smart society—where water has its true value recognised and is therefore managed in ways to avoid pollution and optimize resource efficiency [1]—are key conditions for sustainable development, and Sustainable Development Goal (SDG) 6 Clean Water and Sanitation is in a central position for achieving the Agenda 2030 [2–4].

Water is underpinning our economy and its growth, and it forms an essential component for creating and maintaining jobs in sectors depending on water: agriculture, forestry, fishery, energy, industry, recycling, building and transport. More than three out of four jobs depend on water to varying extents [5]. Sustainable water management and providing infrastructure for access to safe water supply and adequate sanitation contribute to achieving better living standards, increasing social inclusion and creating jobs. Neglecting water issues will have negative impacts on the economy and ultimately jeopardize livelihoods.

The pressures on global water resources could put at risk 45% of the global gross domestic product and 40% of the grain production [6] with predictions that by 2050, 4 billion people will be living in severely water-stressed areas [7]. It also greatly increases the risks for extremely high costs due to natural disasters and setting back development. Costs for inaction on key environmental areas can be much larger than investing in mitigation and adaptation measures [8]: impacts from water risks, for instance, can be five times higher than the cost of addressing them with mitigating actions [9].

Urbanization and rapid population growth in several continents [10] will increase the pressure on water security as more water is needed for water supply, agriculture and business. One-quarter of the world's population today lives in 17 countries where extremely high water stress is experienced, withdrawing more than 80% of their available resources to supply water for agriculture, industries and municipalities [11,12]. These pressures are not equally distributed around the globe, 12 of these countries for example are located in the Middle East and North Africa [11] (please refer to the Supplementary Materials for more information). Urban growth and industrial activities are also the cause of increasing pollution, increasing health risks and deterioration of water resources making them unfit for other uses. Climate change is exacerbating water security challenges by intensifying droughts and changing precipitation patterns, often leading to water-related disasters [13]: over the last 20 years, 90% of the natural disasters were water-related [14].

Around the world, different regions face unique challenges as a function of geographical, social, political and economic characteristics [15–17] (please refer to the Supplementary Materials for more information). In Brazil, a country with overall low water stress [11], Sao Paulo faced the driest year in history in 2014, in an unprecedented water crisis, explained not only by climate change but also environmental and managerial factors [18,19]. The United States, a nation rich in natural and economical resources, is very vulnerable to natural hazards and extreme weather, with disasters having a huge impact on the environment, agriculture and people's livelihoods [14,20,21]. Jordan, located in a region with limited water resources, has made efforts to treat and reuse wastewater, nonetheless, the country also faces, alongside high population growth, a high influx of Syrian refugees, threats and sabotage of their water infrastructure and resources, making water security an extremely political challenge [18]. It may be clear from the above that water security is a broad concept with many dimensions and acting on different scales. Over the years, many definitions of the concept of water security have emerged [2,22–24], some of them covering only one or two dimensions. To operationalize and quantify the concept of water security, it is necessary to develop frameworks that enable the assessment of the level of water (in)security or the performance of water management tasks to achieve or improve water security. Assessment and quantifying are the basis for incentivising improvement actions. Many assessment frameworks have been developed, with focus on different scales, different dimensions and in different levels of details [7,24–27].

As an emerging concept since the 1990s [28,29], water security has been the subject of several reviews focusing on definition [29,30], use and focus on different disciplines [29], application to scales and geographic regions [31] and assessment tools [32]. Cook and Baker [29] reviewed the literature around water security from 1990–2010, exploring definitions, analytical approaches and scales, proposing great insights on the importance of an integrative approach for the study of water security. Nonetheless, the study does not investigate the assessment of water security in terms of aspects included or indicators. A later study by Garrick and Hall [33] proposed a risk perspective overview of water security, including analysis of definitions, indicators, indices and how they vary at different scales. This very valid perspective is, however, not the only existing and adopted one when looking at water security. A recent paper by Octavianti and Staddon [32] reviewed assessment tools, including themes and scale analysis, comparing approaches and arguments used to define measures. This paper, focused on the stages of development of the assessment frameworks, instead of what was actually included—that was expressed as general dimensions.

The complexity of the concept, associated with the issuing research interest and the consequent large body of literature, makes a comprehensive yet graspable overview of the theme, a challenge to be met. To our knowledge, an overview of the definitions of water security, different dimensions, assessment frameworks and its indicators has not yet been produced. In this paper, we review for the first time all these aspects of water security with the intention of being as straightforward as possible in conveying its intricacy without compromising intelligibility.

Water security is at the heart of our society and is, therefore, an important asset for creating prosperity and well-being. It is connected to many other sectors that use water as a resource. By providing an overview of the current state of knowledge on water security, including recent insight in science on how to assess water security and creating action perspectives to improve it, we hope to provide easier access to the complex concept to policymakers and other stakeholders involved in water management and governance. Here, we also aim at identifying gaps in knowledge, hoping that this can support policy development and innovation in the field.

## 2. Methods

This paper provides an overview of how water security is being defined and assessed in the literature. The review was carried firstly by collecting documents from multiple databases (Web of Science, Scopus, Google Scholar) and grey literature.

Using keywords such as *water security*, *framework*, *assessment*, documents were retrieved and selected based on relevance to the subject and analysed. Citation tracing was also employed to include important documents that did not feature in the databases. This was especially important to include grey literature. From that, papers and reports exploring concepts such as *water resilience*, *water insecurity*, *water sustainability*, *water governance* were included in the review sample.

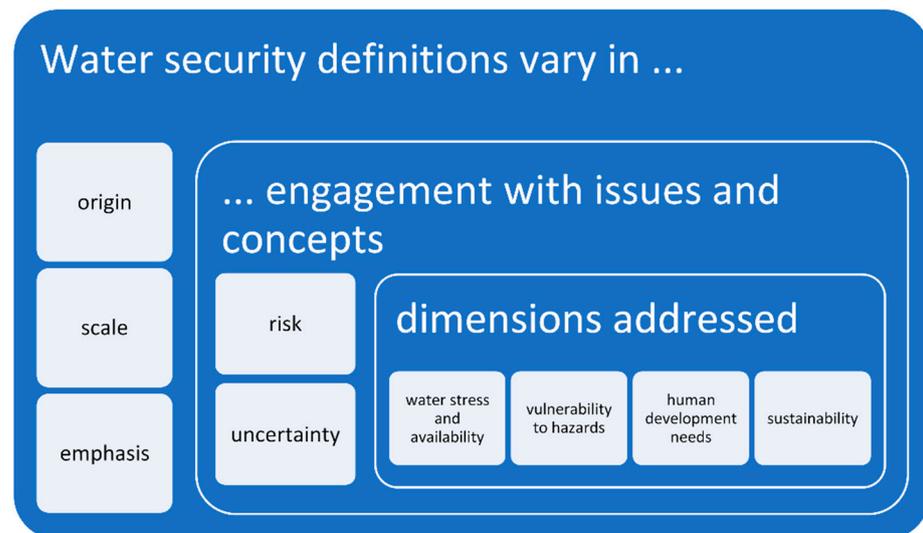
From the review sample, a total of 120 references were submitted to a qualitative analysis. These documents were selected because they could be examined in terms of features related to spatial and temporal scales, methodology and aspects included in assessment frameworks. The data extraction was carried out using a full-text review. For each paper, we first determined the scale and what the authors called the concept to be assessed, such as water security, sustainability, or resilience. This allowed grouping and filtering the papers for further collection of information. Additional content analysis included noting, depending on availability: case study location, conceptual and normalisation methodology, implementation process, stakeholder participation, challenges observed, main conclusions, action perspectives and finally the aspects and indicators included in the assessment framework.

For the analysis of the literature and development of the paper, we defined *aspects* as terms describing or explaining a broader idea associated with water security, for instance, long-term droughts. *Factors* were considered to be circumstance or influence elements, such as water availability; and *indicators* as characteristics or variables that measure the state or level of something, for example, water stress level calculated as freshwater withdrawal as a proportion of available freshwater resources [6]. These were organized based on similarity and divided into categories following the UN water security definition and infographic [34,35].

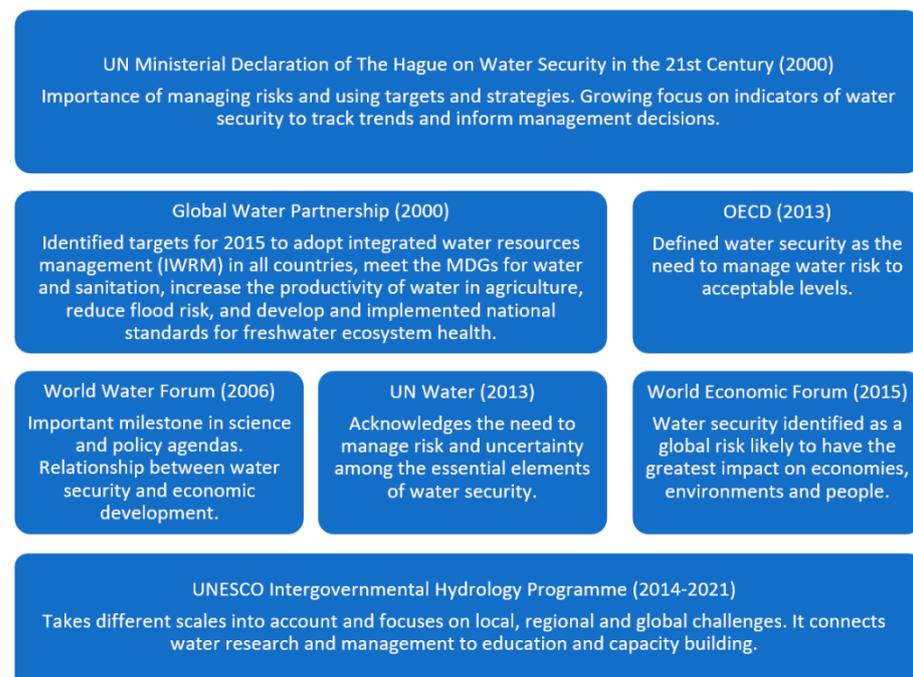
## 3. Water Security Definitions

Water security was first articulated as a policy challenge at the World Water Forum in 2000 in the United Nations (UN) Ministerial Declaration of The Hague on Water Security in the 21st Century and it has remained on the agenda of international organizations since then [36]. The Ministerial Declaration led to wide use of the term in global policy, development and science agendas over the past 20 years and developed into a multi-dimensional concept that has widely differing interpretations [37]. Definitions have proliferated, generating both convergence and confusion about the concept and options for measuring

and managing water security [29]. Detailed analyses on how water security is defined by different authors can be found in the literature [29–31]. Well-known and accepted water security definitions, such as the one proposed by the Global Water Partnership [23], Grey and Sadoff [22] at the World Water Forum in 2006, UN-Water [34], UNESCO [38] and OECD [7] (for definitions, please refer to Supplementary Materials), vary in origin, scale and emphasis, engagement with issues and concepts and the way they address different dimensions (Figure 1). This suggests that consensus on the definition of water security, while important, is unlikely (Figure 2).



**Figure 1.** Water security definitions.



**Figure 2.** Water security: risks [33,39].

Nonetheless, an effort to adopt a holistic definition can enrich and broaden studies around water security. Therefore, we suggest the adoption of the UN definition (Figure 3), also the one we are embracing for the purpose of this paper. However, it should be noted that such an all-encompassing definition presents disadvantages, such as the difficulty

of operationalising it and in identifying a suitable set of indicators that might be used to measure the current situation and changes over time [39].

UN-Water (2013)  
Water security is “the capacity of a population to safeguard sustainable access 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.”

**Figure 3.** UN-Water [34] definition.

#### 4. Water Security Assessment

Assessing water security allows understanding of the current situation and identifying challenges and areas that need attention. It is an essential step to prioritise and address issues, inform planning and implement and monitor water security actions. It is, therefore, crucial to know how to evaluate water security.

##### 4.1. Overview

From the academic, private and governmental and non-governmental organizations, frameworks, approaches and tools have been developed over the years aiming to assess and study water security on different scales.

Because water security is a wide notion and a fairly recent one, many tools developed over the years assessing concepts such as *water resilience*, *water insecurity*, *water sustainability*, *water governance* provide evaluation for aspects encompassed by the concept of water security. Notable frameworks such as City Blueprint Approach [40], Sustainable Cities Water Index [20] and many others consider similar dimensions to the ones incorporated by the concept of water security. Frameworks focusing on the performance of water and sanitation services [41–43] also carry important water security features, such as guaranteeing access to water and adequacy of wastewater treatment efficiency. Alternative initiatives such as the Utility of the Future Program [43] allow benchmarking and support a process of performance improvement for the water industry, which can mean significant improvements in water and energy use efficiency and provide alternatives to current water challenges.

Although designed for different notions, these evaluation methods are often complementary. Van Ginkel et al. [27] compared the results from their water security assessment framework to the assessment outcomes of two other well-known index systems: the Sustainable City Water Index from Arcadis [20] and the City Blueprint from KWR [40]. Their results showed good correspondence despite conceptual differences [27]. While these three frameworks were designed for city scale, it is likely that other frameworks designed for different scales or concepts could provide consistent additional information when applied to the same area. It is, therefore, suggested that future work could include a study of how these evaluation methods compare to and complement each other.

Examples of different frameworks assessing water-related concepts are presented in Figure 4. This figure does not present an exhaustive list of the existing frameworks, but simply provides an illustration of the diversity of concepts and assessment methods around water issues.



**Figure 4.** Examples of frameworks for assessing different water related concepts: Water security [26,44]; Water governance [45,46]; Water sustainability [20,40]; Water resilience [47,48]; Water risk/insecurity [49,50] and Utilities performance [41,43].

#### 4.2. Scales of Application

From the household to the global scale [23], water security is a local, regional, national and global issue. Due to water security having a broad definition, it has been interpreted over the years at different scales.

The boundary of a framework can be assumed at different levels and contexts, changing the focus of the water security assessment. Nevertheless, these boundaries are not absolute and as scales are connected, the aspects included for different scales can also be associated or shared. Community or household water security for instance can bear different aspects for rural or urban contexts [51–54]. Within the city or urban scale, frameworks focusing on utilities' performance [41–43,55] convey aspects such as guaranteeing access to water, improving water usage efficiency, adequacy of wastewater treatment, prevention of pollution incidents among others. Those, although measured for the water industry, will provide results that surpass the boundaries for which the framework was developed and represent improvements for the community or city. Examples of frameworks designed for different scales are presented in Table 1.

The differences in contexts show that water security is a complex problem and a single way to evaluate it would not be adequate to all scales. The spatial scale of water security allows us to focus on specific problems and challenges. Although different levels can be considered they are all connected since improving water security is a response to local, regional and global challenges with multi-level implications.

The study of different scales is also associated with the context in terms of the level of development and specific geographic challenges. The African continent for instance has experienced a rapid urbanization process, linked to migration from rural to urban areas [51] and population growth. This leads to experiences of water stress, scarcity and inequality of water services access in cities. This has fuelled not only studies at the city scale but also at

the domestic level to investigate the household experience of water security in urban and peri-urban areas [51,56–58].

**Table 1.** Water security assessment: scales of application.

Scale	Examples and Considerations
Global	Global water security assessment was carried out by Vorosmarty et al. [59], considering human and biodiversity perspectives: drivers and impacts related to catchment disturbance, pollution, water resource development and biotic factors were quantified at a global scale. Gain et al. [26] also provided a global assessment using the Global Water Security Index, using indicators based on SDG 6.
National/ Country	Usually encompassing all four dimensions from the UN definition [35], frameworks such as the National Water Security Index [25,44] from the Asian Development Bank, the Water Security Scorecard [60] from the Australian Water Association and others developed by scholars such as Dou et al. [61], Marttunen et al. [62], Su et al. [63], Lautze et al. [64] look at water security at a national scale. The National Blueprint Framework [65], although not designed for water security specifically, provides indicators to measure progress on SDG 6.
Basin/ Watershed	With a focus on water quantity aspects such as availability, utilisation and scarcity resources, frameworks at this scale also bring attention to climate change aspects and governance since watershed or basins do not follow administrative boundaries of cities or states, with concerns over the surface and groundwater quantity and quality at this scale often requiring transboundary cooperation. Works developed by scholars such as Babel et al. [66], Yin et al. [67], Xiao et al. [68] Norman et al. [69], Jia et al. [70] provided frameworks for basins of watersheds. Notably, the use of hydrological models is often used, providing valuable predictions.
Regional	An intermediate between the city and national context, studies at a regional scale usually follow administrative boundaries of regions or provinces, sometimes comprising several basins and smaller regions. Encompassing not only urban areas but also areas of different land uses, considerations around agricultural activities, ecological and environmental aspects are present. Scholars such as Liu et al. [71], Li et al. [72], Zhang et al. [73] provided regional evaluations.
City/ Urban	The urban level frameworks tend to incorporate many aspects regarding availability, access and reliability of water services, governance, water hazards, etc. One of the key dimensions of the National Water Security Index by the ADB [25], notable frameworks such as the City Blueprint Approach (KWR) [40], Sustainable City Water Index (Arcadis) [20] and the City Water Resilience Index (ARUP) [47] are city-specific. As are works from scholars such as Van Ginkel et al. [27], Jensen et al. [39], Ghosh et al. [74] and Romero-Lankao et al. [75].
Community	At this scale, frameworks show concern with management strategies, governance and other social aspects. The Canadian Water Sustainability Index (CWSI) [76] was developed to assess the well-being of communities with respect to water. The WaterAid [24] framework highlights the importance of a participatory process involving the community. Authors such as Wutich et al. [52], Shrestha et al. [77], Norman et al. [69] and Dickson et al. [78] considered communities as the scale to assess water issues.
Household/ Individual	Focus on essential needs (access to water and sanitation) and aspects related to health and hygiene, social and gender inequality, emotional stress and food security are present at this scale. One key dimension of the National Water Security Index by the ADB [25], and sometimes described in terms of water insecurity, this level has also been assessed by scholars such as Jepson [79], Hadley and Wutich [80], Wutich [81], Brewis et al. [82], Webb [83] and Tsai et al. [84], among others. The HWISE-RCN by Young et al. [50] is notably investigating experiences, causes and outcomes of water insecurity at the household level.

#### 4.3. Time Dependence

Along with considerations of spatial scale, the temporal variation is equally important in the interpretation and assessment of water security. Temporal distribution of water resources, seasonal effects, climate change, water governance, seasonal demand and demographic variation, amongst other factors, will influence and change water security in space and time.

The application of an assessment framework, as thorough as can be, will invariably represent a moment (or a snapshot) of the evaluated concept. Therefore, as parameters do change over time in the real world, it is crucial to consider the time dependence of water security. To provide a good picture—or a ‘dynamic picture’—of water security, elements such as long-term droughts, changes in precipitation, flood frequency, temperature fluctuation, demand growth and demographic changes, among many other factors or aspects used for water security assessment, need to be interpreted over time.

Research has recurrently pointed out the importance of considering the temporal scale in water security for the identification of needs and persisting problems [26]. The temporal

scale has already been included in the assessment of water security in the literature [61,67] highlighting the importance of such consideration in scenario investigation. To acknowledge the variety of indicators due to climate change, seasonal effects, anthropic influence and other natural changes over time in the analysis of water security is crucial to plan for the future (which is in itself every day more unpredictable) and ensure long-term water security. Thus, innovations related to remote monitoring, modelling, simulation and trend analysis are important tools to study the temporal variability of water security variables.

The time dependence of water security also calls for an ongoing re-evaluation in a region, city, or community. Water security assessment frameworks should be applied as part of an improvement cycle [24] in order to account for changes brought by interventions or pressures. This allows stakeholders to understand the full potential of actions and the update of priority actions, indicators thresholds and goals providing incentives for improvements and new adjustments.

#### 4.4. Approaches and Methodologies for Water Security Assessment

Due to the complexity and different interpretations of the water security concept, there is no standard evaluation method. There are however many approaches, perspectives and methodologies that can be used to translate water security into metrics or frameworks that can help evaluate and provide information on how to improve it.

Water security assessment may be guided by different perspectives. Focus on specific water security aspects may be guided by the discipline. For instance, in the engineering domain, studies on water security give emphasis to flood protection infrastructure and water supply, while environmental studies will focus on water quantity, quality and hydrological variability [28]. Different disciplines will also tend to evaluate certain scales: development studies often study the national scale while hydrologic ones will focus on a catchment scale and social studies on the community scale. In addition to being guided by the discipline, other viewpoints such as problem- or goal-oriented, integrated or policy perspectives can guide the analysis of water security assessment [28].

Approaches such as risk-based, systemic, metabolism approach, Pressure-State-Response (PSR), Driver-Pressure-State-Impact-Response (DPSIR) among others (see Figure 5), are ways to contemplate the problem of water security and decide on the considerations and aspects for a subsequent evaluation. These conceptual models are not exclusive and are often combined by authors to provide a comprehensive evaluation framework.

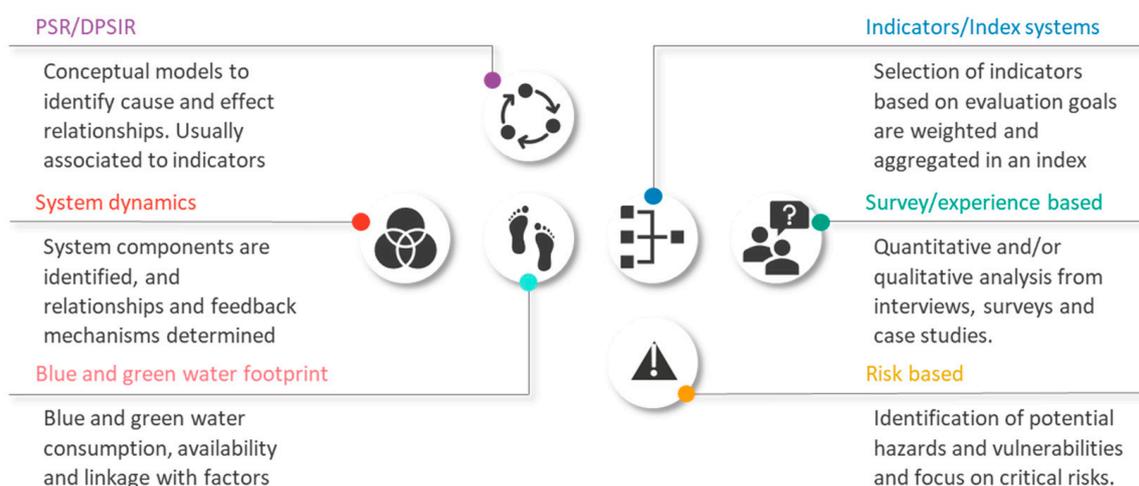


Figure 5. Approaches applied in water security evaluation.

The risk-based approach was adopted by the OECD [7] for instance when interpreting water security as a risk management problem for which the improvement is due to knowing, targeting and managing acceptable levels of risks for the society and the environment. A risk perspective is also adopted by the Sustainable Water Partnership [85] for their

proposed water security improvement framework based on the identification of potential hazards and vulnerabilities and focused on critical risks related to water security. In this framework, a system thinking approach is also applied to relate the causes of the risks. Three main sub-systems are considered—water resources, risk to water security and water management. The systemic approach, another common method applied to water security assessment, is based on the idea of sub-systems and elements and the relationship and feedback interactions between them. Considering the broad nature of the concept of water security, the value of this approach is understandable: the possibility of separating a complex notion into smaller dimensions makes it more easily comprehensible and easier to work with. Authors have considered different subsystems when evaluating water security such as economy and society, water resource and ecosystem [61] or water resources, water environment and water disasters [67].

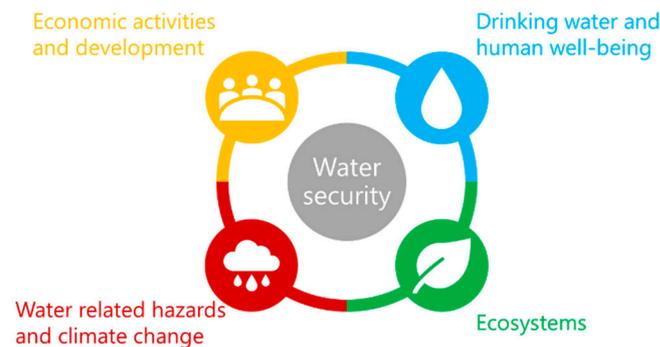
The Pressure-State-Response (PSR), used by the OECD to structure its work on environmental policies [86] and the Driving Forces-Pressures-State-Impacts-Responses (DPSIR) developed by the European Environmental Agency [87] and adopted by the US Environmental Protection Agency (EPA) [88] are conceptual models based on systems thinking approach and thus highlighting cause-effect relationships. Applied to the study of water security they allow the identification of key indicators, considering that the driving forces are the factors that motivate human activities that exert pressures on natural resources and the environment changing its state (quantity or quality of resources). The change of state will have an impact on society that will then respond to these changes through actions in management, behaviour and awareness. These approaches, and variations of this approach, are frequently used by authors as a conceptual model to define indicators [27,66,67,89].

## 5. Water Security Indicators

Very commonly used as a basis for water security evaluation, indicators are often gathered in an index system to convey the different aspects of the concept. At a national level, the Water Security Index by the Asian Development Bank [25] adopts an index system divided into five dimensions (household, economic, urban, environmental, water-related disasters) to a calculated final water security index. Among others, the National Blueprint Framework also adopts a set of indicators to measure the progress on water-related development goals. At the urban scale, notably the City Blueprint [40], the Sustainable Cities Water Index [20] and the City Water Resilience Index [47] also use a set of indicators that can be compared between different countries as well as allowing progress monitoring. Many other studies found in the literature have adopted an index system as part of their proposed water security assessment framework. Although the use of indicators or index systems is very common it is not exclusive. Some conceptual frameworks, such as the water security framework from the OECD [7] provide, instead of a set of indicators, a process to be followed step-by-step in order to evaluate water security according to the local context.

Indicators are sometimes considered under certain dimensions or groups. However, due to the complexity and interconnectivity between different aspects of water security, authors do not always agree on the same categories or even consider the same dimensions of water security. This depends on the scale, context as well as on the definition of water security and methodology adopted. Similar indicators are sometimes adopted into different dimensions: wastewater collection or improved sanitation for instance is sometimes considered as an indicator under an environmental dimension for some authors [90,91], while others consider it under health and wellbeing [47,92] or access to infrastructure [26,65]. This demonstrates that water security assessment is, naturally, a problem as complex as its definition. An important point in the choice of indicators is data availability that is up to date, transparent and reliable. This will also help to determine not only the selection of variables but also the temporal and spatial boundaries of the framework. Populating indicators for water security assessment can require large sets of data and these should be preferably publicly available and especially verifiable to ensure a transparent evaluation.

A survey of water security assessment frameworks was carried out to investigate how the different aspects of water security are being incorporated. There is a variety of indicators that, based on the UN definition [35], were divided into four dimensions, as seen in Figure 6. As a holistic and well-accepted definition, the UN interpretation of water security has been used in the literature to establish dimensions or sub-systems to the development of assessment frameworks [51,93,94]. The work developed by Aboelnga et al. [93] for instance, adopts the four dimensions from the UN framework on water security [35] for the development of a holistic urban water security metric based on the SDG6 and the human rights on water and sanitation.



**Figure 6.** Water security dimensions based on the UN definition [34].

Here, the four dimensions from the UN definition are adopted and, within them, aspects and indicators considered in different water security framework assessments in the literature were divided into categories as seen in Table 2. Differently from studies that have proposed metrics for water security, we gather, through the review process, what has been employed in the literature to measure water security. This provides a summary of what can possibly be adopted to measure the different dimensions, illustrating the complexity and amplitude of this concept. As previously stated, the final choice of what to consider in a metric will depend on methodology, scale, perspective, data availability amongst other factors.

These categories and dimensions can be directly or indirectly related to the SDGs, in particular to Goal 6: *Ensure availability and sustainable management of water and sanitation for all* [6]. The indicator 6.1.1 *Proportion of population using safely managed drinking water services* for instance can be associated to the category *Access to water services* and with indicators related to access to improved drinking water sources and access to piped water/water supply connection. Other references also used related indicators such as accessibility of water points and affordability. The category *Access to water services* is also related to improved sanitation and wastewater collection and therefore can be associated with SDG 6.2.

Some authors use and reference the indicators from the Global Sustainable Development indicators framework [65,93]. Notably, the National Blueprint Framework [65] was based on the SDG 6 to provide a framework to monitor the progress of water-related sustainable development in Europe. The work from Assefa et al. [51] also focuses on SDG 6 for evaluating water security in terms of supply, sanitation and hygiene.

**Table 2.** Water security aspects found in water security frameworks.

Dimension	Categories	Indicators/Aspects
Drinking water and human well-being	Water quantity	Water availability, adequate quantity for basic needs, demand and consumption; diversity of sources; precipitation and water balance; water storage; exploitation of resources; water stress and usage efficiency.
	Quality	Quality of water for human consumption (meeting standards); aesthetic, perception and quality acceptability; water treatment practices.
	Access to water services	Access to improved drinking water source; improved sanitation; piped water or water supply connection; accessibility of water points; affordability of services; wastewater collection/sewage connection.
	Infrastructure reliability	Asset management and maintenance; infrastructure condition/age and capacity; reliability (complaints/blockages/interruptions); service level; service continuity (hours of service); water leakage, non-revenue water.
	Reuse/recycling Hygiene and public health Wellbeing	Water/wastewater reuse; energy or nutrient recovery; rainwater harvesting; solid waste/recycling. Water-related diseases; incidence of diarrhoea; adequacy of water for housework and hygiene; other health problems. Emotional stress, fear, frustration; safety or dispute; deprivation or lost opportunity; recreational opportunities.
Ecosystems	Environment	Surface and groundwater water quality; river health; wastewater generated and adequacy of wastewater treatment; biodiversity; environmental flows; environmental protection actions; pollutants discharge (harmful substances, pollution loading); soil erosion; wildfires; vegetation cover and land use.
	Sustainability	Energy use/efficiency; renewable energy; sustainable natural resources use; sustainable water use; water sensitive urban design.
Water hazards and Climate change	Water-related hazards	Floods (frequency, affected area and population, hazard and vulnerability, protection infrastructure); droughts (frequency/vulnerability/area affected); economic loss; landslides; prevention, preparedness and response; water pollution accidents.
	Climate change	Climate change response; greenhouse gas emissions; salination and seawater intrusion; temperature.
Economic Activities and Development	Economic activities	Water for agriculture, manufacturing; commerce, energy production; broad economic development; water-related business opportunities; food production and demand; water footprint; water use/GDP or GDP/water use.
	Governance	Institutional organization and capacity; accountability and corporate governance; data availability, multi-level and multi-stakeholder participation/engagement; communication and transparency; investment/funding and financial management; legal and regulatory aspects; science, knowledge and innovation; strategic planning; transboundary and international collaboration.
	Socio-economic aspects	Education and awareness; GDP; income/unemployment rate; informal dwellings; population density; social and cultural aspects; urbanization rate.

Nevertheless, water security is much broader than SDG 6 alone (please refer to the Supplementary Materials for more information). The link between the SDG goals supports and legitimate the inclusion of other aspects such as governance, climate change, economic development, inequality, among others, when addressing water security.

Therefore, many water security indicators can also be associated with the other SDGs. SDG 3. *Ensure healthy lives and promote well-being for all at all ages* [6] for instance includes the target of reducing the number of deaths and illnesses from water pollution and contamination (Goal 3, Target 3.9) and the indicator 3.9.2 *Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene* (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services). Similar indicators such as water-related disease incidence are included in several water security assessment frameworks [20,25,27,76,92,93]. SDG 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, is represented in the economic activities and development dimensions; SDG 13 targets action to combat climate change and its impacts and SDG 1 End poverty in all its forms everywhere includes a target on building the resilience of the poor and reduce their exposure and vulnerability to climate-related extreme events and other disasters, can be directly associated with the water hazards and climate change dimension and indicators. Basic water drinking and water and sanitation services are indicators of SDG1; food security and the promotion of sustainable agriculture are part of SDG2 and, safety, resilience and sustainability of cities, including an indicator on the proportion of the population living in informal settlements, are counted in SDG 11. The list goes on since all SDG are interconnected and may be connected to the different dimensions of water security.

## 6. From Paper to Action: Measuring Progress, Achieving Goals and Improving Water Security

Indicators play an important role in describing the complexity of a system, dissemination of information and translating important aspects of a complex system into an accessible format that can be understood and monitored by different stakeholders. As a useful tool to identify critical problems, they have the potential to guide governments and decision-makers in developing action plans and making informed political interventions to tackle areas that need attention in order to improve water security.

The possibility of benchmarking results is an important point when evaluating water security since it has the potential to provide information and share experiences between evaluated areas. The use of indicators can provide not only a way to perceive the evolution of an area in terms of water security but also has the potential to compare cities, countries or areas assessed. It also creates incentives for policymakers and politicians to improve their water management strategies and learn from their best practices since a high or improved score can display the benefits of certain public policies and help promote their administration.

From water security assessment, case studies, experiences, observations, consultations, etc., authors in the literature have gathered a range of experiences allowing identification of solutions, suggestions or interventions that could help improve water security. From these, certain actions with the potential to help achieve water security goals have been identified (see Figure 7). Sharing these actions is as important as measuring and aiming for water security since the only way to achieve goals and improve water security is going from paper to action and implementing measures.

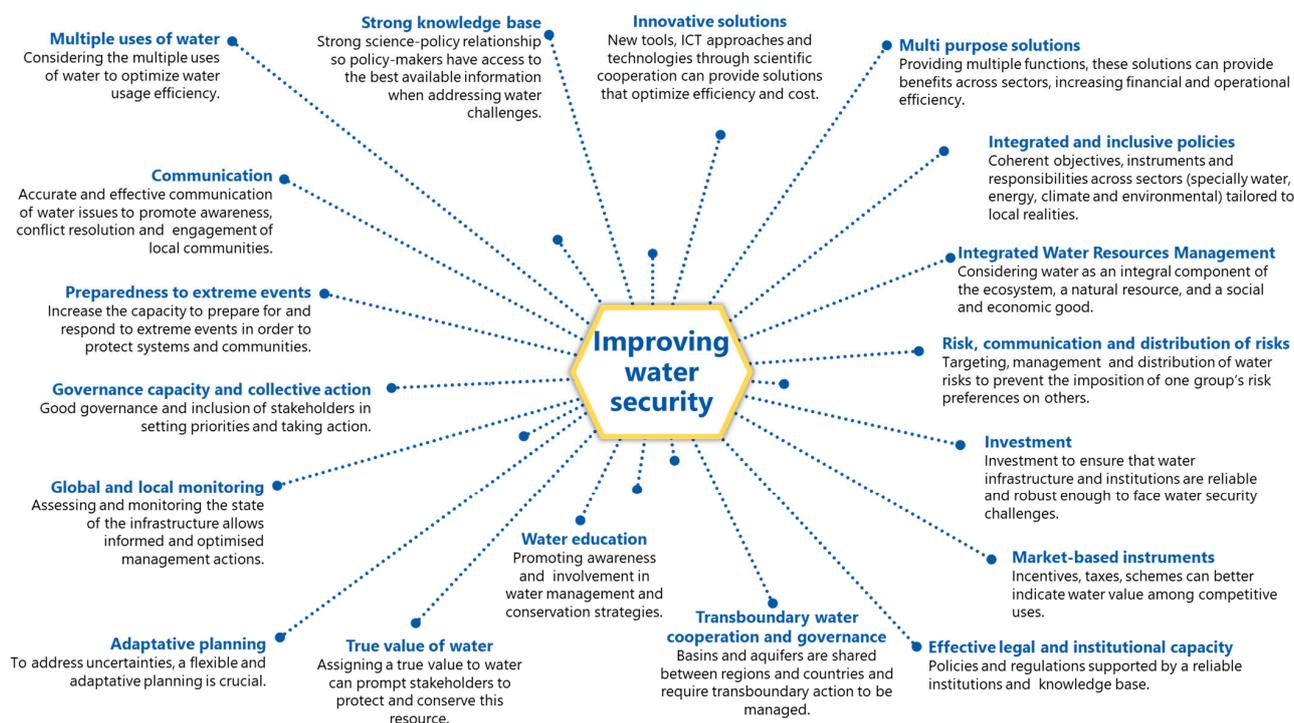


Figure 7. Summary of actions with potential to improve water security.

Water connects the geophysical, social, ecological and economic systems [95] and as consequence, an integrated approach is considered in the literature as the best way to balance the competing water demands—human and environmental [23,29,59]. Integration is key not only in terms of the water cycle but also water sector planning with other sectors such as land use and energy. With the potential to reduce the fragmentation of policies, integrating goals, needs and responsibilities across sectors requires clear national policies on integrated water management, appropriate institutions, effective legislation,

engagement of local communities and collaboration between stakeholders to set priorities and take action [23].

Changing the traditional perspective and adopting an approach that considers innovative solutions to the multiple and integrated uses of water is pointed in the literature as key to sustainability and water security improvement [20,25]. Optimization of water usage efficiency, incorporation the natural assets and environmental values in the design of water infrastructure [22,96] and multi-purpose and tailored solutions [20] for instance are pointed in the literature as key developments for a flexible and resilient approach towards water security.

Information is indispensable for good management. Assessing and monitoring water, environmental, social and economic indicators allow informed and optimized management actions [20,25,90,97]. Therefore, enhancing the knowledge base and consolidating the science-policy interface is imperative to provide policymakers with the best available information when putting in place policies to address water security challenges [5]. Furthermore, a strong knowledge base and science-policy communication can provide the link between innovation and application [38].

Innovative solutions, integrated policies, monitoring, communication as many other of the actions seen in Figure 7 have been facilitated by the use of ICT (Information Communications and Technology) solutions. Research and application of machine learning, modelling and many other smart technologies and tools have shown great potential to accelerate actions and promote more efficient water strategies [1,98].

Better water governance is needed to face water security challenges but also to maintain political stability, economic equity and social justice [95]. Policies and regulations supported by a reliable knowledge base and promotion of dialogue between sectors are some points to consider in order to enable knowledge sharing, cooperation and better water governance to cities [25]. Promoting dialogue and sharing information also help promote awareness, changing the way water challenges and policies are perceived [5,90].

As part of good governance, planning is an important aspect. Even cities with high levels of water security and development will face uncertain future conditions [20]. Integrating climate change adaptation on investments and adopting flexible and adaptive planning are crucial for improving water security. Another important point is the implementation of inclusive policies. This is important to identify disparities in water security and make sure that the responses and interventions are tailored to the local realities [25]. Investment in water infrastructure is also crucial. Ensuring that water infrastructure is reliable and robust enough to face water security challenges is essential to economic development and poverty reduction [25,38].

## 7. Conclusions

Adopting the UN definition for water security, this paper provides an overview of what water security is, how it is being assessed and what can be done to improve it.

Through different scales and approaches, the evaluation of water-related concepts, in particular water security, is an important step into achieving the SDGs. Although different definitions and frameworks have been proposed in the last decades, research questions around water security, and how to improve it, are still of great relevance. Like the concept itself, water security challenges are multifaceted and facing them depends not only on research and innovation but also on policies, management strategies and governance.

The development of frameworks and the potential to measure water security allows a wider and clearer vision view of water challenges. Investigating water security provides crucial information on this ever-changing, multi-faceted concept, allowing to produce the best possible information on needs and challenges. This fuels research to develop means to better measure and improve water security. The search for higher levels of water efficiency and safety at different scales has guided researchers over the last decades to propose innovative solutions in terms of management strategies, assessment methods,

modelling and simulation, smart systems, low cost and water-efficient technologies, remote monitoring and many other fields that can be applied to the improvement of water security.

The scientific output needs to be associated with governance and planning, so these novelties can help face real water challenges and meet needs. The advantages brought by new technologies combined with the possibility to measure the needs and the progression of water security have the potential to influence policies. Information on the relationship between innovation and measured improvement of water security can help to highlight the impact of certain measures and inform stakeholders, thus providing arguments and incentives to policymakers to take action. Furthermore, understanding the interconnection between water security and all that it embodies is crucial to contemplate the impact that these actions have. Climate change, policies, economic activities, population growth, among many others, when subject to planning and efficient actions, will influence water security at different scales.

Integration appears as a key word when approaching water security improvement. Integrating the water cycle, policies, sectors, etc. shows undeniable advantages when facing the current water challenges. Therefore, one could expect that integrating assessment and monitoring would provide a wider vision of water challenges while still accounting for differences in scales and context. As all the scales are connected, the aspects evaluated by different concepts such as sustainability, resilience or water security also fit together. This integration should not be limited to the metric but should also include science-policy exchange: consultation with stakeholders from different levels, dissemination of research output to policymakers and scientific involvement in policymaking, etc. Moving forward, it would be valuable to investigate how integrating assessments could help build an even stronger knowledge base for policy development and water management actions.

**Supplementary Materials:** The following are available online at <https://www.mdpi.com/article/10.3390/su132413702/s1>, S1. Water security challenges around the world; S2. Water security definitions.

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