Water Economics and Policy, Vol. 7, No. 3 (2021) 2150013 (33 pages)

DOI: 10.1142/S2382624X21500132

Economic Research on the Global Allocation of Scarce Water Resources Needs Better Data

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Received 8 December 2020
Revised 5 July 2021
Accepted 6 July 2021
Published 4 September 2021

Water sustainability is central to modern political and academic debates. Despite increasing efforts to promote regional and global integrated water management, climate change, population, and economic growth, and increasing consumption of water-intensive goods project higher water deficiency. Robust economic analyses rely on information about water supply and consumption across different production sectors, type of procurement source (public or private water supply), and water prices. Nevertheless, developing current and future economic water assessments and indicators is impeded by the absence of data. Despite the lack of official national statistics on water withdrawal and consumption, a small number of international and global databases have been constructed and attempt to combine available national water information into databases. Water databases do not commonly define and/or distinguish terms such as water use, water consumption, water supply, or water abstraction, and the associated aspects of water scarcity and sustainability. They comprise variable data quality, provided by numerous sources, and estimated values. This paper evaluates the current state of knowledge of national statistics, international and global water databases. We describe the data collection methods, identify basic concepts and definitions of water terms, followed by the criteria of consistent water databases. We inform about data availability across regions, and present the data content and definitions of national, international, and global water databases. The results show inconsistencies of data

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content and definitions, suggesting no evidence of data harmonization among databases. Therefore, our study cautions researchers to be careful when manipulating and comparing the available water data, especially when deriving policy recommendations or economic conclusions. In the long run, the headway of water research and political assessments depend on political enforcements to refine the meaningfulness of water data and support water collection, reporting, and monitoring. Alternatively, in the short- and medium-run, water data challenges can be addressed by joint research efforts for water data harmonization.

Keywords: Water data; water sustainability; water use; water withdrawal; water economics; water scarcity; water policy.

1. Introduction

Water is essential for life and to human and environmental sustenance. Freshwater accounts for a very small share of water resources and is the base for human activities, encompassing drinking, irrigation, and industrial use (Jackson *et al.* 2001). As water and population are unevenly distributed across the globe, some regions bear higher impacts as water becomes scarce (Berritella *et al.* 2007; Zeng *et al.* 2013). Climate change, population and economic growth, and the increasing consumption of water-intensive input goods project higher water deficiency (Liu *et al.* 2017). In its introductory statement on Sustainable Development Goal (SGD) 6, the United Nations Development Programme (2019) (UNDP) states: “Water scarcity affects more than 40 percent of people, an alarming figure that is projected to rise as temperatures do.” This statement raises concerns as water scarcity is accompanied by and interacts with other scarce natural resources such as fertile land, and with a multitude of ecosystems, which strongly influence human well-being and poverty. Due to the complexity and multidimensional character of water challenges, water resource management deserves special and integrated treatment (Ait-Kadi 2016).

Despite increasing efforts to promote regional and global integrated water management, the target of water sustainability may not be achieved (United Nations 2018). This is especially due to the absence of data, which directly influences the results of water indicators, research outcomes (Ortigara *et al.* 2018; United Nations 2018), and impacts economic assessments of water resources. Economic development through industrialization depends on sufficient water supplies. At the same time, ecosystem services are often negatively affected as water consumption increases (Rijsberman 2006), and climate change is likely to affect the amount, the temporal, and the spatial distributions of water (Liu *et al.* 2017). How these combined and interacting factors influence current and future water scarcity, and its consequences for human wellbeing, depends on knowledge about water availability and use. Assessments need to be combined and consistent with local, spatially disaggregated water-use patterns. Therefore, supporting water research in economic, physical, and political fields requires consistent water data (Berritella *et al.* 2007; Fujimori *et al.* 2017; United Nations 2018).

From an economic perspective, water is an essential production factor (Hertel and Liu 2015). Agriculture is the biggest water user, where 70% of all freshwater withdrawal is supplied to irrigation purposes, followed by industry (20%), and municipal matters (10%) (United Nations 2009). Local water scarcity is potentially alleviated by virtual water trade mechanisms (Oki *et al.* 2017). Water economics enables the assessment of the impact of production, as well as economic and political interventions, on water resources in the context of international food and industrial trade (Calzadilla *et al.* 2010). Computable General Equilibrium (CGE) models, for instance, are used to study water availability, use, and management in the context of international trade by reallocating water using market mechanisms (Calzadilla *et al.* 2016). Spatially disaggregated water data are core to the development of such economic models. Furthermore, robust economic analyses rely on information about water supply and consumption across different production sectors, the type of procurement source (public or private water supply), and water prices. Nevertheless, assessing water use in miscellaneous industrial and agricultural activities is impeded by the widespread absence of data (Liu *et al.* 2016). Despite the lack of official national statistics on water withdrawal and consumption, a small number of international and global databases [EUROSTAT, FAO, WaterGap model (Floerke *et al.* 2013), Organisation for Economic Cooperation and Development (OECD), The World's Water, and UNSD] have been constructed and attempt to combine available national water information into the databases. A challenge in constructing a global water dataset draws from the confusion in defining water terms. Water reports and databases do not commonly define and/or distinguish terms such as water use, water consumption, water supply, or water abstraction, and the associated aspects of water scarcity and sustainability (Gleick 2003; Rijsberman 2006).

This paper evaluates the current state of knowledge of national statistics on water as well as the international and global water databases, and addresses some fundamental questions: What do we know about water data availability and use? How reliable are global water databases? How comparable are the different data sources? The paper is structured as follows: Section 2 presents the systematic methods for data search. Section 3 displays the data analysis by identifying basic concepts and definitions of water terms, followed by the criteria a consistent water database should adhere to. Section 4 sets out the results of the data search, by informing the content and definitions of currently available national, international, and global water databases. Section 5 discusses challenges and potentials to the development of meaningful research and political water assessments. Finally, Sec. 6 draws implications for water research and political actions related to water data.

2. Data Collection Methods

Acquiring water data has long been acknowledged as an issue in the scientific literature. Historical water reports are often non-existent or incomplete (Floerke *et al.* 2013) and lack definitions and details about the data collection process. Following from these concerns, Gleick (2003) provided a comprehensive discussion about water data limitations. The issues range from the absence of a prevailing collection method, including standardized source and collection period reporting, to dubious data definitions and geographical disparities of collection. In this sense, industrialized countries are known as water data-rich (Ortigara *et al.* 2018) as they often have a developed structure of data collection for industrial and agricultural sectors.

Our approach aims to identify a globally consistent database on water consumption and withdrawal, which is the basis for the analysis of water allocation in agriculture and industry. Further aspects of water (e.g., sanitation, water quality, and affordable drinking water) are not considered, as well as single official and unofficial water or environmental reports and water projections. Based on the above-mentioned literature, we selected a set of criteria and apply a three-step search method.

The first step in our search for data consists of searching for global water data references, both in scientific and non-scientific sources. Here we follow the first phase of the methodological framework for extensive literature review and evaluation (Schlichter and Kraemmergaard 2010). The phase defines the types of publications to be considered, where to find them, the period of publication, and keywords. From the scientific literature, we consider studies about biophysical and economic water use published in peer-reviewed journals. The procedure is done through academic search engines: Google Scholar and Web of Science. Papers from the year 2000 onwards are considered by using the following keywords: *water withdrawal*, *water consumption*, *water use*, *industrial water*, *water statistics*, *water scarcity*, and *water and CGE*. We look specifically at the type and source of water data used in the selected papers. This allows us to add additional articles that are referenced as data sources in these studies. Articles using simulated data are excluded, as our interest is finding the collected water data. The enquiry of non-scientific sources, in turn, is likewise done through search engine (Google). We consider governmental and research water initiatives and organizations engaged in water data collection and reporting. The same set of keywords (except "water and CGE") is used. As an attempt to evaluate the characteristics of reported water data, the period is not restricted.

As the second step, we scrutinize the selected databases according to the following criteria:

(a) Global coverage: The dataset should cover all countries across the world.
(b) Documentation of definitions: Definitions of water data are necessary and should be well documented to assure consistency when comparing country-level withdrawal and consumption.
(c) Disaggregated industrial sectors: Reporting water data for different industrial sectors enables assessing the trade-offs of water allocation within and across nations and production activities. Therefore, the aimed consistent global database should convey water use for individual sectors.
(d) Up-to-date data: The use of outdated water information may jeopardize water studies by not depicting the current status of water resources and water use. Therefore, we look for up-to-date databases ranging from 2010 to 2020.
(e) Reliability: Transparency in communicating the years of data collection and reporting, and information regarding the entity responsible to collect the data.

Subsequently, since no database fully meets the aforementioned criteria, in a third step, we search for the official online national water statistics of water consumption and withdrawal. Similar to the first step, we exclude single official and unofficial water or environmental reports and water estimations. The latter are disregarded for not representing a prominent platform for water data reporting, namely, an online easily accessible platform for water data reporting and monitoring. Due to (human) resource constraints, we could not search for water statistics in all countries, but had to prioritize according to the following criteria: include all G20 countries and the three major economies in each region (e.g., in Africa we selected Nigeria, Egypt, and South Africa). In addition to this list of countries, we added countries with a presumably significant water scarcity (e.g., Chile, India, Israel, Spain, and Tanzania). We also added countries that have comprehensive water statistics (e.g., Australia, Denmark, The Netherlands, Palestine, and Tunisia). Given the extensive data and literature search, we believe we did not overlook a country with comprehensive water statistics. Further details are presented in Sec. 3.2, including the full list of countries.

The language capacity of our inquiry encompasses English, Spanish, German, Portuguese, and French. Similar to the first step, we make use of search engines with the following keywords: *water withdrawal*, *water consumption*, *water use*, *industrial water*, and *water statistics*; together with the respective country's name.

This enables us to spot the countries with national water statistics. Subsequently, for the remaining countries, we search for water data on online platforms of environmental ministries and statistical offices. For the nations with no indication of water statistics, we further examine the country-specific references of the global water databases from the first step. Hence, we are able to track back the existence of water statistics and further details about the entity responsible for reporting national water data, and the types of data sources (e.g., single reports, open access statistics, and official statements). Additionally, we consider the scientific literature on national studies. We replicate the scientific search done in the first step as a way to find country-specific water studies, which could potentially reference national water databases.

The criteria applied in the first step do not entirely fit the third step since the latter targets only the occurrence of national water statistics. Moreover, national water reporting systems are highly heterogeneous and differ on the desired frame for water reporting. Nevertheless, we provide and compare the main characteristics, definitions, and national institutions responsible to manage water data in Sec. 4.

3. Analysis

The analysis presented here is twofold. Section 3.1 highlights the issue of water definitions, describes various forms of water allocation, and discusses the relevant characteristics of water use and values. Section 3.2 assesses the consistency of global water databases, and aspects of data search for national statistics.

3.1. *Defining water terms*

Water is a dynamic resource occurring in temporally and spatially variable cycles that provide services to the environment and society (Rijsberman 2006). The hydrological cycle is composed of blue and green water. Blue water is the share of precipitation that goes to aquifers, lakes, and composes surface water and groundwater resources (Savenije 2000). This is the main source to sustain human needs, industrial production, and irrigation agriculture. Originated from Falkenmark (1995), the term green water is the part of precipitation intercepted by vegetation, stored into the soil, transpired back to the atmosphere, or temporally available for vegetation growth (Quinteiro *et al.* 2015). In fact, green water is essential to 60–70% of the world's food production (Rost *et al.* 2008). Accounting for both blue and green water resources is crucial to the completeness of reports and accuracy of water-use projections (Liu *et al.* 2009). However, water indicators and reports have widely neglected green water in their composition (Zeng *et al.* 2013).

Water use is determined by interrelated factors such as water type (blue and green), seasonal variability, technology level, and population density, among others. For instance, water withdrawals for domestic and energy purposes are higher in regions with high population density (Huang *et al.* 2018). During cropping seasons, drought regimes call for irrigation in the Western USA, Eastern China, and India. In this period, irrigation agriculture requires large amounts of water for food and biomass production (Rio Carrillo and Frei 2009; Wada *et al.* 2014). Assessing the global spatial distribution of production activities and water withdrawals from 1971 to 2010, Huang *et al.* (2018) observed increasing withdrawal rates. The authors found that 68% of withdrawals are designated to irrigation, followed by electricity (11%), households (9%), manufacturing (7%), and less than 5% to mining and livestock production. Assessing water issues required a broader knowledge about water-use patterns along with various production processes. Nevertheless, the absence of water data and contrasting water definitions create conceptual confusion and hinder concise data collection (Gleick 2003). Similarly, defining water categories guides data collection, the development of reports, data documentation, and water assessments.

The term water use often refers to water consumption or withdrawal. However, these two categories are very different. Following Gleick (2003), here we define water use as a general term referring to any type of water manipulation. Water withdrawal varies enormously over countries and production activities, it denotes the amount of water removed from a natural source and appointed to human activities (Gleick 2003; Rijsberman 2006). In industries, water is withdrawn by means of private infrastructure and supplied by public procurement (Hertel and Liu 2015). A portion of withdrawals is lost and returns to the hydrological cycle before entering the production processes. The remaining is split into a share that is directly consumed into production and the water that is further discharged back to the natural water system. Therefore, consumption, or consumptive use, refers to the share of water withdrawal that does not return to the hydrological cycle. In agriculture, consumptive use, also denoted as water depletion (Liu *et al.* 2009), is the amount of irrigated water captured by plants and not available for further reuse (Hertel and Liu 2015).

Water need and demand are interrelated terms; the first is subjectively oriented and refers to the minimum amount of water to sustain a certain activity, while the latter describes the amount of water desired by potential users, usually larger than the minimum requirement of water. Especially in regions facing limited water resources, demand is a considerable policy matter (Banda *et al.* 2007). Understanding how users behave towards different water prices can support policymakers designing instruments to regulate water use (Strand and Walker 2005).

This follows the principle that water demand responds to price signals, where water prices lead to more efficient water allocation between competing users (Rogers *et al.* 2002). Nevertheless, this strategy is arguable as the price information are imperfect or unobserved, and when the price demand elasticity is very low (Banda *et al.* 2007; Gaudin 2006). Moreover, studies have also shown that various water demands are price-unresponsive (Gaudin *et al.* 2001; Martínez-Espiñeira and Nauges 2004). For instance, Scheierling *et al.* (2006) discussed that pricing policies to reduce irrigation water use might come with negative consequences, as high prices would inflict minor water-use reduction, but would rather affect agricultural income and wealth. A similar effect is observed by Berbel and Gómez-Limón (2000) where water demands respond only after farm incomes decrease up to 40%.

Furthermore, there are other water-related terms non-uniformly defined in the literature: water conservation, efficiency, and productivity. Gleick (2003) described water conservation as the reduction in water losses triggered by technology development, or institutional efforts to promote behavioral changes. Water efficiency is a precise measure of conservation, representing the relationship of the amount of water used relative to the minimum requirement to accomplish an activity. Maximum water-use efficiency holds if water use converges to its minimum water requirement (Gleick 2003). Lastly, water productivity is defined as the unit ratio of output and water use (Gleick 2003). Units may be either physical (e.g., volumes, tons) or economic (e.g., dollar value of output or service) terms (Gleick 2003).

In water economics, defining withdrawal and consumption is especially necessary to study water values (Gibbons 1986). In general terms, water values rise when the supply of water is lower than its relative demand (Ward and Michelsen 2002). For decades, water was seen as abundant, with no active economic and political mechanisms to regulate resource uses. This concept has gradually changed as water supply has fallen short in many countries (Gibbons 1986), resulting in multifold conflicts over water between competitive users and geographical regions (Gibbons 1986; Ward and Michelsen 2002).

From the geographical dimension, water is used instream or off-stream. The former refers to the activities occurring on the water stream (e.g., navigation, hydropower generation, and recreation), while the latter is the removal of water from the natural cycle to sustain further activities (e.g., agriculture, industry, and municipal water demand). Quantity, quality, and time are other dimensions that likewise influence the analysis of water use (Gibbons 1986; Turner *et al.* 2004). Analyses based purely on the quantitative aspects of water use are somewhat limited. Water is not necessarily consumed during the process of being used and can even be reused several times, which also generates utility to users. In fact, the proportion of water consumed as a portion of withdrawals varies tremendously across uses. Reusing water stems from competitive and complementary relationships with other uses, meaning that reusing water is expected to trigger serious effects to subsequent uses (Gibbons 1986; Ward and Michelsen 2002).

3.2. *Selection process for water database*

Table 1 sets out the list of water data references found on the first step of data search. These datasets represent the most cited sources for water data in scientific research and the databases found on non-scientific sources. The references do not follow a common data structure and differ from reporting collected (empirical) data and estimates. Generally, there are two main categories of water studies: those based on statistical water records of empirical data on withdrawal and availability; and those based on simulated water accounts derived from hydrological models (Hanasaki *et al.* 2012). The latter are likewise based on empirical evidence to obtain realistic estimation results. All references from Table 1 are examined to identify detailed characteristics of the data. We exclude sources that do not contain collected data on water withdrawal and consumption. In this matter, although applied as databases, two references contain model estimates for water withdrawal

Table 1. List of Water References and Respective Country Coverage

Water Data References	Country Coverage
EUROSTAT	EU members
EXIOBASE (2020)	Global
FAO-AQUASTAT	Global
H08	Global
OECD*	OECD, EU, G7, G20
PCR-GLOBWB	Global
UNSD	Global
Water footprint (2020)	Global
WaterGap model	Global
The World's Water	Global

Source: EUROSTAT: https://ec.europa.eu/eurostat/web/environment/water. EXIOBASE: https://www.exiobase.eu/, Stadler *et al.* (2018). FAO-AQUASTAT: http://www.fao.org/aquastat/en/. H08: Hanasaki *et al.* (2012, 2017). OECD: https://stats.oecd.org/BrandedView.aspx?oecd_bv_id=env-data-en&doi=data-00602-en. PCR-GLOBWB: Sutanudjaja *et al.* (2018), Van Beek *et al.* (2011). UNSD: https://unstats.un.org/unsd/envstats/qindicators.cshtml. Water footprint: https://waterfootprint.org/en/resources/waterstat/. WaterGap model: http://watclim.cesr.de/, Floerke *et al.* (2013). The World's Water: http://worldwater.org/wp-content/uploads/2013/07/ww8-table2.pdf.
Note: *OECD (35), EU (28), Euro area (17), G7, and G20.

and consumption: H08 (Hanasaki *et al.* 2012, 2017) and PCR-GLOBWB (Sutanudjaja *et al.* 2018; Van Beek *et al.* 2011); or comprise a set of own methods to derive an alternative character of water consumption (Water footprint). Likewise, EXIOBASE (2020) builds the water accounts based on data from FAO and Water footprint (2020) to estimate water consumption in agriculture; and the WaterGap model (Floerke *et al.* 2013) to account for water in industrial sectors (Stadler *et al.* 2018). Such references are excluded for not representing a database of collected data on water consumption and withdrawal.

Subsequently, Table 2 describes water databases according to the consistency criteria. None of the databases meets all consistency criteria. From the global coverage criterion, we define two groups: global and international water databases. The latter is here defined as those composed of countries belonging to a specific group. This is the case of EUROSTAT, reporting data from members of the European Union; and the Organisation for Economic Cooperation and Development comprising data from the signatory OECD countries. All databases from Table 2 present a glossary with their own data definitions. Data on single industrial sectors (e.g., manufacturing, electricity, and services), however, are presented only by EUROSTAT, OECD, and the WaterGap model. The remaining databases treat industrial water as an aggregation of various industrial sectors. The number and type of industrial sectors in the aggregation are specific to every database.

Another important criterion involves up-to-date data. As an attempt to report the most recent information for freshwater withdrawal and consumption, databases make use of reporting and data acquiring strategies, for instance information from the national correspondents (FAO 2021). However, we identified that both The World's Water database and WaterGap model only account for data from 2000 or even earlier. Up-to-date data is directly related to the reliability criterion. In this sense, we draw attention to the importance of distinguishing the year the reports

Table 2. Water Databases and Criteria for a Consistent Global Database: Global Coverage, Definitions, Industrial Sectors, Up-to-Date Data, and Reliability

	Criteria				
Databases	Global Coverage	Definitions	Single Sectors	Up-to-Date	Reliability
EUROSTAT		×	×	×	×
FAO-AQUASTAT	×	×		×	×
OECD		×	×	×	×
UNSD	×	×		×	×
WaterGap model	×	×	×		
The World's Water	×	×			

are updated and the year the data refer to. To better exemplify, the updated report of The World's Water database dates from 2013, however, the observations in the report range from 1975 to 2010. Indeed, the constraints to acquire water data are known and water databases are composed of data from various years. Nevertheless, transparency is required when communicating the sources of each data point. Knowing the sources enables following back every detail of the data, such as definitions, collection method, and the organizations responsible for data collection. Our search asserts that both The World's Water and WaterGap databases lack complete information of data sources, and do not provide further details to prove for reliability.

Furthermore, we analyze global and international water databases from Table 2 according to their data content and definitions, by applying the following water categories: water withdrawal, water use, and procurement source. The two first categories were chosen for representing the most common data reported in water databases, while the last category informs about the differentiation between public and private water supplies. Additionally, withdrawal data are also distinguished in agricultural water, industrial water, municipal water, surface water, groundwater, and total freshwater withdrawals. Therefore, we examine the definitions of all data categories. Moreover, sectoral aggregation is included because it informs whether data are available for single industrial sectors (e.g., manufacturing, electricity) or in an aggregated manner. Lastly, we provide information about period and collection interval. These categories describe, respectively, the years data are reported and the frequency of water collection.

Following from the lack of consistency on global water databases, we look for water statistics at the national level. We search specifically for official online national water statistics that report water consumption and withdrawal data, using the criteria mentioned in Sec. 2. Our search was in 40 countries (Table 3).

Table 3. Regional Selection of Countries as Targets of Further Water Data Search

Region	Countries
Africa	Algeria, Egypt, Kenya, Morocco, Nigeria, South Africa, Tanzania, Tunisia, Uganda
Asia	Bangladesh, China, India, Indonesia, Japan, South Korea, Turkey
Middle East	Saudi Arabia, Israel, Palestine
North America	Canada, Mexico, USA
South America	Argentina, Brazil, Chile, Colombia
Oceania	Australia, New Zealand
Europe	Croatia, Denmark, France, Germany, Ireland, the Netherlands, Poland, Portugal, Spain, Sweden, the United Kingdom, Russia

We came across several official websites and single water reports but could not find water statistics for all countries. For instance, the "Direción General de Aguas" (DGA)[1] is a public authority responsible to manage the water resources in Chile. The DGA reports an extensive list of data referring to water rights, water market, and characteristics of water resources, among others. However, we did not find data on water withdrawals and consumption. We also examined the "Escenarios Hídricos 2030 Chile",[2] which is a big national collaboration of public and private entities to promote dialog and agreement towards water issues. The initiative developed an extensive report accounting for aspects of water in Chile, as well as definitions of water terms. Similarly, in Mexico, the government created CONAGUA,[3] which is an authority responsible to promote sustainable water resources management and water security. We could not find freely accessible water consumption and withdrawal information. We further consulted the 2011 water statistical report released by CONAGUA. The report contains various aspects of water resources and use in Mexico. In Colombia, the national department of statistics (DANE — Departamento Administrativo Nacional de Estadística)[4] is the official agency to manage national data. Despite accounting for environmental statistics, water data are not reported. Similarly, for countries like South Africa,[5] Tanzania,[6] Japan,[7] Morocco,[8] Algeria,[9] and Turkey,[10] we identified statistical reports but did not find comprehensive online water statistics platforms.

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[1]Chilean governmental general water authority: https://dga.mop.gob.cl/Paginas/default.aspx.

[2]Escenarios Hídricos 2030 Chile. We looked into the 2018 report "Radiografía del Agua: Brecha y riego hídrico en Chile". *Source*: http://escenarioshidricos.cl/publicaciones/.

[3]CONAGUA website: https://www.gob.mx/conagua. The 2011 water report: http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/SGP-1-11-EAM2011.pdf.

[4]DANE website: https://www.dane.gov.co/.

[5]Statistics South Africa: http://www.statssa.gov.za/?page_id=595. South Africa 2010 water report: https://www.statssa.gov.za/publications/D04058/D04058.pdf.

[6]The National Environment Statistics Report, 2017 contains several aspects of water management in Tanzania: https://www.nbs.go.tz/nbs/takwimu/Environment/NESR_2017.pdf.

[7]Japan Water Agency (Independent Administrative Corporation) website: https://www.mlit.go.jp/tochimizushigen/mizsei/water_resources/contents/corporation.html. For reports of the Ministry of Land, Infrastructure, Transport and Tourism: http://www.mlit.go.jp/en/index.html.

[8]The annual reports from the General Division of Statistic encompass general information of water use across productive sectors: https://www.hcp.ma/Bookcases-des-Annuaires-Statistiques-du-HCP_a2071.html.

[9]Compendium National sur les Statistiques de L'Environnement Report: https://www.ons.dz/IMG/pdf/CompenAlg2006.pdf. Algeria Water Sector M&E Rapid Assessment Report: https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/assessments/libya_water_sector_me_rapid_assessment_2014.pdf.

[10]World Bank report of 2016: https://documents1.worldbank.org/curated/en/600681476343083047/pdf/AUS10650-REVISED-PUBLIC-Turkey-NCA-Water-Valuation-Report-FINAL-CLEAN.pdf.

Respectively for India[11] and Russia,[12] we came across governmental water reports, which did not contain the targeted data, and we were not able to assess them due to language limitations. Our search on Nigeria, Uganda, Bangladesh, Indonesia, and Argentina was not successful. For the remaining countries of Table 3, the water statistics are further analyzed based on the definitions of water data content and the institutions engaged to collect and report water data.

4. Results

The results are described for global and national databases. Section 4.1 contains the analysis of global and international water databases, by highlighting their data content and definitions. Section 4.2 presents water national statistics across region and describes the type of data reported and definitions.

4.1. *Global and international databases*

Table 4 presents the data structure of global and international databases. Water withdrawal is the most readily available water information across the databases. In addition to presenting the total amount of water withdrawal, FAO and UNSD

Table 4. Informational Content of Global Water Databases, Type of Data Available, Timeframe Coverage, and Collection Period

	Withdrawal					Aggregated		
Database	Total Freshwater	Surface Water	Groundwater	Use	Procurement Source	Industrial Sectors	Period	Collection Interval
EUROSTAT	×	×	×	×	×		2009–2018	Yearly
FAO-AQUASTAT	×	×	×			×	1960–2015	Five years
OECD*	×				×		1970–2018	Yearly
UNSD**	×	×	×			×	1990–2016	Yearly
WaterGap model	×			×			Various	Irregular
The World's Water	×			×		×	Various	Yearly

Notes: *Data partly sourced from EUROSTAT. **Data partly sources from National Statistics, OECD, and EUROSTAT.

[11]The report "River Basin Atlas of India" contains noteworthy information of water resources in India. However, it does not contain empirical data on water use. *Source*: Government of India, Ministry of Water Resources: http://nwm.gov.in/?q=surface-water-2.

[12]FAO reports water withdrawals from Russia based on the Federal Agency of Water Resources 2018 report. The reference is available only in Russian, which hinders our analysis due to language capacity. *Source*: http://www.mnr.gov.ru/docs/proekty_pravovykh_aktov/proekt_gosudarstvennogo_doklada_o_sostoyaii_i_ob_okhrane_okruzhayushchey_sredy_rossiyskoy_federatsi/.

differentiate between surface water and groundwater withdrawals. However, withdrawal data reported by UNSD are based on FAO. The exchange of data information occurs among all databases. For instance, according to the data glossaries, OECD reports European water accounts from EUROSTAT. FAO is the main statistical database for water resources and management in agriculture. FAO's data quality is highly diverse, however, no other database presents similar crop and country coverage for water resources (Berritella *et al.* 2007). Distinguishing between surface water and groundwater withdrawals is important since both sources have particular characteristics and compete with different users (Hertel and Liu 2015). Surface water availability varies with climatic conditions (e.g., precipitation and vegetation cover) (Hertel and Liu 2015), and is the dominant source for irrigation (Wada *et al.* 2013). Groundwater is less vulnerable to climatic variation and is recharged according to precipitation (Hertel and Liu 2015).

Water use is less-frequently reported. This information is available only in EUROSTAT, WaterGap model, and The World's Water databases. However, special attention should be given to the term "use", as it might be applied with different meanings, either referring to consumption or general terms of water manipulation. This distinction is key to understand the specific definition of water terms to avoid confusion. Seldom available is the differentiation of procurement sources. Water is either supplied by a public procurement or self-abstracted. Such information is available in the OECD and the EUROSTAT data platforms. For instance, industrial water is largely self-supplied as companies invest in the private infrastructure of water caption (Hertel and Liu 2015; Rio Carrillo and Frei 2009). This informs how sectors are reliant on the public water supply system.

Concerning industrial water, data are often reported as an aggregation of various sectors. Each database aggregates sectors differently, which hampers comparison among them. In other words, relating industrial water withdrawal among FAO, UNSD, and The World's Water is not possible due to diverse sectoral aggregation. Disaggregated industrial water accounts (e.g., manufacturing, cooling and electricity, and services) are provided by OECD, EUROSTAT, and the WaterGap model, yet with own classifications.

Although the period category in Table 4 indicates a large sample of years, water observations are not available for all years and all categories. For instance, the manufacturing water supply in EUROSTAT for the United Kingdom is only available for the year 2011, or Switzerland for 2012. Databases have to deal with lack of data and, therefore, make use of mechanisms to impute and estimate water quantities. The WaterGap model is an exception to this spotty coverage because it is not a water database engaged to collect or report data. Instead, the WaterGap model acquires data from various sources in the development of the model.

The water literature heavily uses the model as a database due to its sectoral and country coverage.

Using water data in a coherent way depends on concise comprehension of how data are composed and defined. Table 5 contains the definitions of water categories that are used in the selected international and global water databases. Water withdrawal is divided into production sectors that receive water and the type of source the water is abstracted from. FAO breaks down withdrawal into industry, agriculture, and municipal activities. Industry encompasses thermoelectric cooling and nuclear power plants, dairy and meat industries, and industrial processing of harvested agricultural products (excludes hydropower). Agriculture, in turn, considers water withdrawn for irrigation, livestock, and aquaculture purposes. In the FAO accounts, water in industries and agriculture is only self-supplied, while the municipal category refers to the water provided by the public system for domestic activities and industrial purposes. Water is abstracted from surface water and groundwater resources. FAO also differentiates the amount of water taken from such resources. Surface water withdrawal is defined as the water extracted from rivers, lakes, and reservoirs (including returned water). Groundwater withdrawal, in turn, is defined as the removal of water from groundwater resources. Total freshwater withdrawal is the sum of surface water and groundwater withdrawals, subtracting water that is made available by other means (e.g., desalination and municipal treatment).

In contrast to FAO, the OECD presents water withdrawal for single industrial sectors, such as mining, cooling and electricity, and for irrigation agriculture. The data only refers to water removed from a public procurement, and there is no differentiation between surface water and groundwater resources. Water use is defined as the "use of water by agriculture, industry, energy production and households, including instream uses such as fishing, recreation, transportation and waste disposal". This definition does not sufficiently clarify whether "use" refers to a general term of water manipulation or to a specific water category. Apart from withdrawal quantities, there is no additional data available in the OECD.

EUROSTAT presents information for all water categories. Withdrawal is defined as the process of taking water from surface water and groundwater resources. Data are available for single industrial sectors such as mining, manufacturing, construction, and services, both by public and self-supplied water. Surface water withdrawal refers to the removal of water from surface resources, such as lakes, rivers, streams, and canals, while groundwater is the "process of removing freshwater from underground sources, either temporarily or permanently". Public procurement is the network unit that collects, purifies, and distributes water to various activities. Private supply is the abstraction of water by the user for their

Table 5. Definitions of Selected Water Categories used in International and Global Water Databases

	Water withdrawal							
Global databases	Industry	Agriculture	Municipal	Surface withdrawal	Groundwater withdrawal	Total freshwater withdrawal	Water use	Public private ratio
EUROSTAT	Process of taking water from a source. Surface and groundwater water collected for use by households and enterprises. Includes public and private water supply for mining, manufacturing, constructions, households, agriculture, foresity, fishing, and services.			Removal of water from natural or artificial waterways containing freshwater, including lakes, rivers, streams and canals.	Process of removing freshwater from underground sources, either temporarily or permanently.	Percentage of its long-term annual average available water from renewable ground freshwater resources	Water actually used by end users (e.g. households, services, agriculture, industry) within a territory for a specific purpose such as domestic use, irrigation or industrial processing.	Public: Water supplied by economic units engaged in collection, purification and distribution of water. Private: Abstraction of water by the user for own final use.
FAO-AQUASTAT	Self-supplied withdrawal for thermoelectric cooling and nuclear power plants; water for dairy and meat industries and industrial processing of harvested agricultural products. Does not include hydropower.	Self-supplied water withdrawal for irrigation, livestock and aquaculture purposes.	Withdrawal for the direct use by population. It is usually computed as the total water withdrawn by the public distribution network (includes industrial public supply).	Water extracted from rivers, lakes and reservoirs. Includes withdrawal of primary and secondary (water previously withdrawn and returned) renewable surface water resources.	Water extracted from aquifers. Includes renewable primary, secondary groundwater, and water from overabstraction of renewable groundwater or from fossil groundwater.	Sum of surface and groundwater subtracting (desalinated water, direct use of treated municipal wastewater, direct use of agricultural drainage water).	*No Data*	*No data*

Table 5. (*Continued*)

	Water withdrawal							
Global databases	Industry	Agriculture	Municipal	Surface withdrawal	Groundwater withdrawal	Total freshwater withdrawal	Water use	Public private ratio
OECD	Freshwater removed from ground or surface water resources (permanently or temporarily) and conveyed to a place of use. Refer to public water supply for irrigation, industrial processes and cooling of electric power plants. Includes mining and drainage, excludes hydroelectricity generation .			*No data*	*No data*	*No data*	Use of water by agriculture, industry, energy production and households. Includes in-stream uses (e.g. fishing, recreation, transportation, and waste disposal).	*No data*
UNSD	Water removed from any water source (surface water sources, such as rivers, lakes, reservoirs or rainwater, and groundwater sources) either permanently or temporarily. Includes abstraction by the water supply industry for distribution and direct abstraction by other activities from own use.			Water removed from any surface sources (permanently or temporarily).	Water removed from any groundwater source (permanently or temporarily).	*No data*	*No data*	*No data*

Table 5. (*Continued*)

	Water withdrawal							
Global databases	Industry	Agriculture	Municipal	Surface withdrawal	Groundwater withdrawal	Total freshwater withdrawal	Water use	Public private ratio
WaterGap model	Total amount of water that is taken from the terrestrial part of the water cycle.			*No data*	*No data*	*No data*	Part of the with-drawal that does not return to the terrestrial water cycle.	*No data*
World's Water	Water removed from a source for use. Includes water use for power plant cooling and industrial productions. Water abstraction for irrigation and livestock	Household, munic-ipal, commer-cial and governmental water use.	*No data*	*No data*	*No data*	Withdrawal and use are synonyms. *No data*		

own final use. EUROSTAT also provides data for water use, defining the data as water "actually used by end users". In general terms, the definition is not sufficient to assert whether the data refers to water consumption or any other category of water utilization.

Water abstraction in the UNSD database is defined as the amount of water removed from a surface water or groundwater resource permanently or temporarily. Data are not differentiated between industry, agriculture, and domestic sectors, but represent the sum of yearly withdrawal quantities of sectors altogether. The sectoral aggregation is not clear, because it is obtained from numerous sources. In fact, there are several notes throughout the UNSD data reports concerning data quality, and that data definitions and estimation methods vary substantially. Yearly surface water and groundwater abstraction numbers are available and refer to the water temporarily or permanently removed from surface water and groundwater resources.

The WaterGap model defines withdrawal as the removal of water from the water cycle, and use as the water that does not return to the terrestrial cycle. The World's Water database breaks down water withdrawals into industry (water withdrawal for power plant cooling and industrial production), agriculture (irrigation and livestock), and municipal (household, municipal, commercial, and governmental water use) sectors. There is no clear specification for industrial processes; neither there is a differentiation of surface water and groundwater resources, nor public and self-supplied water. Water use, however, corresponds to a general term implying water manipulation, and here applied as a synonym of withdrawal.

4.2. *National statistics*

Table 6 sets out countries (from the preselected list) that have an established national water statistical system. Even in industrialized nations with comprehensive water statistics, elements such as water reporting, collection period, and definitions vary significantly. The institutions responsible to collect, monitor, and report water statistics are predominantly governmental agencies, but in some countries also the scientific research institutes report (e.g., the USA) and independent agencies (e.g., Portugal and New Zealand).

We identified water statistics mostly from European countries. Detailed sectoral data are also available for Oceania and North America. Latin America, Asia, and Africa are under-represented, as we could only identify official online national water statistics for few countries from these regions. Table 6 displays some of the water categories reported by every national database, followed by their definitions. For instance, Canada reports statistics on water use and water withdrawal for various industrial sectors, both on national and county levels. In the Canadian database, water withdrawal is defined as the amount of water extracted from water

Table 6. Informational Content, Definitions, and Institutions of National Water Statistical Systems

Region	Information Content	Definitions	Institution
North America			
Canada	Water use in industries and household	*Water withdrawal*: Water extracted from water bodies. *Water use*: Water withdrawn from water resources to support society in economic and residential sectors.	Governmental Agency
USA	Water use, withdrawal, public supply, domestic, thermo-electric, industrial, mining, aquaculture and irrigation, and livestock	*Withdrawal for each category of use*: Total amount of water removed from the water source for a particular use. *Water use*: Water that is used for a specific purpose.	Scientific Institution
South America			
Brazil	Water use in industries, irrigation, and hydropower generation	*Water withdrawal*: Water extracted from water resources. *Water consumption*: Water withdrawal that does not return to the hydrological cycle.	Governmental Agency
Oceania			
Australia	Water use, consumption in various productive sectors	*Total water use*: Sum of distributed water use, self–extracted water use, and reuse. *Water consumption*: Total water use minus instream water use and distributed water supplied to other users.	Governmental Agency
New Zealand	Water use and consumption	*Water use*: Distinguished between consumptive and non-consumptive water uses. *Consumptive uses*: Water uses in which water is not returned to its original stream.	Governmental Agency Independent Research Institute
Africa			
Egypt	Water consumption in companies, water produced	*No definitions reported*	Governmental Agency
Tunisia	Total water use and supply	*No definitions reported*	Governmental Agency
Asia			
China	Water supply and use	*Water supply*: Water removed from different water resources.	Governmental Agency

Table 6. (*Continued*)

Region	Information Content	Definitions	Institution
		Water use: Water provided to different activities.	
South Korea	Total water consumption, water supply	*No definitions reported*	Governmental Agency
Middle East			
Saudi Arabia	Water consumption, water use, and supply	*Water consumption*: Quantity of water consumed (used) in a corporation, which does not return to its original source after being withdrawn. *Water supply*: Main source of drinking water including distributed water, bottles, wells, purification, and public power network.	Governmental Agency
Israel	Water production and consumption	*Water production*: Pumping water. *Water consumption*: No definition reported.	Governmental Agency
Palestine	Water supply and consumption for the domestic sector, agriculture supply	*Water consumption*: Water withdrawn from groundwater or surface water resource for industrial, domestic, and irrigation purposes or for any other use.	Governmental Agency
Europe			
Croatia	Water supply and water utilization	*Water supply*: Water used in supplying enterprises/trade companies, irrespective of whether it was used for own purposes or sold to other users. *Water utilization*: Water used by a reporting unit for its own purposes in the period of one year.	Governmental Agency
Czech Republic	Public water supply	*Water production*: Pumping the water. *Water consumption*: Carrying water to the main consumers.	Governmental Agency
Denmark	Water supply, discharge, and consumption	*Water use*: Same as water consumption. *Water supply*: Water abstracted by public waterworks — loss in handling of the water.	Governmental Agency

Table 6. (*Continued*)

Region	Information Content	Definitions	Institution
France	Water withdrawal	*Water withdrawal*: All abstractions related to activities generated by agriculture, industry (including energy), drinking water supply, or others.	Governmental Agency
Germany	Water extraction, public and non-public water extraction	*Public supply*: Water daily distributed.	Governmental Agency
Ireland	Domestic metered public water consumption	*No definitions reported*	Governmental Agency
The Netherlands	Water use and abstraction	*Water use* (including leakage): Combination of "self-abstracted/ produced and used water" added to the amount produced and supplied by others, for the distinguished water types.	Governmental Agency
Poland	Consumption of water for needs of the national economy and population during the year	*Water consumption*: Water used by the plants for production, exploitation, and administration purposes or for social and living needs of employees (excludes water delivered to residential buildings located in the plant).	Governmental Agency
Portugal	Water withdrawal, water supply, and water consumption	*Water withdrawal*: Water used from surface water and groundwater resources for various activities. *Water supply*: Distribution of water to various activities. *Water consumption*: Water provided to registered consumers.	Autonomous Public Agency
Spain	Water supply for various economic activities	*Water use*: Water used (from self-supply and public supply) that has an entry into the industrial establishment to provide for the needs of the productive process. *Water consumption*: Water that, after being used, does not return to the environment.	Governmental Agency
Sweden	Water withdrawal and use	*Water use*: Abstracted water added to purchased water minus returned water (water returned without use).	Governmental Agency

Table 6. (*Continued*)

Region	Information Content	Definitions	Institution
The United Kingdom	Public supply and self-supply of water for England and Wales	*No definitions reported*	Non-ministerial Office

Source: Statistics Canada: https://www.statcan.gc.ca/eng/about/about?MM=as. United States Geological Survey: https://www.usgs.gov/media/images/categories-water-use. Brazilian National Water Agency: https://www.ana.gov.br/. Australian Government Bureau of Meteorology: http://www.bom.gov.au/water/waterinaustralia/. Australian Bureau of Statistics: https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4610.0Explanatory%20Notes12015-16?OpenDocument. New Zealand Ministry for the Environment: https://www.mfe.govt.nz/. New Zealand Institute of Economic Research: https://nzier.org.nz/. Egypt Data Portal: https://egypt.opendataforafrica.org/xbeofib/clean-water-produced-consumed-by-use-egypt-2007-2013. Tunisian Statistics: http://www.ins.tn/en/themes/environnement#sub-378. China Statistical Yearbook: http://www.stats.gov.cn/tjsj/ndsj/2015/indexeh.htm. South Korea Statistical Information Service: http://kosis.kr/eng/index/index.do. Saudi Arabia General Authority for Statistics: http://www.stats.gov.sa/en. Israel — Central Bureau of Statistics: https://www.cbs.gov.il/en/Pages/default.aspx. State of Palestine: http://pcbs.gov.ps/site/lang__en/771/default.aspx. Croatian Bureau of Statistics: https://www.dzs.hr/default_e.htm. Czech Statistical Office: https://vdb.czso.cz/vdbvo2/faces/en/index.jsf?page=statistiky#katalog=30842. Statistics Denmark: https://www.statbank.dk/statbank5a/default.asp?w=1680. French Ministry of Ecological Transition (Ministère de la Transition Écologique) — EAU France: http://www.data.eaufrance.fr. Glossary: http://www.glossaire-eau.fr/sites/default/files/glossaire_eau_biodiv_en_20210608.pdf?v=1623167652. German Federal Office of Statistics: https://www.destatis.de/DE/Home/_inhalt.html. Ireland Central Statistics Office: https://www.cso.ie/en/. Dutch Central Statistical Office (CBS): https://opendata.cbs.nl/statline/portal.html?_la=nl&_catalog=CBS.https://opendata.cbs.nl/statline/portal.html?_la=en&_catalog=CBS Statistics Poland: https://bdl.stat.gov.pl/BDL/start. Statistics Portugal: https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_main. Spanish Institute of Statistics: https://www.ine.es/en/index.htm. Statistics Sweden: https://www.scb.se/en/. UK Office for National Statistics: https://www.ons.gov.uk/.

bodies, either surface water or groundwater resources; whereas water use is generally related to the utilization of water to support economic activities and residential sectors. The Canadian water statistics also report water consumption, water discharge, and other categories. For simplification, these terms are not presented, yet the level of detail on definitions and sectoral disaggregation is noticeable. The data structure and definitions of water categories of the USA statistics are very similar to the Canadian water statistics. Data are collected every five years, available at the country and state levels, differentiating industrial sectors and type of procurement. Likewise, water use is not defined as a synonym of consumption; rather it is related to production activities, such as aquaculture, hydropower generation, irrigation, and domestic purposes, among others.

Out of the selected Latin American countries, the only water statistics platform found was from Brazil. Water withdrawal and consumption are available for various industrial sectors that are supplied by the public water system. The definition of withdrawal is similar to the previous sources. Consumption is the part of the water withdrawal that does not return to the hydrological cycle, which also corresponds to the definitions presented in the aforementioned databases.

Similarly, Australia and New Zealand have detailed water statistics, covering various productive sectors and surface water as well as groundwater resources. Australia differentiates public and self-supplied water. Water use is defined as the sum of distributed water, self-supplied water, and reused water, therefore suggesting that use refers to various types of water manipulation. In turn, water consumption is the subtraction of instream water use and the distribution of water to other sectors from total water use. In the New Zealand database, the definitions *per se* are not available. The information about water use suggests that the database distinguishes between the uses of consumptive and non-consumptive water, where consumptive water use is the water use not returned to its original stream.

Water statistics from Africa are available for Egypt and Tunisia. Egypt statistics presents yearly water consumption and water produced for non-residential units (e.g., city councils, industrial plants, and water companies). Nevertheless, detailed information of definitions and the collection process are not provided. Similarly, Tunisian statistics reports data for water supply and use but further details are not available.

In Asia, water statistical systems are found for China and South Korea. Chinese statistics report water supply and use from 2000 to 2014, both at the country and city levels. The accounts are presented for agriculture, households, and industry. Water supply is defined as the water removed from different water resources (synonym of withdrawal). Water use is the water provided for different activities. There is no differentiation of water consumption and discharge, and water use across activities sums the total water supply. For South Korea, the Statistical Information Service reports water supply and consumption at the district level. Information on water supply is represented by the amount of private and public water works (water utilities) in every district and the amount of water supplied (m^3 per day) by water works. Water supply data is available from 2008 to 2018. Water consumption is reported in thousand m^3 per year (from 1991 to 2018). The South Korean water statistics does not provide data definitions, which hampers further analysis or comparison to other databases.

In the Middle East, we found water statistics for all three selected countries. Saudi Arabia reports water statistics for consumption, supply, and various aspects of desalinated water. Water consumption and use are treated as synonyms and are defined as the water withdrawal that does not return to its original source. Data are available for agriculture, industries, and municipal uses. Water supply is the main source of drinking water. It includes water purification, a public system to distribute water to households, bottled water, and water taken from wells located close to households. Israeli statistics report data on water consumption and water production. Water production is defined as "pumping water" to main consumers. However, the glossary does not present the definition of water consumption. For the Palestinian statistics, consumption and withdrawal are synonyms. Although the definition of withdrawal refers to water removal for various economic activities, data refer only to water in the domestic sector.

Water statistics are well documented in Europe, but every national water reporting system presents particular structures of data collection and reporting. In various online water platforms, explicit definitions are not readily available, at least in English. This is the case of Czech Republic, Denmark, Ireland, and the United Kingdom. Nevertheless, Statistics Denmark provides details regarding the collection and reporting process. Water data are differentiated by public and self-supplied water; accounts are available for water supply, discharge, extraction, and consumption for agriculture, domestic, and various industrial sectors. Information privately provided by the Danish Statistics indicate that water use and consumption are treated as synonyms. European countries displayed in Table 6 have different water definitions. In the Dutch statistics, water use is the combination of self-abstracted water and water provided by external procurements (similar to the Spanish statistics). The Swedish statistics, however, regards water use as the sum of the water abstracted and purchase but subtracting water that returns to the hydrological cycle. In the Dutch statistics, water use also accounts for leakages, which is similar to the definition of water extraction in the German statistics.

These differences imply that combining and comparing such data requires a careful analysis of the definitions. The Polish statistics, for instance, define water consumption as general means of water manipulation. It does not seem to consider returned water and leakages. From that, comparing water consumption between Poland and Spain would not be possible, because the Spanish statistical system computes water consumption as the volumes of water used in various activities, and not returned to the hydrological cycle after use. Additionally, Portuguese water consumption would also not allow for any comparison with the above, as it refers to the water provided or supplied to registered consumers.

5. Discussion

Our study investigates the state of the arts of global, international, and national water databases accounting for water withdrawal and consumption. We provide an approach for water data search, followed by the analysis of data definitions and consistency. The need for water data and improvement of water statistics are widely acknowledged (Floerke *et al.* 2013; Gleick 2003; Ortigara *et al.* 2018; Rijsberman 2006; United Nations 2018; Zeng *et al.* 2013). In the political sphere, the United Nations have placed increasing efforts to improve the SDG-6 data monitoring and reporting. There are considerable data challenges to progress towards the SDG-6 targets for sanitation, water quality, resources management, and water use (Ortigara *et al.* 2018; United Nations 2018). Nevertheless, this paper does not focus on the SDG debates. Rather, the analysis of water data centers on potential for future (economic) water research.

Water data are the basis to develop assessments and indicators, and to understand the status of water resources and management (Gleick 2003; Rijsberman 2006). Empirical water data are likewise essential to the development of hydrological (Hanasaki *et al.* 2012) and economic models, in order to obtain more robust scenario results. Nevertheless, the knowledge gap is pronounced as water statistics have very different reporting structures and often deal with obsolete data (Floerke *et al.* 2013). Our research indicates that few countries report own water statistics and water categories are aggregated and defined differently across databases. Additionally, as of now, there is no prevailing method or framework to collect, monitor, and report water data. Databases must also deal with the challenge of missing data. They are constantly improving their mechanisms to acquire water accounts, and even estimate and impute data. The lack of data poses difficulties to compare observations across databases, a problem excacerbated by the fact that it is difficult to control for the differences in sectoral aggregation and definitions.

Water in agriculture is better documented than in industrial sectors. Despite the highly variable data quality, FAO reports water categories on the global level since the 1960s. However, assessing the impact of energy production, mining, manufacturing, food processing, and services in water resources is only possible with a meaningful understanding of sectoral amounts of water used, consumed, and discharged. Industrial water use concerns the intake of water by manufacturing, thermals, mines, and electricity generation (Dupont and Renzetti 2001). Thermoelectric plants encompass nuclear and fossil fuel energy facilities (Inhaber 2010). Water is used in various processes in the industrial production chain. Besides being part of the final output, water is used for cooling and for steam production as an intermediate input (Dupont and Renzetti 2001). In power plants and manufacturing facilities, water is reused to reduce effluent steam, recapture raw materials, and reduce energy costs (Dupont and Renzetti 2001). Water and energy are intrinsically related as water is essential to energy production, and distributing water across services requires energy. In the USA, for instance, energy production demands way more water than any other industrial sector (Inhaber 2010).

In general terms, power generation is one of the biggest water-demanding sectors (Rio Carrillo and Frei 2009). However, the amount of water that is consumed within the production system represents a small share of total industrial abstractions. The main reason for this discrepancy is that water is mainly utilized for cooling purposes, and is subsequently discharged back into the cycle to potential downstream uses (Hertel and Liu 2015).

Looking at the complexity of water flows in industries, detailed water data could potentially refine the analyses from volumes to water values. Economic assessments would be able to identify the water values to upstream and downstream users, as well as the opportunity costs of water in various production activities. Considering solely total water withdrawal or supply limits the understanding of the real utilization and value of water within the production processes. The available industrial water databases, however, show insufficient evidence of water consumption and discharges and often report industries as an aggregation of various industrial sectors altogether. Moreover, as there are insufficient policy enforcements to regulate water, industries mostly capture water by their own structural means. Therefore, prices are often non-existent.

From a political science perspective, Berg (2020) provided an extensive analysis of data that is used to support policy action. He asserted that improving data quality is crucial as reliable information could help policymakers and analysts to potentially avoid inefficient investments and inadequate operational incentives. Reliability here means that decision makers are informed about the whole process of data collection, communication, and storage. Enhancing data reliability strengthens the collaboration of private and public initiatives involved in water utility management, but also supports the development of key performance indicators and benchmarking to regulate operations in developing nations.

Nevertheless, acquiring water data from low-income countries is challenging due to several reasons: records and registers might have been destroyed during conflicts; data might be stored in "information silos" and in a hard way to access; collecting and cataloging water data might not be a priority when compared to other public services; low human resources to improve data reporting into information systems; and management boards might avoid transparency to conceal operational disruptions and corruption (Berg 2020). These reasons suggest that the lack of data is both a financial problem to establish a systematic structure of data collection and reporting and also an intentional way to avoid transparency and, therefore, maintaining corruption, and the gains of those who benefit from investment in the water sector (Berg 2020). In fact, the lack of data does not incentivize policymakers to improve inefficient utilities as society is not informed about the problems and inadequate practices (Berg 2007).

A way to respond to this problem would be establishing data collection and reporting procedures as a condition to obtain investment funds from development agencies, governments, and other funding initiatives in general (Berg 2020). Systematic data collection enables benchmarking strategies, which are instruments to compare the performance of water utilities and indicators at the local level and across nations over years (Berg 2007). In regions with limited technical resources, training community-based organizations to collect water data represents an alternative to monitoring water utilities and resource management (Berg 2020). A good practice would be providing data to a central operation that is able to analyze the data content and sources, in a way to enhance data accuracy (Berg 2020).

Improving the procedures to collect and report water data, or even successfully applying the above-mentioned suggestions, is unlikely to be implemented in the near future. Yet, reliable data are key to understand and interpret limited information about water availability and use. Definitions of water categories are essential when assessing the consistency and comparing data from various sources. Following from that, our study selects two important water categories (consumption and withdrawal) and investigates the data treatment in terms of definitions and data reporting. For that, we analyze the scientific literature and global and national databases. Despite structural and conceptual differences in the datasets, the exchange of data is common among international and global databases. In fact, they mostly rely on national statistics to acquire data. The definitions of different water categories provided in previous sections indicate that comparing, or even combining, various water accounts is difficult and often misleading. The definitions of water categories are diverse, regarding either how numbers are composed of or what they represent. Given the differences in definitions, there is no evidence of data harmonization among international and global databases.

Harmonization supports interpretation, access, monitoring, and reporting of data (Porter *et al.* 2014). Collaborative research initiatives for model harmonization have allowed comparing and improving biophysical and economic models to assess food security, hunger, and food price volatility (Porter *et al.* 2014). Additionally, Fuchs *et al.* (2013) harmonized various data sources to develop accurate historical land change data in Europe. Following such initiatives unfolds the potential for water modelers to likewise develop water data harmonization. Water economic research relies on data for different productive sectors at the local and global levels. The absence of data is a reality. Moreover, the state of the arts of water databases suggest that there is little consistency in defining water categories, and various methods for data collection trigger uncertainty when comparing data. Such issues call for policy enforcements to improve data collection at the national level, and possibly together with national statistical agencies. Nevertheless, implementing water data collection depends on political efforts particularly from sovereign estates. Such endeavor is not likely to be met in the short or medium run. Alternatively, joining efforts of modelers to develop meaningful ways of dealing with water data problems would facilitate data interpretation and collaboration of institutions worldwide.

This study provides a list of global and national water databases, their reporting structure, definitions, and organizations responsible for data management. We show that data are treated differently across databases, and that even in the pre-selected countries, lack of data is evident and low-income nations are under-represented. Nevertheless, this paper can be potentially used as a "starting point" to initiate water reporting in places where water statistic system is still missing. Moreover, throughout the paper we discuss essential aspects to bear in mind when communicating water data.

Meanwhile, databases undergo ongoing improvements of water data especially to estimate missing values. However, when using and comparing the currently available water data, it is key to critically analyze what each number actually represents, understand to which level data are comparable, and think carefully about how they can be used to estimate reliable results.

6. Conclusion

Following the knowledge gap often pointed out in the water literature and the difficulties of acquiring water data to support studies in various fields, we assess the state of the arts of water databases at global, international, and national levels. This paper distills important information regarding water data availability across regions, and presents the structure of databases as well as data compositions and definitions. We address the importance of clarifying water definitions, and promoting a concise report and monitoring, especially when employing the currently available data for policy and research assessments. The overall conclusion is that there are considerable inconsistencies of available data, which hamper comparison across databases.

In times where water is present in many political debates, evaluating the global interplay of water resources and scarcity requires refined water models, which in turn rely on water data. In the long run, headway of water research and political assessments depend on political enforcements to refine the meaningfulness of water data and support water collection, reporting, and monitoring. However, lack of data transparency and weak governmental enforcement to establish water utility monitoring may also be intentional due to economic interest of those controlling water resources. Alternatively, in the short- and medium-run, water data challenges can be addressed by joint research efforts for water data harmonization. Following from that, developing model comparison exercises would not only contribute to international research cooperation, but also improve communication about water issues internationally and among policymakers, refine evaluation of uncertainties, improve integration of assessments, compare water models, and support the implementation of policy relevant to water issues.

It is unrealistic to expect that the goals of improving data harmonization, collection, and even definitions will be met in the near future. However, this paper contributes to raising awareness in the scientific community on the need to improve water reporting and diminish the knowledge gap, and further investigate the potentials to improve water data reporting. Moreover, our study cautions researchers to be careful when manipulating and comparing the available water data. Especially when deriving policy recommendations or economic conclusions based on the *status quo* databases, the use of the data requires a critical analysis of what data actually represent and how they can be translated into realistic findings.

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