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Match words with deeds: Curbing water risk with the Sustainable Development Goal 6 index

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A R T I C L E I N F O

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A B S T R A C T

Since the 2030 Agenda for Sustainable Development being unanimously endorsed worldwide in 2015, how to achieve sustainable water security in accordance with Sustainable Development Goal (SDG) 6 targets has become a new measure of curbing water risk. In this study, the composite SDG 6 index ($SDG6_I$) was developed exclusively on the basis of the SDG 6 targets for the first time. The seven SDG indicators covering five outcome-based targets were selected to systematically portray diverse water challenges (drinking water, sanitation and hygiene, wastewater treatment, water productivity, water stress, water resources management, and transboundary cooperation) for integrated water risk assessment. A quantitative spatial analysis was conducted to reveal the global implementation baseline of the SDG 6 indicators and subsequently the $SDG6_I$ by 232 countries and territories where the SDG 6 dimensions (water accessibility, water quality, water availability, and water governance) have taken the lead and fallen behind in development. First, most countries are on track to achieve universal water accessibility by 2030, yet African countries in general need to strengthen the implementation capacity of service coverage. Second, mostly only countries in Australia and New Zealand as well as Europe and Northern America are on track to achieve the targets of water quality and water availability. Third, water governance confronts the prominent challenges, both in water resources management and transboundary cooperation globally. Curbing water risk entails adequate policy measures. These measures— such as promoting socioeconomic development, improving policy effectiveness, and fostering multi-level governance and collaboration—need to be designed and implemented through nexus thinking to deliver sustainable water security.

1. Introduction

In September 2015 in New York, USA, a new era commenced (United Nations, 2015). The 2030 Agenda for Sustainable Development (the 2030 Agenda), unanimously endorsed by all 193 United Nations (UN) Member States, features an integrated and indivisible global framework comprising 17 Sustainable Development Goals (SDGs) and 169 targets to tackle social, economic, and environmental challenges in the realm of sustainable development (United Nations, 2018). Being one of the three key cornerstones of sustainability, the environment is embedded in over half of the SDGs that address sustainable use and management of natural resources (United Nations Environment Programme, 2019b). In particular, freshwater resources in sufficient quantity and quality are of utmost importance (Niva et al., 2020). The establishment of SDG 6—*Ensure availability and sustainable management of water and sanitation for all*—articulates the augmented concerns not only for sustainable water security issues in the global political program (United Nations, 2018) but also their corresponding impacts across the 2030 Agenda, due to the interlinkages and interdependencies between SDG 6 and other SDGs (Taka et al., 2021). Just like Yin and Yang, a theory of dualism in ancient Chinese philosophy, water risk and water security are intertwined—as water risk increases, water security decreases (Zhao et al., 2017). Therefore, how to achieve sustainable water security in accordance with SDG 6 targets becomes a new measure of curbing water risk.

On a par with the view seen through a kaleidoscope, the concept of water risk is multidimensional and multifaceted (Liu and Zhao, 2020). It underpins the subjectivity of an actor (either an individual or an entity, i.e., each sector of society and the organizations within them) regarding the likelihood and to what extent various water-related challenges are experienced by the actors (UN Global Compact's CEO Water Mandate, 2014). These water challenges encompass critical issues for water accessibility, water quality, water availability, water governance, natural disasters (flood and drought), and climate change (Bonnafous et al., 2017). The extent is determined by the severity of the challenge's effect, which depends on the intensity of the challenge and the vulnerability of

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Nomenclature

CEWP	China Europe Water Platform
CI	composite index
EE	enabling environment
EU	European Union
F	financing
GDP_t^{2010}	total gross domestic product (constant 2010 US dollars)
GEO-6	the sixth Global Environment Outlook
HD	human development
HDI	Human Development Index
I_{611}	indicator 6.1.1
I_{621}	indicator 6.2.1
I_{631}	indicator 6.3.1
I_{641}	indicator 6.4.1
I_{642}	indicator 6.4.2
I_{651}	indicator 6.5.1
I_{652}	indicator 6.5.2
IP	institutions and participation
ISIC	International Standard Industrial Classification
IWRM	integrated water resources management
MDG	Millennium Development Goal
MI	management instruments
N	number of transboundary river basins in a country
P_{DW}	population using safely managed drinking water services
P_S	population using safely managed sanitation services
P_t	total population
RCS	River Chief system
SDG	Sustainable Development Goal
$SDG6_I$	Sustainable Development Goal 6 index
TC_i	level of transboundary cooperation for transboundary river basin i
TRB	transboundary river basin
TWAP-RB	Transboundary Waters Assessment Programme - River Basins Assessment
UN	United Nations
WA_t	total renewable water availability
WP	water productivity
WS	water stress
WW_{ST}^{hh}	amount of safely treated household wastewater
WW_t^{hh}	total amount of household wastewater
WWD_t	total water withdrawals by all economic activities
WWI	water withdrawal intensity

the actor (UN Global Compact's CEO Water Mandate, 2014).

Extant studies to date have largely focused on one specific water challenge for water risk assessment. Fukuda et al. (2019) explored how the Millennium Development Goal (MDG) targets for drinking water were formulated and achieved. Müller et al. (2020) developed a framework conceptually integrating risk assessment of water scarcity and sustainability assessment of water reuse for risk reduction. Graham et al. (2020) estimated future changes of virtual water trading in the regions that suffer water stress. Skuras and Tyllianakis (2018) investigated the factors influencing the public's risk perceptions of water quality. Zhou et al. (2018) scrutinized the role of water governance in high water-risk enterprises through the lens of water information disclosure. Zhao et al. (2019) analyzed how climate change may affect the global economy by decreasing water availability in some regions. As one of the very few exceptions, Schaefer et al. (2019) constructed a supply-chain water risk index by taking into account the physical water risks (water stress, seasonal variability, and drought severity) and amplifying water risks (external dependency ratio, governance and regulation, and infrastructure).

Nonetheless, the complexity of water risk has been fundamentally underacknowledged, resulting in an incomplete picture that portrays more integrated and systematic assessment approaches to water risk. SDG 6 is accompanied by eight targets, of which targets 6.1–6.6 are built upon outcomes and targets 6. a–6. b refer to the means of implementation (Requejo-Castro et al., 2020). These six outcome-based targets embody a broad spectrum of water risk, including water accessibility (targets 6.1 and 6.2), water quality (targets 6.3 and 6.6), water availability (targets 6.4 and 6.6), and water governance (target 6.5). In this regard, sound operationalization of SDG 6 through a composite index (CI) approach is tailored to the need for examining the complexity of water risk.

The CI approach that incorporates a sufficient number of indicators is essential use for SDG policymaking and benchmarking (Del Río Castro et al., 2021). Its framework consists of (1) formulating appropriate indicators for each target (Barbier and Burgess, 2019); (2) attaining accessible, timely, and reliable data (United Nations, 2015); and (3) designing an index that facilitates the interpretation of indicators as a single measure (Kynčlová et al., 2020). The CI approach thereby signifies the foundation of monitoring progress towards the SDGs at the local, national, regional, and global scales; this allows policymakers to evaluate the baseline and changes in indicator performance (Requejo-Castro et al., 2020). A growing body of literature has attested its prime applicability to quantitative SDG assessment, such as (1) index construction for a single SDG (e.g., SDG 9 index (Kynčlová et al., 2020)) or all SDGs (e.g., locally and nationally (Wang et al., 2020), regionally (Guijarro and Poyatos, 2018), and globally (Sachs et al., 2018)); and (2) mapping synergies and trade-offs between a single SDG (e.g., SDG 6 (Requejo-Castro et al., 2020) and SDG 7 (Fuso Nerini et al., 2018)) and all SDGs or interactions among the SDGs (Pradhan et al., 2017; Fonseca et al., 2020). Yet such employment of the CI approach in SDG 6 assessment apropos of curbing water risk is hitherto what present studies have lacked.

Consequently, the aim of this study is to develop a composite SDG 6 index ($SDG6_I$) as a tool for empowering adequate policy measures towards the delivery of sustainable water security throughout the world. To bridge this knowledge gap, a quantitative spatial analysis was conducted to explore the global implementation baseline of the SDG 6 indicators and subsequently the $SDG6_I$ by country. This is the first study to integratedly and systematically assess water risk by a composite index exclusively built upon the SDG 6 targets and their indicators. The specific objectives are to (1) construct a composite $SDG6_I$, including conceptual framework development, indicator selection and formulation based on data availability, and index weighting and aggregation; (2) examine the country-level baseline of the indicators' implementation and their contributions to the $SDG6_I$, revealing which SDG 6 dimensions (water accessibility, water quality, water availability, and water governance) of countries have taken the lead and fallen behind; and (3) investigate what policy measures are adequate to curb water risk.

2. Materials and methods

2.1. Conceptual framework

An intuitive solution for constructing a composite index to monitor the progress of countries towards achieving sustainable water security is using indicators that are assigned to tracking the SDG 6 targets (Kynčlová et al., 2020). There are 11 official SDG 6 indicators in the global indicator framework that were developed by the Inter-Agency and Expert Group on SDG Indicators and adopted by the UN General Assembly (United Nations Statistics Division, 2017). These indicators all have well-established definitions and integrated monitoring methodologies (UN Water, 2016), but data is not available for all indicators or in all UN Member States (United Nations Environment Programme, 2019b). The $SDG6_I$ was developed by seven modified SDG 6 indicators, which covers five outcome-based targets and ensures data availability in the majority of countries worldwide (**Table 1**). The modification made in this study is a refinement of the indicator formulation to fill the data vacuum (Del Río Castro et al., 2021). A detailed rationale for these indicators can be found in the following section. Furthermore, the implementation baseline of the indicators was assessed at a starting point, including (but not limited to) the year 2015, which leads to a comprehensive picture going beyond the results from UN's synthesis report on SDG 6 (United Nations, 2018).

2.2. Indicators

2.2.1. Indicator 6.1.1 - drinking water

Indicator 6.1.1 is the solo indicator representing SDG target 6.1 (United Nations, 2018; **Table 1**). It is adopted from UN MDG target 7. C (*Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation*) (United Nations, 2020). By 2015, 2.6 billion people around the world gained access to improved drinking water sources (United Nations, 2020). Indicator 6.1.1 is presented as

$$I_{611} = \frac{P_{DW}}{P_t} \times 100 \tag{1}$$

where I_{611} is Indicator 6.1.1 (%), P_{DW} is population using safely managed drinking water services, and P_t is total population.

2.2.2. Indicator 6.2.1 - sanitation and hygiene

Indicator 6.2.1 is the solo indicator demonstrating SDG target 6.2 (United Nations, 2018; **Table 1**). It is also built upon UN MDG target 7. C (United Nations, 2020). By 2015, there were globally 2.4 billion people still using unimproved sanitation facilities, including 946 million practicing open defecation, despite the progress of 2.1 billion people gaining access to improved sanitation (United Nations, 2020). The equation of Indicator 6.2.1 is expressed as

$$I_{621} = \frac{P_S}{P_t} \times 100 \tag{2}$$

where I_{621} is Indicator 6.2.1 (%), and P_S is population using safely managed sanitation services.

2.2.3. Indicator 6.3.1 - wastewater treatment

Indicator 6.3.1 is one of two indicators developed for SDG target 6.3 (United Nations, 2018; **Table 1**), yet the solo indicator used in this study, owing to the unavailability of data on water quality (the another indicator). In accordance with United Nations (2018), the definition of Indicator 6.3.1 is the percentage of wastewater generated by households (sewage and fecal sludge) and economic activities (based on International Standard Industrial Classification (ISIC) categories) that is safely treated. However, data on safely treated agricultural and industrial wastewater is still not well-documented across the globe (United Nations, 2018). Therefore, Indicator 6.3.1 was correspondingly modified for this study and is presented as

$$I_{631} = \frac{WW_{ST}^{hh}}{WW_t^{hh}} \times 100 \tag{3}$$

where I_{631} is Indicator 6.3.1 (%), WW_{ST}^{hh} is the amount of safely treated household wastewater, and WW_t^{hh} is the total amount of household wastewater.

2.2.4. Indicator 6.4.1 - water productivity

Indicator 6.4.1 is one of two indicators representing SDG target 6.4 (United Nations, 2018; **Table 1**). It is defined as the change in water use efficiency (water productivity) over time (United Nations, 2018). The term "water productivity" instead of "water use efficiency" was applied in spite of these two terms having an identical definition in this study. This was to differentiate it from the definition of water use efficiency commonly used for irrigation (Cai et al., 2017). In preference to assessing changes over time, the level of water productivity was investigated here because neither absolute nor relative changes can reflect the baseline level of water productivity (United Nations Environment Programme, 2019b). For instance, Country A had 80% increases with a 10 baseline value, while Country B had 10% increases with an 80 baseline value. This does not mean that Country A had a much greater level of water productivity than Country B. So the equation of Indicator 6.4.1 is expressed as

$$\begin{cases} I_{641} = 100 (WP \geq 40) \\ I_{641} = 100 - \dfrac{40 - WP}{40} (WP < 40) \end{cases} \tag{4}$$

where I_{641} is Indicator 6.4.1 (%), 40 is the value of global average water productivity (US dollars/m^3) (Cai et al., 2017), and WP is water productivity, as

$$WP = \frac{GDP_t^{2010}}{WWD_t} \tag{5}$$

where GDP_t^{2010} is the total gross domestic product (constant 2010 US dollars), and WWD_t is the total water withdrawals by all economic activities.

2.2.5. Indicator 6.4.2 - water stress

Indicator 6.4.2 is the other indicator demonstrating SDG target 6.4 (United Nations, 2018; **Table 1**). According to its definition (ratio between total water withdrawn by all economic activities and total renewable water resources, after taking into account environmental water requirements) (United Nations, 2018), scaling is required to allow the values within the range between 0 and 100% in ascending order, which is in line with other indicators for aggregating the index. Indicator 6.4.2 is thus presented as

$$\begin{cases} I_{642} = 100 - 100 \times WS (WS < 1) \\ I_{642} = 0 (WS \geq 1) \end{cases} \tag{6}$$

where I_{642} is Indicator 6.4.2 (%), and WS is water stress, as

$$WS = \frac{WWD_t}{WA_t - WWI} \tag{7}$$

where WA_t is total renewable water availability, and WWI is water withdrawal intensity (environmental water requirements).

2.2.6. Indicator 6.5.1 - water resources management

Indicator 6.5.1 is one of two indicators developed for SDG target 6.5 (United Nations, 2018; **Table 1**). This indicator is collected through a survey instrument containing 33 questions across four key components of integrated water resources management (IWRM), namely enabling environment, institutions and participation, management instruments, and financing (UNEP-DHI Centre on Water and Environment, 2020a). Thereby, the equation of Indicator 6.5.1 is expressed as

$$I_{651} = \frac{EE + IP + MI + F}{4} \tag{8}$$

where I_{651} is Indicator 6.5.1, EE is enabling environment, IP is institutions and participation; MI is management instruments, and F is financing.

Table 1
Indicator framework of Sustainable Development Goal 6 Index.

Goal	Target	Indicator	Definition	Unit	Scaling	Source
6. Ensure availability and sustainable management of water and sanitation for all	6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services	Population using an improved drinking water source (piped water into dwellings, yards or plots; public taps or standpipes; boreholes or tubewells; protected dug wells; or protected springs and rainwater) that is located on premises and available when needed and which is free of fecal and priority chemical contamination.	%	No	WHO/UNIEF (2020)
	6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2.1 Proportion of population using safely managed sanitation services	Population using an improved sanitation facility at the household level that is not shared with other households and where excreta is safely disposed of in situ or treated off site, including a handwashing facility with soap and water in the household. Improved sanitation facilities include flush or pour flush toilets to sewerage systems, septic tanks or pit latrines, improved pit latrines (pit latrines with a slab or ventilated pit latrines), and composting toilets. A handwashing facility is a device to contain, transport, or regulate the flow of water to facilitate handwashing.	%	No	WHO/UNIEF (2020)
	6.3 By 2030, improve water quality by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials, halving the proportion of untreated waste water and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of safely treated household wastewater	Percentage of wastewater generated by households (sewage and fecal sludge) that is safely treated.	%	No	WHO/UNIEF (2020)
	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Level of water productivity	Output from a given economic activity (based on International Standard Industrial Classification (ISIC) categories), per volume of net water withdrawn by the economic activity. This indicator includes water use by all economic activities, focusing on agriculture (excluding the portion generated by rain-fed agriculture), manufacturing, electricity, and water collection, treatment, and supply (looking at distribution efficiency and capturing network leakages). By assessing the level of water productivity, the gap between water productivity and the defined global average is examined.	%	No	(FAO, 2016; World Bank, 2020)
		6.4.2 Level of water stress	Ratio between total freshwater withdrawn by all economic activities (based on ISIC categories) and total renewable freshwater resources, after taking into account environmental water requirements (also known as water withdrawal intensity). This indicator includes water withdrawals by all economic activities, focusing on agriculture, manufacturing, electricity, as well as water collection, treatment, and supply.	%	Yes	FAO (2016)
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation	The degree to which integrated water resources management (IWRM) is implemented, by assessing the four components of policies, institutions, management tools, and financing. It takes into account the various users and uses of water, with the aim of promoting positive social, economic and environmental impacts at all levels, including the sub-national and transboundary levels where appropriate.	0–100	No	UNEP-DHI Centre on Water and Environment (2020a)

(*continued on next page*)

Table 1 (*continued*)

Goal	Target	Indicator	Definition	Unit	Scaling	Source
		6.5.2 Level of transboundary cooperation	The degree to which extent of transboundary river basin within a country that has an operational agreement or other arrangement for water cooperation is implemented. For the purpose of the indicator, an "arrangement for water cooperation" is a bilateral or multilateral treaty, convention, agreement, or other formal arrangement among riparian countries that provides a framework for cooperation on transboundary water management. The criteria for the arrangement to be considered "operational" are based on key aspects of substantive cooperation in water management, such as the existence of institutional mechanisms, regular communication among riparian countries, joint or coordinated management plans or objectives, and a regular exchange of data and information. By assessing the level of transboundary cooperation, the degree of each transboundary river basin within a country is aggregated.	%	No	UNEP-DHI Centre on Water and Environment (2020b)

2.2.7. *Indicator 6.5.2 - transboundary cooperation*

Indicator 6.5.2 is the other indicator representing SDG target 6.5 (United Nations, 2018; **Table 1**). Globally there are 286 transboundary river basins (TRBs) (UNEP-DHI Centre on Water and Environment, 2020b), yet it is worth noting that this indicator is only applied in the country that has at least one TRB. In accordance with United Nations (2018), the definition of Indicator 6.5.2 is the percentage of transboundary basin area within a country that has implemented an operational agreement or other arrangement for water cooperation that aims to qualify transboundary cooperation. However, this study moved forward to explore how to quantify the level of transboundary cooperation. The Transboundary Waters Assessment Programme - River Basins Assessment (TWAP-RB) Data Portal assigned a score of 1–5 to each TRB to indicate its level of transboundary cooperation (from best to worst) (UNEP-DHI Centre on Water and Environment, 2020b). Being in alignment with both the indicator definition and the purpose for aggregating the index, the TWAP-RB score system was modified to range from 100% to 0%, i.e., 100% = 1, 75% = 2, 50% = 3, 25% = 4, and 0% = 5. Hence, Indicator 6.5.2 is presented as

$$I_{652} = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} TC_i \quad (9)$$

where I_{652} is Indicator 6.5.2 (%), N is the number of TRB in a country, and TC_i is the level of transboundary cooperation for TRB i.

2.3. *Sustainable Development Goal 6 index*

To arrive at a composite SDG6$_\mathrm{I}$, the constituent components are required to be weighted and aggregated (Sachs et al., 2018). To underscore the policymakers' commitment to treat all SDG 6 targets equally in an integrated and indivisible manner (Sachs et al., 2018), fixed equal weights were assigned among different indicators in the same target (component) category as well as among different targets (components) (Cai et al., 2017). This also implies that it is of vital importance and a necessity for countries to take all targets into account, particularly where incremental progress might be expected to be either fastest or slowest with regard to improving their SDG6$_\mathrm{I}$ scores (Sachs et al., 2018). Moreover, Sachs et al. (2018) considered all three options (i.e., arithmetic mean, geometric average, and Leontief function) for aggregating the SDG index and found that the arithmetic mean method has the advantage of easing interpretation, with an index score between 0 and 100 indicating the average initial placement of a country between worst and best on the average of either a single SDG or multiple SDGs. Consequently, the SDG6$_\mathrm{I}$ was quantified as

$$SDG6_I = \frac{I_{611} + I_{621} + I_{631} + \frac{I_{641}+I_{642}}{2} + \frac{I_{651}+I_{652}}{2}}{5} \quad (10)$$

According to Sachs et al. (2018) and UNEP-DHI Centre on Water and Environment (2020a), the SDG6$_\mathrm{I}$ score was classified into the six following categories:

(1) Very high (90[, 100]): The vast majority of indicators fully implemented and targets consistently achieved;
(2) High (70[, 90]): Indicators generally implemented and targets generally achieved;
(3) Medium-high (50[, 70]): Capacity to implement indicators generally adequate;
(4) Medium-low (30[, 50]): Implementation of indicators underway;
(5) Low (10[, 30]): Implementation of some indicators begun; and
(6) Very low ([0, 10]): Implementation of indicators generally not begun.

2.4. *Spatial analysis*

The spatial analysis was conducted by 232 countries and territories worldwide on the basis of global databases used in this study (**Table 1**). To facilitate interpretation, these countries and territories were categorized into eight SDG regions as follows (United Nations, 2018; **Fig. S1**; **Table S1**):

(1) Australia and New Zealand: 2;
(2) Central and Southern Asia: 14;
(3) Eastern and Southeastern Asia: 18;
(4) Oceania: 21;
(5) Northern Africa and Western Asia: 25;
(6) Latin America and the Caribbean: 48;
(7) Sub-Saharan Africa: 51; and
(8) Europe and Northern America: 53.

3. Results

3.1. Indicator profiles

3.1.1. Water accessibility

Thanks to the substantial achievement of the aforementioned MDG, the global average I_{611} baseline reached 85.7%, which was the greatest among all the indicators and showed the high implementation level of safely managed drinking water services around the world (Fig. 1). However, there was a spatial disparity between countries and territories, as their I_{611} values ranged from 9.2% (very low) to 100% (very high) (Fig. 1; Table S2). From a regional perspective, Australia and New Zealand (99.6%, very high), Europe and North America (94.2%, very high), and Latin America and the Caribbean (91.6%, very high) took the lead, followed by Northern Africa and Western Asia (88.1%, high) and Oceania (86.1%, high) above the global average, while Eastern and Southeastern Asia (83.3%, high), Central and Southern Asia (75.3%, high), and Sub-Saharan Africa (73.4%, high) stayed at the bottom (Fig. S1; Fig. S2a).

With the aid of the effective MDG progress, the average I_{621} baseline worldwide was 73.8%, which indicated the high implementation level of safely managed sanitation services globally (Fig. 2). Similar to I_{611}, a huge difference among countries and territories was unveiled, owing to their I_{621} values varying between 12.8% (low) and 100% (very high) (Fig. 2; Table S3). Looking through the lens of SDG regions, Sub-Saharan Africa (51.5%, medium-high) and North Africa and Western Asia (62.9%, medium-high) fell behind the global average, whereas target 6.2 was generally achieved in the rest of the regions, i.e., Central and Southern Asia (75.5%, high), Eastern and Southeastern Asia (80.4%, high), Australia and New Zealand (80.7%, high), Latin America and the Caribbean (83.9%, high), and Europe and North America (84.9%, high) (Fig. S1, Fig. S2b).

3.1.2. Water quality

Vis-à-vis other indicators, I_{631} had the most difficulty with data availability (Fig. 3; Table S4). Despite this fact, the distinct spatial heterogeneity by country and territory was still detected (Fig. 3; Table S4). With a value of 50.8%, the global average I_{631} baseline narrowly surpassed the threshold of the medium-low category and landed at the medium-high implementation level of safely treated household wastewater (Fig. 3). Among these eight regions, Australia and New Zealand (76.7%, high) and Europe and North America (72.6%; high) held a solid basis in the global average, and Eastern and Southeastern Asia also contributed (57.7%, medium-high) (Fig. S1; Fig. S2c). However, the others were struggling with the indicator implementation, such as Northern Africa and Western Asia (49.1%, medium-low), Oceania (33.9%, medium-low), Latin America and the Caribbean (26.5%, low), and Central and Southern Asia (18.3%, low). Sub-Saharan Africa generally did not start the implementation (3%, very low) (Fig. S1; Fig. S2c).

3.1.3. Water availability

On a global scale, the average I_{641} baseline (51.6%) hit the medium-high implementation level of water productivity by a very small margin (Fig. 4). It was rooted in the polarization of the indicator implementation across countries and territories (Fig. 4; Table S5). When taking a close look at SDG regions, Central and Southern Asia (13.3%, low) just started to tackle water productivity, while Australia and New Zealand (85.2%, high) and Europe and Northern America (80.4%, high) were at the forefront of improving water productivity (Fig. S1; Fig. S2d). Around the global average, there were Oceania (52.8%, medium-high), Sub-Saharan Africa (48.5%, medium-low), and Northern Africa and Western Asia (47.9%, medium-low) (Fig. S1; Fig. S2d). Implementation was progressing in Latin America and the Caribbean (13.3%, low), along with Eastern and Southeastern Asia (35.2%; medium-low) (Fig. S1; Fig. S2d).

Because I_{642} requires scaling for aggregating the index, the $SDG6_I$ score categories were not applicable to its interpretation of water stress levels. In accordance with Vörösmarty et al. (2005), the range of I_{642} values was divided as follows: (1) 90%[, 100%]: low level of water stress or no water stress at 100%; (2) 80%[, 90%]: medium-low level of water stress; (3) [60%, 80%]: medium-high level of water stress; and (4) <60%: high level of water stress. Globally, the average I_{642} baseline attained 74.0%, which denoted the medium-high level of water stress (Fig. 5). At the regional scale, the evident spatial characteristics of I_{642} were found (Fig. 5; Fig. S1; Table S6). Australia and New Zealand (92.8%, low) had the best baseline, followed by Sub-Saharan Africa (89.8%, medium-low), Europe and Northern America (84.7%, medium-low), and Latin America and the Caribbean (82.7%, medium-low) (Fig. S1; Fig. S2e). Oceania (77.9%, medium-high) and

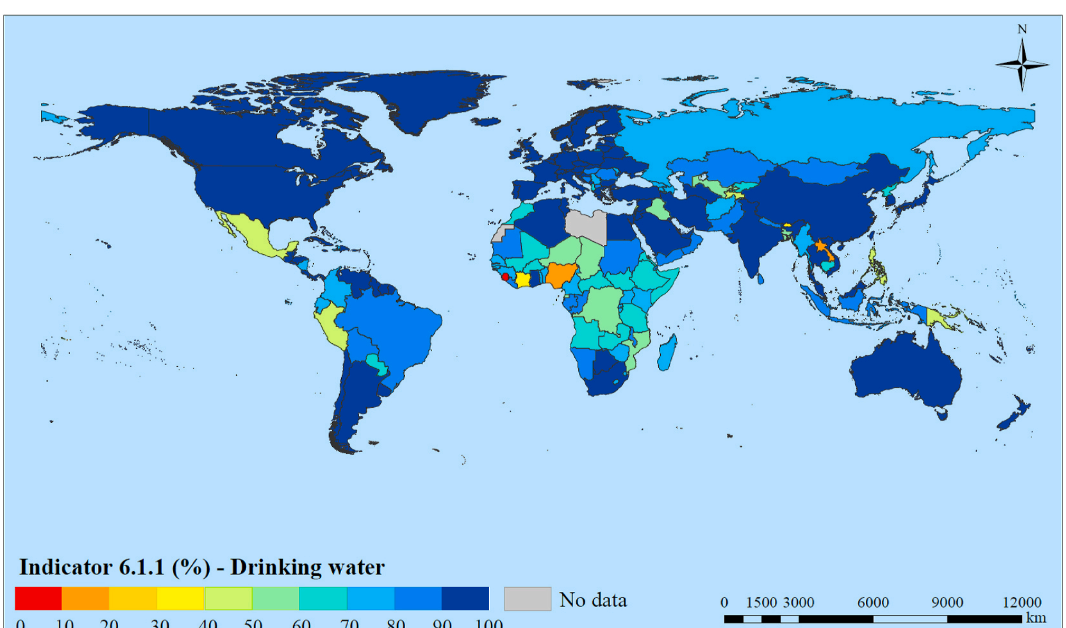

Fig. 1. Global baseline of Indicator 6.1.1 by country and territory.

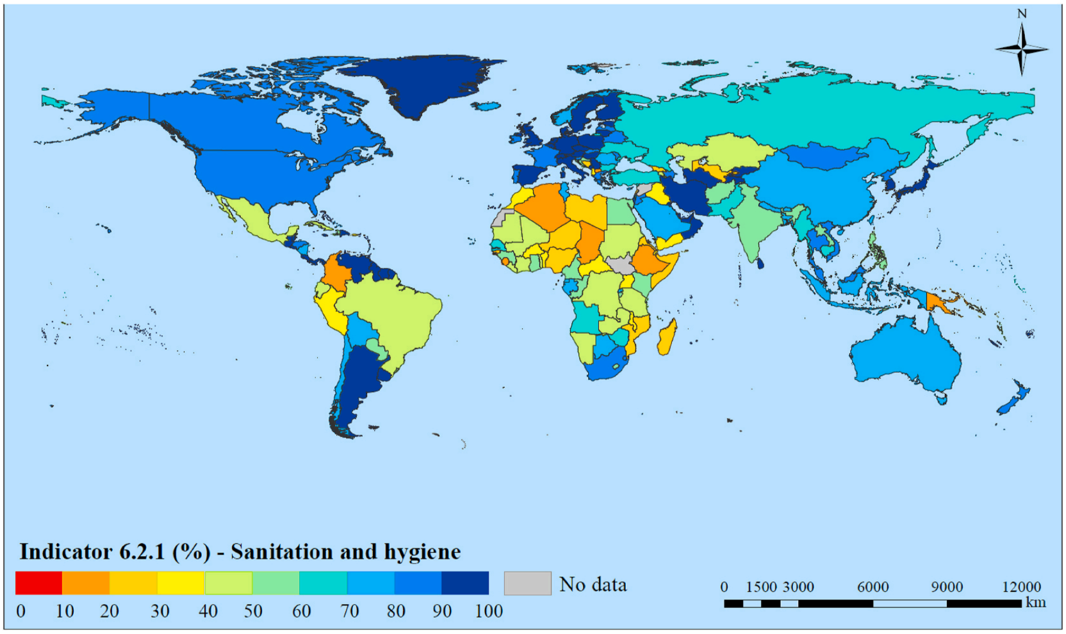

Fig. 2. Global baseline of Indicator 6.2.1 by country and territory.

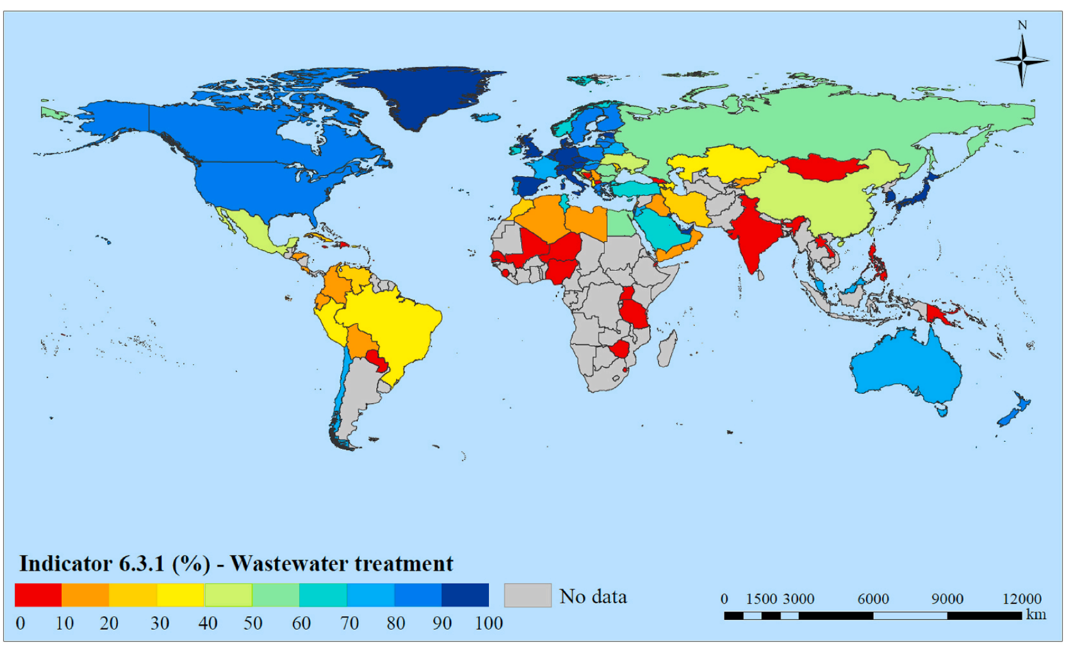

Fig. 3. Global baseline of Indicator 6.3.1 by country and territory.

Eastern and Southeastern Asia (71.7%, medium-high) were around the global average (Fig. S1; Fig. S2e). The high level of water stress was spotted in both Central and Southern Asia (44.3%) and Northern Africa and Western Asia (24.3%) (Fig. S1; Fig. S2e).

3.1.4. Water governance

Globally, the average I_{651} baseline (49.2%) was at the medium-low implementation level of IWRM, with a pronounced spatial diversity in the indicator in countries and territories (Fig. 6; Table S7). Zooming in on eight regions, half of them, including Latin America and the Caribbean (34.5%, medium-low), Central and Southern Asia (37.1%, medium-low), Oceania (38.5%, medium-low), and Sub-Saharan Africa (40.6%, medium-low) were at the global average (Fig. S1; Fig. S2f). As for to the other half, Europe and Northern America (67.4%, medium-high), Northern Africa and Western Asia (54.8%, medium-high), and Eastern and Southeastern Asia (52.7%, medium-high) had a generally adequate capacity of implementation, whereas Australia and New Zealand achieved a great score (72.0%, high) (Fig. S1; Fig. S2f).

The uniqueness of I_{652} lies in its applicability to countries and territories with at least one TRB. In this sense, some countries and territories by default do not have any data of this indicator (such as Australia and New Zealand). The global average I_{652} baseline was the poorest, with a value of 36.6%, which showed the medium-low implementation level of transboundary cooperation (Fig. 7). Since the I_{652} values by country and territory ranged from 0 (very low) to 100% (very high), the manifest spatial variety was disclosed (Fig. 7; Table S8). Except for Europe and Northern America (54.9%, medium-high) playing a leading role in the global average, the majority of regions—namely Central and

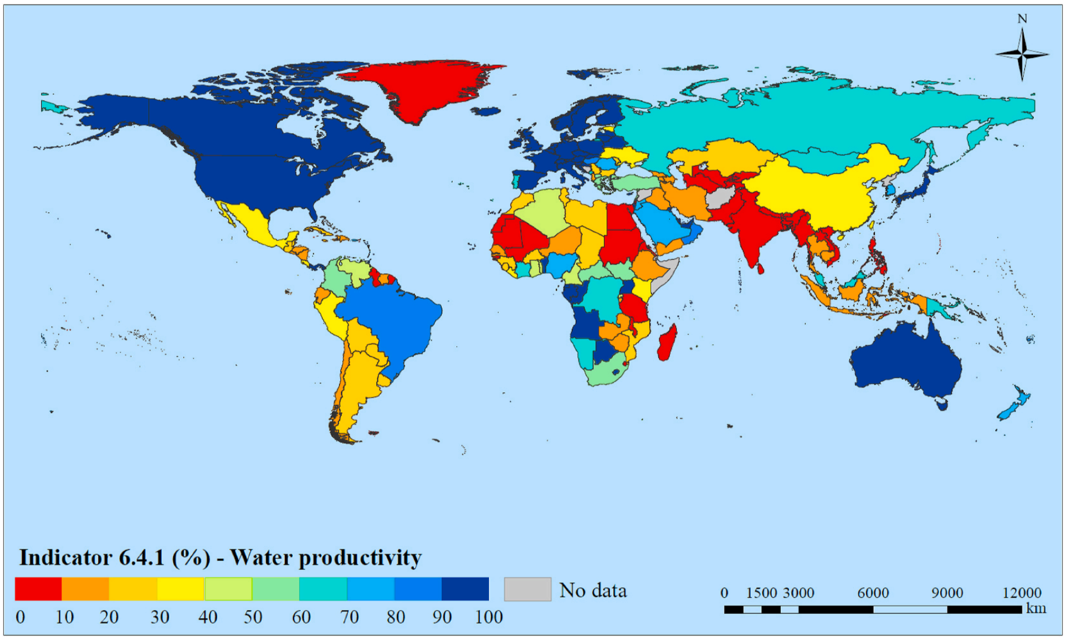

Fig. 4. Global baseline of Indicator 6.4.1 by country and territory.

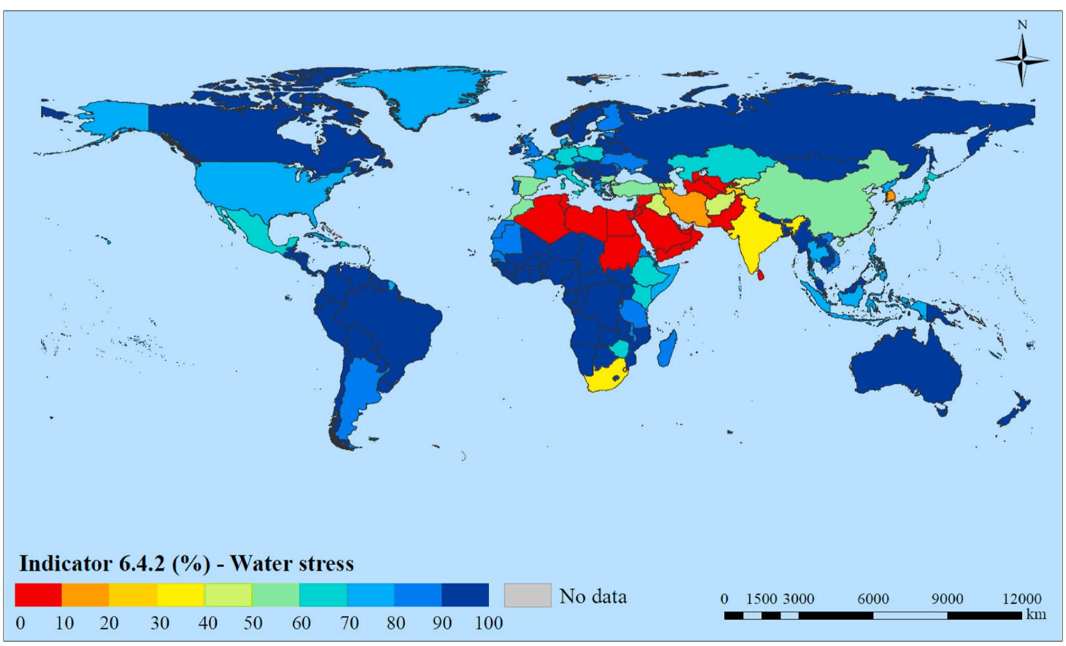

Fig. 5. Global baseline of Indicator 6.4.2 by country and territory.

Southern Asia (40.7%), Sub-Saharan Africa (36.3%), Northern Africa and Western Asia (35.7%), and Oceania (32.0%)—were placed in the medium-low category (**Fig. S1**; **Fig. S2g**). However, the implementation was merely launched in Latin America and the Caribbean (24.0%, low) and in Eastern and Southeastern Asia (13.7%, low) (**Fig. S1**; **Fig. S2g**).

3.2. Index profile

Based on the results of these seven indicators, the SDG6$_I$ scores by country and territory were attained worldwide (**Fig. 8**; **Table S9**). The global average SDG6$_I$ baseline reached 65.7 (medium-high), which indicated that countries and territories generally had adequate capacity to implement SDG 6 indicators (**Fig. 8**). However, the SDG6$_I$ score varied drastically from country (territory) to country (territory) (**Fig. 8**; **Table S9**). For the regions above the global average, Australia and New Zealand (83.6), Europe and Northern America (79.8), and Oceania (71.1) had the high implementation level of SDG 6 indicators, followed by Latin America and the Caribbean (67.8, medium-high) (**Fig. S1**; **Fig. S2h**). On the other hand, the medium-high implementation level was detected in Eastern and Southeastern Asia (61.5), Sub-Saharan Africa (56.4), Northern Africa and Western Asia (55.2), and Central and Southern Asia (53.1), despite their SDG6$_I$ scores lagging behind the global average (**Fig. S1**; **Fig. S2h**).

The core of the SDG6$_I$ development is to underline the policymakers' commitment to treat all SDG 6 targets equally in an integrated and indivisible manner (Sachs et al., 2018). Therefore, investigating the

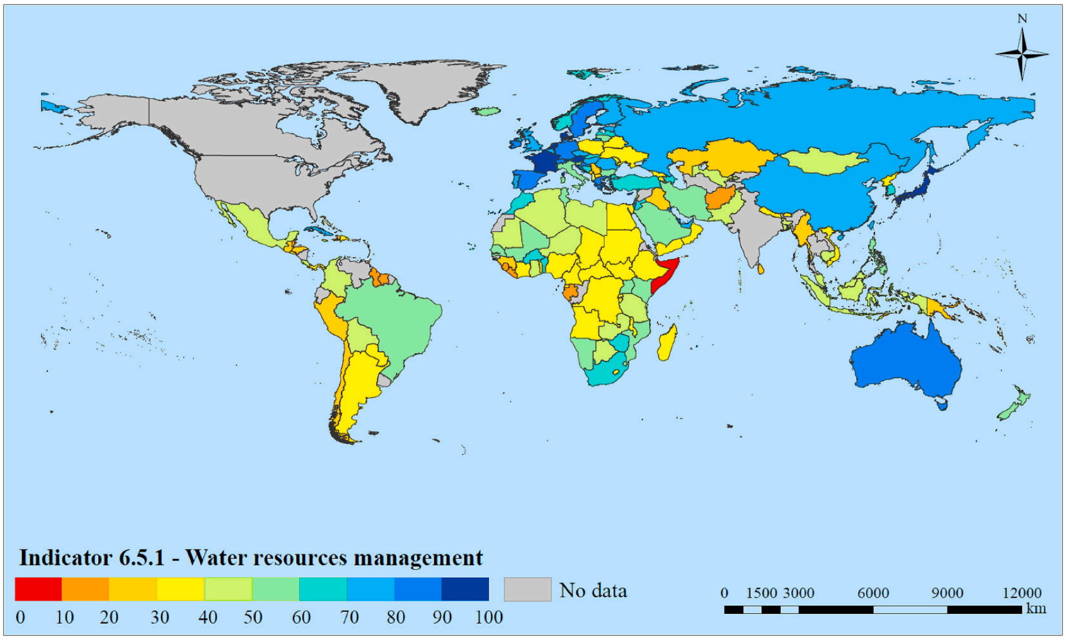

Fig. 6. Global baseline of Indicator 6.5.1 by country and territory.

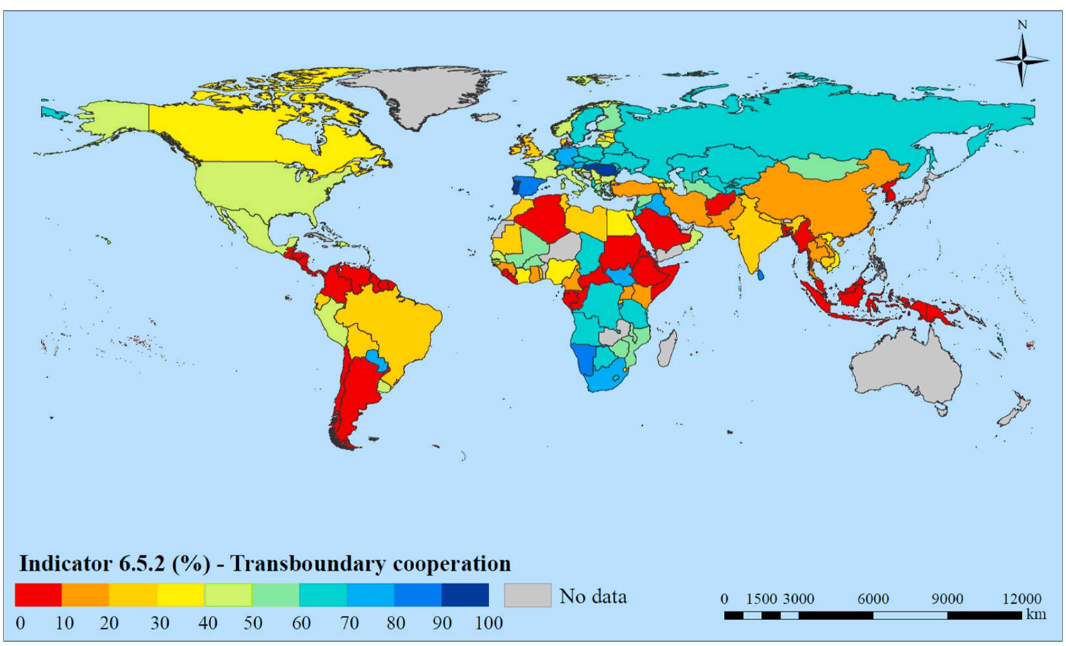

Fig. 7. Global baseline of Indicator 6.5.2 by country and territory.

baseline relationship between the $SDG6_I$ score and its components helps to understand the severity of water risk embodied in particular indicators as well as where incremental progress might be expected to be either fastest or slowest (Sachs et al., 2018). At either the global or regional scale, only the baselines of I_{611}, I_{621}, and I_{642} generally had better performance than that of the $SDG6_I$ score (**Fig. S3**), which shows that achieving sustainable water security substantially depends on enabling and accelerating progress in water quality, water availability, and water governance, while maintaining and improving the implementation of water accessibility.

4. Discussion

4.1. Policy implications and measures

The profiles of the SDG 6 indicators and $SDG6_I$ illustrated the distinct spatial heterogeneity among countries and territories at the implementation level. They also revealed which countries and territories have taken the lead and which ones have fallen below the baseline in each of the SDG 6 dimensions (water accessibility, water quality, water availability, and water governance). In this regard, the policy implications of the $SDG6_I$ and its indicators were subsequently investigated. It led to what macro-scale policy measures being adequate to curb water risk, in which they would help (1) build a solid base of common elements for

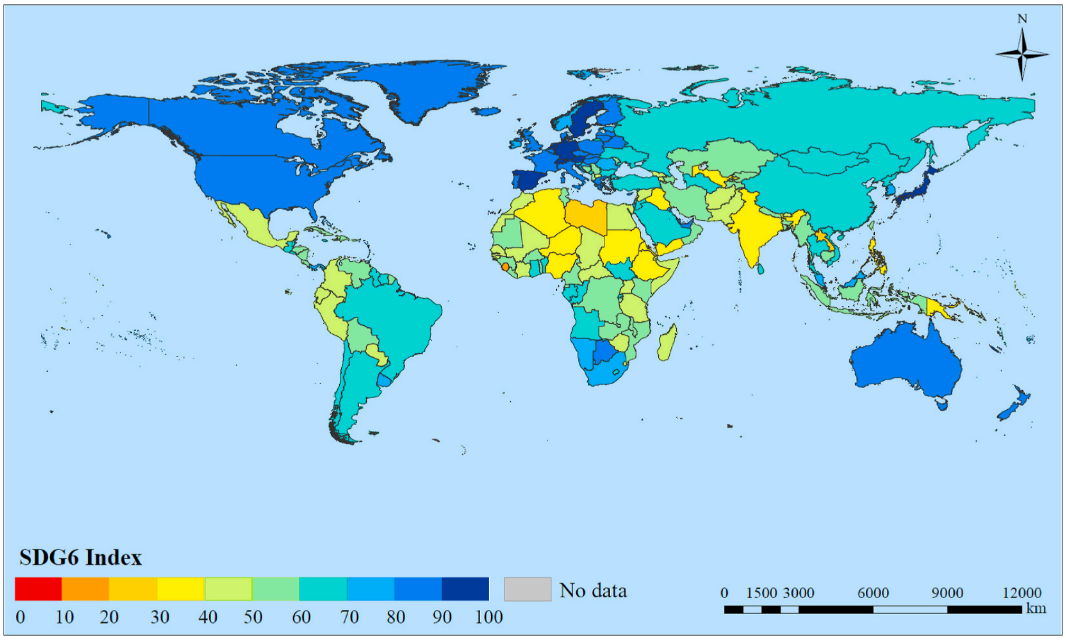

Fig. 8. Global baseline of Sustainable Development Goal (SDG) 6 Index by country and territory.

policy design; (2) increase the engagement of an intricate network of stakeholders throughout the policy cycle; and (3) decouple water challenges from economic growth and associated production and consumption patterns (United Nations Environment Programme, 2019a).

4.1.1. Promoting socioeconomic development

The unevenness of national progress on SDG 6 stems from the countries' varied socioeconomic development, economic growth being one aspect but by far not the sole one (United Nations, 2018). An assessment of socioeconomic development helps identify the extent of the anthropogenic impacts on SDG 6 dimensions (You et al., 2020). Among extant assessment approaches, the Human Development Index (HDI) is the most extensively used, despite the substantial and technical concerns (Biggeri and Mauro, 2018). The HDI can be applied to manifest the capability of governments and other actors in making policy choices that lead to effective and efficient improvements in implementing the SDG 6 indicators (Varis et al., 2019).

It is thus of great interest to compare the aforementioned SDG profile results to the HDI scores. As 190 (out of 232) countries and territories were divided into four human development (HD) groups (very high, high, medium, and low) (United Nations Development Programme, 2020; **Table S10**), the spatial patterns of the HD group composition across eight SDG regions were disclosed in a highly scattered manner (**Fig. S3**). Australia and New Zealand (100%) and Europe and Northern America (69.8%) were in the lead in the very high HD group, followed by Latin America and the Caribbean (45.8%) in the high HD group, Central and Southern Asia (57.1%) and Oceania (23.8%) in the medium HD group, and Sub-Saharan Africa (60.8%) in the low HD group, whereas the countries in Eastern and Southeastern Asia and Northern Africa and Western Asia were generally distributed evenly in each group (**Fig. S3**; **Table S10**).

The notable variation in the SDG 6 indicators and $SDG6_I$ was also clearly portrayed (**Fig. 9**). In spite of I_{642} (water stress) being exceptional, there were generally gradually decreasing trends from the very

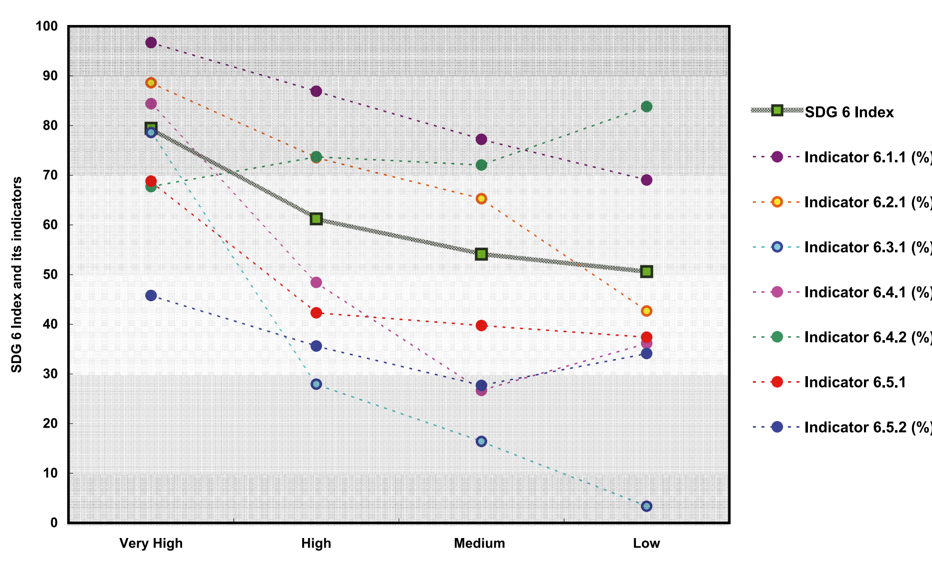

Fig. 9. Global baseline of Sustainable Development Goal (SDG) 6 Index and its indicators by Human Development Index (HDI).

high HD group to the low HD group regarding the implementation level of the $SDG6_I$ and other six SDG 6 indicators (**Fig. 10**; **Table S10**). This reveals that the degree of a country's socioeconomic development largely preconditions its progress on SDG 6 and the challenges it confronts in the SDG 6 dimensions. This is in line with similar findings from the regional evaluation in Africa (United Nations Educational, Scientific and Cultural Organization and UN Water, 2019a), Latin America and the Caribbean (United Nations Educational, Scientific and Cultural Organization and UN Water, 2019b), and the Arab States (United Nations Educational, Scientific and Cultural Organization and UN Water, 2019c). In addition, it is noteworthy that the opposite phenomenon of the I_{642} mainly resulted from Northern Africa and Western Asia with their high level of water stress, in accordance with the profile of the regional baseline (**Fig. 5**; **Fig. S1**; **Table S10**).

Socioeconomic development is a double-edged sword (Cai et al., 2018a). It intensifies the insecurity in the SDG 6 dimensions, as economic growth is still a priority for most countries, while it strengthens the resilience against water risk via infrastructure investment, financing paradigm, smart technology, and human capacity (Zhao et al., 2021). Promoting socioeconomic development as a measure of curbing water risk therefore centers on circular economies and eliminating inequalities in human development.

The concept of the circular economy underscores the quality of economic growth, which echoes the primary need to the change global norm of looking only at GDP (Coscieme et al., 2020). Taking water availability as an example, the circular economy enables the reshaping of the economic structure, which can greatly reduce agricultural water withdrawals and boost industrial water productivity (Cai et al., 2016) as well as alleviate water competition between sectors driven by climate change (Flörke et al., 2018).

Marginalized communities and disadvantaged groups exist in every country, both developed and developing. They are more vulnerable to the exposure of water risk (United Nations, 2018). The key to overcoming the perennial hurdle of "leave no one behind" relies on localizing the implementation in alignment with the specific challenges in SDG 6 dimensions the country faces (Del Río Castro et al., 2021). Inequalities need to be eliminated by means of (1) addressing differences also in aspects of human development other than income and wealth; (2) going beyond summary measures of inequality that focus on only a single dimension; and (3) shaping the prospects of new generations (United Nations Development Programme, 2019).

Hence, beyond GDP, beyond income, beyond averages, and beyond today constitute the foundation of promoting socioeconomic development (United Nations Development Programme, 2019). The implementation of this measure is ensured by policy effectiveness (**Fig. 10**).

4.1.2. Improving policy effectiveness

The core of policy effectiveness is to underline both policy (a statement of intent to change behavior in a positive way) and policy instrument (the means or a specific measure to translate that intent into action) (United Nations Environment Programme, 2019a). Therefore, to understand the substance of policy design is a prerequisite for improving policy effectiveness. The sixth Global Environment Outlook (GEO-6) pointed out that good policy design encompasses the following objectives: (1) setting a long-term vision (goal); (2) establishing a baseline and quantifying targets, indicators, and time frames with milestones; (3) conducting ex ante (before implementation) and ex post (after implementation) cost-benefit or cost-effectiveness analysis; (4) building in policy monitoring regimes with stakeholder involvement during implementation; and (5) conducting post-intervention evaluation of policy outcomes and impacts (United Nations Environment Programme, 2019a). In this regard, good policy design crafts positive feedback loops towards policy effectiveness.

The assessment of policy effectiveness would entail both qualitative and quantitative methodologies to examine which policies have worked best in which circumstances, under what governance arrangements, and whether that experience is transferable to other contexts (Cai et al., 2018b). A dual approach, combining a theory-based top-down evaluation and an outcome-based bottom-up evaluation, has been acknowledged as the best available option for assessing policy effectiveness, despite the known limitations (United Nations Environment Programme, 2019a). A sufficient amount of literature has demonstrated its

Fig. 10. Adequate policy measures for curbing water risk through nexus thinking.

promising applicability to the environmental domain, such as electrical waste and electronic equipment management policy (Morris and Metternicht, 2016), climate policy (Martin and Saikawa, 2017), renewable energy policy (Bersalli et al., 2020), air quality policy (Tan and Mao, 2020), and carbon market policy (Yi et al., 2020). Yet such employment of the dual approach in assessing SDG policy effectiveness is still an open issue to be deciphered.

Addressing this knowledge gap would draw a sobering picture of the policy sensitivity of indicators (United Nations Environment Programme, 2019a). According to the profiles of the SDG 6 indicators and $SDG6_I$, the following research questions need to be investigated in the future: (1) which of these seven SDG 6 indicators are policy-sensitive; (2) what are the corresponding policies to which these indicators are sensitive; and (3) which of these policies are being taken into account by governments to accomplish accelerated progress on policy-sensitive indicators.

As a measure of curbing water risk, improving policy effectiveness is thus dependent on good policy design, a top-down and bottom-up assessment approach, and policy-sensitive indicators. The implementation of this measure is achieved through multi-level governance and collaboration **(Fig. 10)**.

4.1.3. Fostering multi-level governance and collaboration

Roles and responsibilities of all governmental and non-governmental actors are indispensable in policy design and implementation (Messerli et al., 2019). The 2030 Agenda views multi-level governance and collaboration as the two main types of partnership for implementing the SDGs (Horan, 2019). Regarding multi-level governance, a vertical partnership approach reflects that policy instruments are implemented by governments in multilayered governance arrangements with the active involvement of the private sector and civil society at all levels (United Nations Environment Programme, 2019a). China's River Chief system (RCS) is one example. In 2016, China made its first attempt at decentralization reform to combat water pollution in about 200,000 rivers nationwide by establishing a four-tier RCS at the provincial, city, county, and township levels (She et al., 2019). Governments (chiefs) at each level are entitled to devise their own policies for rivers under their jurisdictions, while public participation and supervision are greatly encouraged (Liu et al., 2020). Also, the RCS has improved local water governance in transboundary cooperation (Liu et al., 2020).

In terms of multi-level collaboration, a horizontal partnership approach refers to intersectoral collaborations across a wide range of stakeholders (Beisheim and Simon, 2018). The European Union (EU) and China have been joining forces as equal partners for better water through the China Europe Water Platform (CEWP) since 2012. The CEWP, being a regional component of the EU Water Initiative, promotes water-related policy dialogue, joint research and business development, as well as participatory and grassroots approaches in practicing effective, efficient, and transparent water governance (China Europe Water Platform, 2020). At the CEWP's high-level meeting in September 2017, the EU and China signed a Memorandum of Understanding and the *Turku Declaration*, affirming their dedication to achieve SDG 6 side by side (China Europe Water Platform, 2020). Moreover, multi-level collaboration enhances support to the least developed countries, especially African countries, which will bring about a thriving planet for all mankind (Messerli et al., 2019).

Being a measure of curbing water risk, fostering multi-level governance and collaboration thereby lies in how to guarantee inclusiveness in policy processes with actors from all sectors—locally, nationally, and internationally. The implementation of this measure is accelerated by social cohesion **(Fig. 10)**.

4.2. Index applicability

As the $SDG6_I$ is very generic in character and exclusively built upon the SDG targets, its index-construction methods are therefore apt to be applied on other SDGs with the following outline.

First, the index construction for a specific SDG (SDG x) requires the indicator framework to follow the "STAR" protocol (Straightforwardness, Transparency, Availability, and Readiness).

1. Straightforwardness: the indicators shall be selected from the official UN-adopted SDG indicators, as they all have well-established definitions and integrated monitoring methodologies to track the SDG x targets. The selected SDG x indicators shall systematically portray its diverse challenges for integrated risk assessment and cover a number of outcome-based targets embodying various SDG x dimensions.
2. Transparency: the data of the selected SDG x indicators shall be collected from global open-access databases.
3. Availability: the indicator modification shall be made and justified for tackling the data vacuum to ensure data availability of the selected SDG x indicators in a majority of countries worldwide.
4. Readiness: the selected SDG x indicators shall be ready to provide the direct feedback of policy implications, based on the global implementation progress of the SDG x targets. It would help identify which indicators are policy-sensitive for policy effectiveness assessment.

Second, the indicator framework is dynamic, as the data availability of the SDG indicators may vary over time due to the advancement of monitoring technologies. It is therefore of prime importance and necessity to set an exact timeline for examining the indicator framework and accordingly refining the index construction.

Third, the standardized procedures of the index construction offer a possibility for strengthening how to map synergies and trade-offs among different SDGs through the lens of policy measures, which would help enable and accelerate to achieve SDGs across the 2030 Agenda.

5. Conclusions

This is the first time that a composite Sustainable Development Goal (SDG) 6 index has been globally developed exclusively on the basis of the SDG 6 targets and their indicators to assess water risk in an integrated and systematic manner. The implementation profiles of the indicators and index rendered which SDG 6 dimensions (water accessibility, water quality, water availability, and water governance) of 232 countries and territories around the world have taken the lead and fallen behind in the development. The highlights can be summarized as follows:

- Most countries are on track to achieve universal water accessibility by 2030, regarding either safely managed drinking water or sanitation services. Countries in Africa in general, however, need to strengthen the implementation capacity of service coverage.
- Apropos of water quality and water availability, mostly only countries in two SDG regions, Australia & New Zealand and Europe & Northern America, are on track to achieve the targets. The indicators' implementation in the rest of world is still underway.
- Water governance confronts prominent challenges both in water resources management and transboundary cooperation globally.

In accordance with the baseline profiles, the policy implications of the SDG 6 Index ($SDG6_I$) and its indicators were subsequently investigated. It led to three adequate macro-scale policy measures to curb water risk, i.e., promoting socioeconomic development, improving policy effectiveness, and fostering multi-level governance and collaboration. Due to many deep interlinkages and interdependencies, these measures need to be designed and implemented through nexus thinking to deliver sustainable water security, particularly in the context of the adverse impacts of the COVID-19 pandemic on SDG 6 progress.

Furthermore, the innovative contributions that this study made shed some light on the applicability of the SDG Index construction, with the key points below:

- The index construction requires the indicator framework to follow the "STAR" protocol (Straightforwardness, Transparency, Availability, and Readiness).
- The indicator framework, owing to its dynamic nature, needs to be examined within a specific time period for refining the index construction.
- Mapping synergies and trade-offs among different SDGs across the 2030 Agenda can be reinforced with the standardized procedures of the index construction.

CRediT authorship contribution statement

Jialiang Cai: conceived the original idea, Methodology, developed the methods, Formal analysis, collected and analyzed the data, carried out the figures, took the lead in writing the manuscript. **Dandan Zhao:** Methodology, developed the methods, carried out the figures. All authors discussed the results, provided critical feedback, and helped shape the final manuscript. **Olli Varis:** conceived the original idea.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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