Environmental Science and Ecotechnology 27 (2025) 100611

Contents lists available at ScienceDirect

Environmental Science and Ecotechnology

journal homepage: www.journals.elsevier.com/environmental-science-and-ecotechnology/

Original Research

Steep sustainability challenges in transboundary basins worldwide

Yiqi Zhou [a,b], Yanfeng Di [c,d], Xianjin Huang [a,b,*], Shilin Fu [d,e], Xinxian Qi [a,b,**], Chao He [f], Georgia Destouni [g,h,i,***]

[a] School of Geography and Ocean Science, Nanjing University, Nanjing, Jiangsu, 210023, China
[b] Key Laboratory of Carbon Neutrality and Territory Optimization, Ministry of Natural Resources, Nanjing, Jiangsu, 210023, China
[c] State Key Laboratory of Desert and Oasis Ecology, Key Laboratory of Ecological Safety and Sustainable Development in Arid Lands, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011, China
[d] University of Chinese Academy of Sciences, Beijing, 100049, China
[e] National Engineering Research Center for Desert-Oasis Ecological Construction, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011, China
[f] National Science Library (Wuhan), Chinese Academy of Sciences, Wuhan, 430071, China
[g] Department of Physical Geography, Stockholm University, Stockholm, 106 91, Sweden
[h] Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, Stockholm, SE-100 44, Sweden
[i] Stellenbosch Institute for Advanced Study, Stellenbosch, 7600, South Africa

A R T I C L E I N F O

Article history:
Received 14 July 2025
Received in revised form
1 August 2025
Accepted 1 August 2025

A B S T R A C T

Transboundary hydrological basins span international borders and are essential to global water systems, human development, and environmental sustainability. Nearly 40 % of the world's population lives within these basins, which supply critical resources such as freshwater, food, energy, and biodiversity. Yet their sustainability remains poorly understood, as existing assessments often overlook the unique social, environmental, and political complexities of transboundary basins. This study addresses that gap by developing and applying a systematic framework to assess Sustainable Development Goals (SDGs) progress across 310 transboundary basins worldwide. Here we show that transboundary basins score significantly lower on average SDGs achievement (an SDG Index score of 42 on a scale of 0–100) compared to national averages (a score of 67), with considerable variation between regions. We identify four distinct types of transboundary basins in terms of SDGs achievement and associated challenges. We also show that progress on a specific set of goals can drive broader sustainability within each basin type. Notably, achieving clean water (SDG 6), sustainable economic growth (SDG 8), and healthy livelihoods (SDG 3) is linked to overall SDGs success in 38 % of transboundary basins worldwide. Our results highlight the importance of basin-level analysis for revealing sustainability patterns overlooked by national assessments. This framework can inform future basin research and support policy development in transboundary regions.

1. Introduction

Transboundary hydrological basins traverse international borders, connecting nations in a complex network of water, environmental, political, economic, and security-related interdependencies [1,2] and play an essential role in the Earth System [3,4]. Approximately 40 % of the world's population resides in transboundary basins, while over 90 % lives in countries that share these basins [5], their water [6], and other ecosystem services they provide [4,7]. Encompassing 62 million km^2 of land globally [6], hydrological basins provide vital resources for human livelihoods, host important cultural landmarks, and attract millions of tourists annually [8]. They are also essential in driving socioeconomic progress and enhancing human welfare; for example, hydropower in these basins supplies at least 16 % of electricity and 70 % of

* Corresponding author. School of Geography and Ocean Science, Nanjing University, Nanjing, Jiangsu, 210023, China.
** Corresponding author. School of Geography and Ocean Science, Nanjing University, Nanjing, Jiangsu, 210023, China.
*** Corresponding author. Department of Physical Geography, Stockholm University, Stockholm 106 91, Sweden.
E-mail addresses: hxj369@nju.edu.cn (X. Huang), xqi@nju.edu.cn (X. Qi), georgia.destouni@natgeo.su.se (G. Destouni).

https://doi.org/10.1016/j.ese.2025.100611

global renewable energy [9]. Furthermore, transboundary basins are home to a high proportion of the world's biodiversity [10,11].

The combined impacts of climate change, population growth, land-use changes including urbanization, and infrastructural development shape societal and environmental conditions and trends within national hydrological catchments and transboundary basins [12–14]. However, in transboundary basins, these driving factors may manifest differently and have diverse societal and environmental effects across countries or regions within them, leading to varying levels of achievement of the United Nations (UN) Sustainable Development Goals (SDGs). Different countries may also have varying biases and limitations in their reporting of national SDGs achievements. Overall, when viewed across transboundary basins, these variations may paint different pictures of regional sustainability than they would for individual countries or national hydrological catchments.

Furthermore, a combination of scarce water resources and high population densities, along with water conflicts in some regions [15], can lead to forced displacement, violent conflicts, and political instability [16,17]. Countries located downstream rely on water inflows from and thus depend on upstream countries within a transboundary basin. This increases the impact of human activities on downstream countries by including those driven by actions outside their national borders. For example, upstream land-use changes and dam constructions that change runoff and other water conditions in the downstream countries [18–21]. In transboundary basins, international displacement, conflicts, instability, and upstream–downstream relationships occur and thus are reflected in SDGs achievements across an entire basin, which may differ from those reported separately for individual countries or national catchments.

Cooperation between countries within transboundary basins may be essential for achieving overall regional sustainability. For example, Indicator 6.5.2 of SDG 6 (clean water and sanitation) underscores the importance of ensuring equitable and sustainable water resource management [22]. However, research has thus far focused primarily on the implementation of SDG 6 at national, industry, policy, and sector levels, with particular focus on developing countries as well as agricultural and forest sectors [23–35], while transboundary basins and the regional sustainability achievements across them have received little attention.

Overall, compared to individual countries or national catchments, transboundary basins encompass a wider range of variations across the full spectrum of natural, social, and human activities, resource dependency, governance, and other conditions that link to and shape progress toward many SDGs [36,37] (Supplementary Fig. S1). However, sustainability assessments are mostly conducted at the country level [38–40] or for national catchments [41]. This national focus overlooks the unique, big-picture perspectives, less influenced by national reporting biases, that transboundary basins can offer, along with their broader natural–social complexities and sustainability challenges. This has resulted in the absence of an operational framework for systematically assessing overall regional SDGs achievement over transboundary hydrological basins. This study addresses this gap by developing and applying a systematic framework for synthesizing and linking nation- and basin-level scales to assess and identify improvement pathways for overall regional SDGs progress in and across the world's many transboundary basins.

This study covers 310 transboundary basins worldwide, across 98 indicators of SDGs achievements (Supplementary Table S1). It quantifies environmental Gini coefficients (EGCs), indicating environmental inequality, to compute novel combined SDGs scores for these basins in 2020 and employs a *k*-means algorithm to categorize the basins into four main types of clusters based on SDG achievement. It also identifies the primary driving factors underlying this clustering and typology using a classification and regression tree (CART) model. In addition, by employing a Bayesian network model, this study quantifies the number of transboundary basins that achieve SDGs under various improvement avenue scenarios. Overall, the framework developed and tested in this study can support researchers, policymakers, and local communities in transboundary basin governance, thereby fostering a deeper understanding of cross-border SDG progress.

2. Methodology

Given the spatial mismatch between hydrological boundaries and administrative units, understanding and assessing sustainability in transboundary basins requires the integration of multisource and multiscale gridded datasets. Previous studies have focused on either national-level SDGs assessments or hydrological modeling within individual or multiple selected basins, but few have systematically addressed SDGs progress across transboundary basins worldwide. We build upon such efforts by bridging global, national, and subnational data scales to construct an SDG indicator system specifically tailored to the transboundary basin context. At the core of our approach is the EGC, which enables a grid-based evaluation of available water resource distribution inequalities, thereby revealing intra-basin disparities and providing a quantitative foundation for constructing basin-level SDG indices. To reconcile the heterogeneity in spatial and temporal resolution across datasets, we establish clear principles for indicator selection (e.g., data availability, thematic relevance to SDGs, and suitability at the grid or subnational scale) and apply consistent resampling and normalization procedures to integrate and rasterize SDGs proxies across national boundaries. This enables the construction of a composite SDG Index for 310 transboundary basins with coherence, systematic structure, and methodological soundness.

2.1. Four interrelated steps for calculating SDG index scores in transboundary basins

The UN utilizes over 230 indicators to assess the 17 SDGs, which are defined primarily at the global or national level. We propose an indicator framework tailored for basin-level analysis that integrates elements from the global indicator framework of the SDGs and targets, along with the EGC, to depict environmental inequality. This framework for computing transboundary basins' SDG Index scores (Supplementary Fig. S2) comprises four key steps, which reflect two parallel routes of analysis: (1) the current distribution of water resources in transboundary basins and (2) the integration of individual SDG as representative categories of resources.

2.1.1. Step 1: indicator collection and clipping

In transboundary basins, water is a vital resource, and its equitable and sustainable allocation is crucial for achieving balanced development between upstream and downstream regions. Achieving such allocation requires a delicate balance between efficiency and fairness to address the inherent complexities and sensitivities of basin governance. One of the most prominent characteristics of transboundary basins is the conflict between upstream and downstream areas, which centers predominantly on the allocation of water as a vital resource.

To quantify the distribution of water resources in transboundary basins, this study introduces the EGC, a metric designed to evaluate allocation equity (Supplementary Text S1). The EGC extends the application of the traditional Gini coefficient, analogous to the Area-based Resource Gini (AR–Gini) method [42], by incorporating economic, ecological, and social dimensions into a multicriteria evaluation framework. In this framework, the *y*-axis represents water availability, while the *x*-axis comprises multicriteria indicators—such as temperature and precipitation—enabling an assessment of the equity of water resource distribution among subbasins. Lower EGC values indicate greater inequality in distribution, with water resources being disproportionately concentrated in specific subbasins, often favoring upstream regions over downstream ones.

Recognizing the significance of water resources in transboundary basins, this study utilizes water availability as the dependent variable in EGC calculations. Water availability is defined as the net difference between water supply from precipitation and water demand from evapotranspiration, which reflects streamflow and changes in water storage [43]. Based on this definition, we selected 14 relevant indicators, including one for precipitation and 13 for evapotranspiration (Supplementary Table S2). Global raster data were resampled to a resolution of 0.1°, and the data were clipped based on the basin boundaries delineated in the Transboundary Freshwater Dispute Database (https://transboundarywaters.science.oregonstate.edu). This process yielded a dataset encompassing 636,141 grid points with complete data coverage for each indicator (Supplementary Fig. S3 and Table S2).

To address the current absence of comprehensive raster-scale SDGs datasets, this study employs proxy data for SDGs rasterization, a widely adopted approach in related research [44,45]. We selected SDGs data for the year 2020 (Supplementary Table S3) and accounted for the heterogeneity between upstream and downstream regions. Given that upstream and downstream areas are often located in different countries, a regional heterogeneity allocation method was employed. Specifically, indicators representative of the 17 SDGs (e.g., global subnational poverty data as a proxy for SDG 1 at the subnational level, as detailed in Supplementary Table S3) were standardized to a 0–1 scale to generate weights. These weights were then multiplied by national-level SDG data, enabling the allocation and mapping of SDG indicators from the national to the subnational level, ultimately producing rasterized data for subregions within transboundary basins (Supplementary Fig. S4 and Table S3).

It is noteworthy that the 17 SDGs can be conceptualized as representing 17 categories of critical resources. For example, SDG 4 (quality education) reflects educational resources, SDG 6 (clean water and sanitation) represents water resources, and SDG 7 (affordable and clean energy) corresponds to clean energy resources. In the context of transboundary basins, achieving SDGs essentially reflects the goal of equitable resource allocation. By employing the EGC method, this study not only highlights the inequalities in water resource distribution between upstream and downstream regions but also provides a quantitative tool to deepen our understanding of the equity of resource allocation within basins. This approach offers critical insights and support for advancing the comprehensive objectives of the SDGs.

2.1.2. Step 2: EGC determination indicators

We developed three models to select key indicators for calculating the EGC: a model based on the Akaike information criterion (AIC) to evaluate the optimal number of indicators, a regression model to address collinearity issues, and a random forest (RF) model to assess the importance of indicators.

The AIC, which introduces a penalty term to minimize model parameters, was used to screen indicator combinations, thereby enhancing model-fitting performance and reducing the risk of overfitting. The analysis revealed that when the indicator set included six variables, the model achieved the minimum AIC value, indicating that this combination was optimal for constructing a model to assess the distribution of water resource availability.

To address collinearity issues, we applied a multiple linear regression model to evaluate the relationships between 14 explanatory variables and the dependent variable. Collinearity (or multicollinearity) refers to a high correlation among two or more variables in a statistical model, which can obscure the identification of true predictors of the dependent variable [46]. Variance inflation factor (VIF) analysis was conducted to identify and exclude variables with VIF values greater than 5, thereby mitigating multicollinearity [30]. This process resulted in the exclusion of five indicators, leaving nine variables for the RF model.

To identify the most influential variables in the RF model and their relationships with water resource availability, we calculated the importance of the Shapley additive explanations (SHAP) feature for each variable. SHAP is a game-theoretic approach that quantifies the contribution of each feature to a model's predictions, providing an interpretable framework for machine learning outputs. Based on the SHAP feature importance analysis, we selected six key indicators (2 m temperature, wind speed, leaf area index, normalized difference vegetation index, groundwater storage, and population) with SHAP values exceeding 13 for EGC calculation (see Supplementary Table S4).

The integration of these three approaches ensured the robustness and scientific validity of the model, thereby providing a reliable basis for calculating EGC.

2.1.3. Step 3: EGC calculation

Several methods have been developed to calculate the Gini coefficient accurately, with most studies using the Lorenz curve and trapezoidal area methods to approximate its value. This method involves approximating the Gini coefficient by summing the areas of all trapezoids under the Lorenz curve [47]. In this study, the EGC was first calculated from a subbasin perspective, considering all grids controlled by each subbasin. The subbasins were ordered based on the ratio of explanatory variables to the dependent variable, from smallest to largest. Then, the cumulative proportion of each explanatory variable, along with the corresponding cumulative proportion of the dependent variable in each grid, was calculated. The calculation formulas are as follows [47–49]:

$$G_j = 1 - \sum_{i=1}^{n} \left(X_{j(i)} - X_{j(i-1)}\right)\left(Y_{j(i)} + Y_{j(i-1)}\right), \tag{1}$$

$$E = \sum_{j} G_j, \tag{2}$$

where j represents the index of the variable, such as total precipitation for the first variable, 2 m temperature for the second, etc.; i represents the grid number controlled by each subbasin; G_j is the Gini coefficient calculated for variable j; $X_{j(i)}$ is the cumulative proportion of variable j for grid i; and $Y_{j(i)}$ is the cumulative proportion of available water for grid i. When $i = 1$, $(X_{j(i-1)}, Y_{j(i-1)}) = (0,0)$. E represents the overall EGC. A higher EGC value indicates that a given subbasin possesses more abundant resources, particularly available water. However, since the total available water within the same basin remains constant, this implies that other subbasins have less available water, resulting in greater inequality in resource distribution.

2.1.4. Step 4: SDGs for transboundary basins

We sourced our indicators from the 2020 *SDG Index and*

Dashboards Report, an official publication by the UN based on its *Indicators and Monitoring Framework for the Sustainable Development Goals* report. The Sustainable Development Solutions Network has annually assessed progress toward the 17 SDGs since 2015 through the SDG Index and Dashboards Report, which offers a rigorous, quantitative, and transparent methodology for gauging changes in the SDGs and was employed to calculate the SDG Index score in this study.

We combined the EGC of the subbasins contained within each country (i.e., for each basic calculation unit) with the country's SDG Index score to compute the SDG Index score for each transboundary basin, which serves as a composite measure that integrates individual scores for all 17 SDGs and indicates the overall performance of each transboundary basin in advancing toward the SDGs [50,51]. In calculating the SDG Index score, all 17 SDGs are assigned equal weight, underscoring the significance of incorporating comprehensive solutions for each SDG [39]. The computed scores for the 17 SDGs in the transboundary basins are depicted in Supplementary Fig. S5.

2.2. Pattern recognition (clustering)

We applied the k-means algorithm to cluster the SDG Index scores and individual SDGs of 310 transboundary basins, which resulted in the global transboundary basins being categorized into four distinct clusters (Supplementary Fig. S6 and Table S5). The k-means algorithm, selected for its centroid-based partitioning clustering method, was considered suitable for the dataset due to the number of data points (n) and its exclusive segregation approach, which assigns each object to precisely one group. Here, k represents the number of specified clusters, with $k \leq n$. Essentially, the algorithm divides the data into k groups, each characterized by a defined centroid, thereby ensuring that each group contains at least one object [52].

The objective function for the k-means clustering algorithm is the squared error function [53]:

$$J = \sum_{k=1}^{k} \sum_{i=1}^{n} \left| \left| (x_i - \mu_k)^2 \right| \right|, \tag{3}$$

where J is the objective function (sum of the squared error), k is the number of clusters, n is the number of objects (data points), x_i represents object i, μ_k is the centroid for the cluster containing x_i, and $(x_i - \mu_k)$ denotes the Euclidean distance between point x_i and centroid μ_k.

2.3. Correlation analysis

We employed Pearson correlation coefficients to approximate the interactions among the SDGs [40]. A positive value indicated synergy, while a negative value suggested a trade-off; the absolute value of the correlation coefficient denoted the strength of the interaction. Subsequently, we computed the Pearson correlation between each pair of SDGs, utilizing significant correlation coefficients ($p < 0.05$) for further analyses.

2.4. Classification and regression tree

To identify the most influential SDGs and their key indicators shaping transboundary basins, we applied the CART algorithm. CART is a decision tree-based technique widely used in exploratory data analysis and predictive modeling due to its ability to handle complex datasets and uncover hierarchical relationships among variables. This method was used to divide the dataset into increasingly homogeneous subgroups through recursive binary splitting, enabling the identification of key indicators and thresholds that drive variations in SDG Index scores. Given the continuous nature of this indicator, CART regression methods were employed, using the analysis of variance criterion to minimize within-group variance and maximize between-group differences [54].

By employing CART, we pinpointed the SDGs and indicators most critical to influencing SDG performance across different clusters of transboundary basins. The approach not only highlighted the primary contributors to sustainability challenges but also captured the nuanced interplay between SDGs at the basin level, providing actionable insights for policy design and resource allocation in transboundary contexts.

2.5. Scenario analysis

Given the pessimistic outlook on the sustainable development of transboundary basins in 2020, we employed Bayesian networks to conduct scenario analyses focusing on the most critical goals for global transboundary basin development (SDGs 3, 6, and 8). A Bayesian network—also known as a belief network, probability network, or causal network—is a concise and intuitive directed acyclic graph structure [55]. In this structure, nodes represent random variables—either discrete or continuous—and the directed edges indicate the interdependence between these nodes. Each node in the network is associated with a conditional probability distribution, thereby providing valuable information on the probability.

Bayesian networks are adept at data mining and can uncover quantitative relationships between variables through parameter settings [56]. Leveraging Bayesian posterior probability prediction capability, we can assess the influence of specific variables on target nodes across various scenarios. In this study, scenario assumptions were based primarily on the following principles: identifying the most critical SDG for each clustered transboundary basin as the evidence node for scenario analysis and selecting multiple significant SDGs as prediction scenarios simultaneously.

3. Results

3.1. Sustainable development in transboundary basins worldwide

A major difference emerged between the global average SDG Index score of 42 for the 310 transboundary basins (on a scale ranging from 0 [worst] to 100 [best]) and that of 67 for individual countries worldwide (Supplementary Text S2). The difference reflects the steeper sustainability challenges faced in transboundary basins, with their wider-ranging conditions and higher complexity, including international resource sharing and collaboration difficulties, compared to individual countries or national catchments. The corresponding differences for different world regions and specific SDGs are discussed further in the Supplementary Text S2. Focusing here on the scores for transboundary basins, those in Europe had the highest median SDG Index score (66.5), followed by North America (48), South America (47), Asia (34), and Africa (19) (Fig. 1b).

The basins in Europe thus exhibited generally high SDG Index scores, along with high EGC values (average 0.51; Supplementary Text S1), reflecting a relatively balanced resource allocation across the continent. Basins such as the Isonzo (an SDG Index score of 78), the Gauja (75), and the Vecht (74) formed European clusters of high-value aggregation. In contrast, transboundary basins in Africa had relatively low SDG Index scores—for example, basins such as Galana (54.5), Congo (19), and Nile (13) formed African clusters of

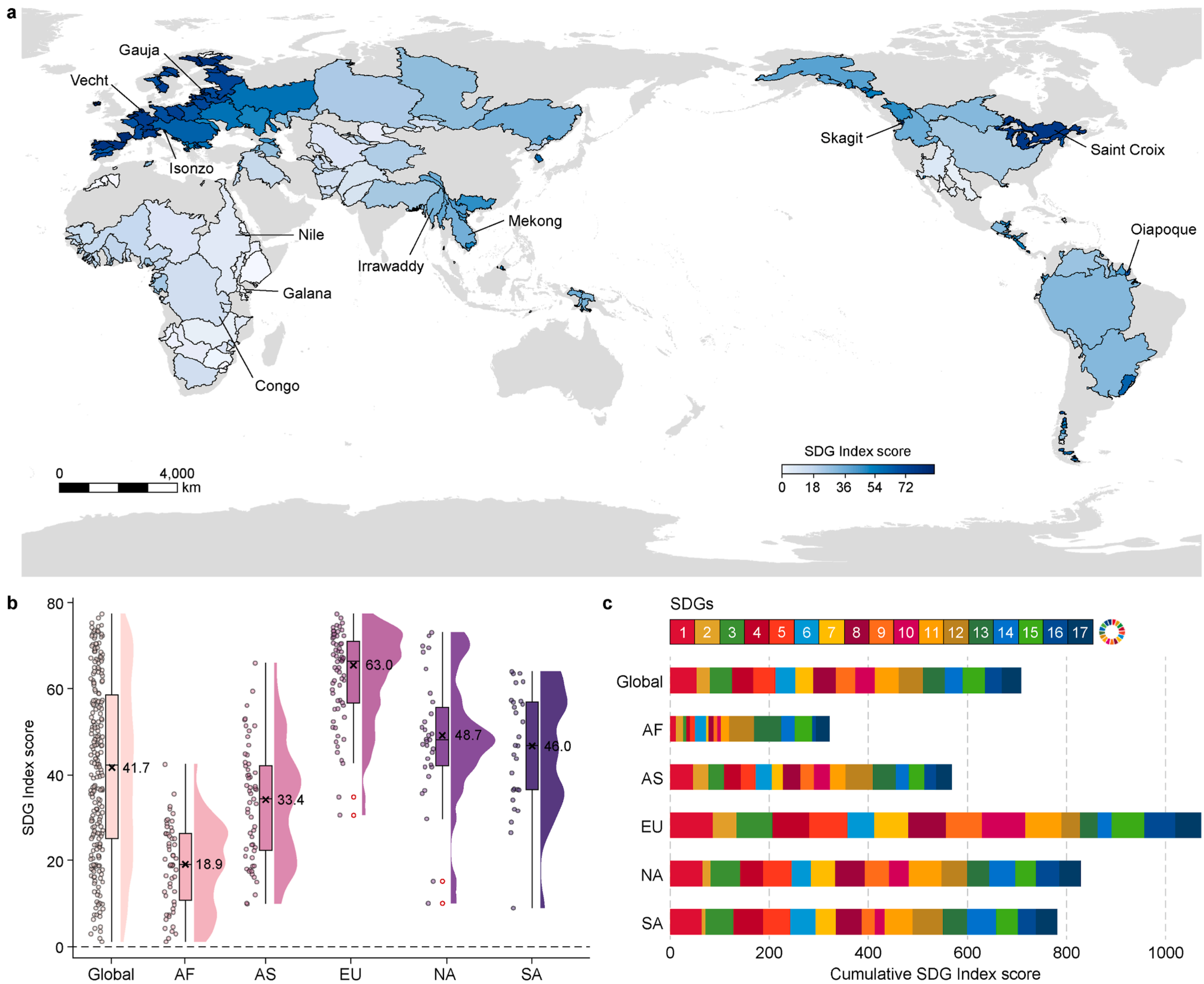

Fig. 1. SDG Index scores of transboundary basins and individual SDG Index scores across continents in 2020. **a**, SDG Index scores in 2020. **b**, Distribution of continental-level SDG Index scores in 2020. The violin plots show the distribution density of SDG Index scores for transboundary basins within each continent. Boxplots indicate the interquartile range (IQR), median (central line), and whiskers (1.5IQR). The overlaid dots represent individual transboundary basins. The crosses (×) denote the mean SDG Index scores, and the accompanying numbers indicate the corresponding values. **c**, Cumulative continental-level individual SDG Index scores in 2020. See Supplementary Table S1 for a description of each SDG number. AF: Africa; AS: Asia; EU: Europe; NA: North America; SA: South America.

low-value aggregation. However, the EGC values of these basins (average 0.40) were not the lowest. North and South American transboundary basins, such as Oiapoque (64) in South America and Saint Croix (73) and Skagit (72) in North America, had relatively high SDG Index scores. Due to variations in precipitation, its partitioning between evapotranspiration and runoff, and other natural conditions, the North and South American basins had distinctly different EGC values (0.47 and 0.39, respectively). While North American countries had outstanding national-level SDG Index scores, particularly the United States (76) and Canada (78), the corresponding transboundary basin scores—for example, the basins of Mississippi (30) and Nelson-Saskatchewan (36), which are shared between the United States and Canada—were relatively low. These regional differences highlight that transboundary water governance, water security, and resource equity are critical factors in achieving the SDGs (Supplementary Text S2). Notably, the EGC value (0.51) for Asia was identical to that for Europe, and the SDG Index scores of transboundary basins in Southeast Asia outpaced those in Central Asia. This was particularly true for transboundary basins jointly managed by China and countries such as India, Myanmar, and Thailand, including those of the Mekong (37) and Irrawaddy (37) (Fig. 1a).

The SDG Index scores of most transboundary basins worldwide were concentrated around the second quartile (Q2) value of approximately 42, with similar median and mean score values across each continent. The scores of individual transboundary basins were relatively evenly distributed over the whole score scale in Africa and South America, concentrated around the median in North America, and more concentrated around the third quartile (Q3) in Europe and Asia (for further statistical details, see Supplementary Table S6).

Overall, the transboundary basins continue to face pressing issues, necessitating urgent attention to their shared cross-border attributes. This was particularly evident in their relatively small progress on SDG 2 (zero hunger), which lagged behind other SDGs, with an average score of 27 (Fig. 1c). While European transboundary basins had relatively high SDGs scores, they still faced challenges in enhancing the protection of aquatic resources to meet SDG 14 (life below water; score of 29). The South American transboundary basins excelled in SDG 1 (no poverty; 63) and SDG 12 (responsible consumption and production; 62) but had lower scores in other SDGs. Transboundary basins in North America and Asia exhibited SDG performance similar to those in South America, but the North American basins were still grappling with the challenges of zero hunger (SDG 2; 17). The African transboundary basins showed limited progress across most SDGs yet exhibited good performance for SDGs 12 (responsible consumption and production; 51) and 13 (climate action; 54).

3.2. Challenges persist for sustainable development in transboundary basins

Four distinct transboundary basin types (I–IV; Fig. 2) emerged as clusters based on their SDG Index scores and individual SDG performances (Supplementary Fig. S5 and Table S5). Clustering revealed distinct sustainable development challenges for each basin type due to the complex interplay of various factors within each basin (e.g., access to clean water, economic growth, and transboundary cooperation). Overall, SDG 6 (clean water and sanitation) emerged as a generally important SDG, which remains to be achieved across basins globally, followed by SDG 8 (decent work and economic growth) (Fig. 2).

Positive and negative SDGs scores correlations further indicated possible synergies and trade-offs associated with the various SDGs in the transboundary basins (Fig. 3). These correlations indicate possible synergistic opportunities for and trade-off barriers to future sustainable development trajectories in transboundary basins. Overall, considerably more synergies (positive correlations) than trade-offs (negative correlations) emerged across all four basin clusters. Examining all 17 SDGs across all basins worldwide showed trade-offs between SDG 12 (responsible consumption and production) and SDG 13 (climate action) with other SDGs. Major trade-offs, characterized by relatively strong negative exponential score correlations, were seen primarily for Cluster III (inclusive growth basins) and Cluster I (institutional governance basins), particularly between SDG 2 (zero hunger) and SDG 10 (reduced inequalities). In contrast, no trade-offs were seen for Cluster II (sustained growth basins), while Cluster IV (social coordination basins) showed trade-offs between SDG 10 and SDG 15 (life on land).

For Cluster I (institutional governance basins), management and cooperation mechanisms emerged as essential for ensuring sustainable management of natural resources (Fig. 4a), as part of the performance for SDG 16 for peace, justice, and strong institutions (Fig. 2b). Many basins in this cluster are situated in North America, Northeast Asia, and Eastern Europe, including the Amur River, Fraser River, and Yukon River. The average SDG Index score for this type of transboundary basin was 49 (Supplementary Table S7), 7 points higher than the global average.

Basins in Cluster II (sustained growth basins) face challenges such as poor water quality, poverty, and high disease prevalence (Fig. 4b). Cluster II basins are found primarily in Central North America, Central Asia, and Africa, including the Niger River. The most influential SDGs in this cluster were SDG 6 (clean water and sanitation), SDG 8 (decent work and economic growth), and SDG 1 (no poverty) (Fig. 2b).

Basins in Cluster III (inclusive growth basins) are primarily situated in Western Europe and face the main challenge of reconciling urban development with environmental conservation (Fig. 4c). These basins are typically located in regions with robust economic development and high social well-being, as exemplified by high achievement levels for Goal 8 (decent work and economic growth) and Goal 11 (sustainable cities and communities) (Fig. 2b), including the Seine River basin and the Rhine–Meuse River basin. Cluster III transboundary basins had the overall highest SDG Index scores (Supplementary Table S7), showing complementary advancements in both river ecosystems and human settlement well-being.

Basins in Cluster IV (social coordination basins) are especially prone to extreme hydrological events, such as flooding or extreme aridity (Fig. 4d). They have a relatively dominant presence in South America and South Asia, with examples including the Amazon River and Mekong River basins. This type of transboundary basin exhibited a relatively low SDG Index score of 36 (Supplementary Table S7).

3.3. Multifaceted goal cooperation needed for SDG achievement

As per the SDG Index scores recorded in 2020, only three transboundary basins in the inclusive growth basin type (Cluster III) had reached the target level of “SDG achieved” (Fig. 5a), indicating substantial impediments to SDG progress in transboundary basins worldwide. Globally, the majority of basins were still at the “Challenges remain” and “Significant challenges” levels—comprising 84 and 90 basins, respectively—and 58 basins were at the “Major challenges” level. Among the four types of basin clusters, the majority of basins (50) in Cluster III were at the “Challenges remain” level, while the majority of basins in Clusters II (53) and IV (45) were at the “Major challenges” and “Significant challenges” levels, respectively. In Cluster I, basins were divided between the “Challenges remain” level (32) and the “Significant challenges” level (39).

Although SDG 6 is a broadly important goal that remains unmet across the different basin clusters (Fig. 2b), focusing solely on achieving this goal has yielded relatively limited progress toward overall sustainability, with only about 17 transboundary basins worldwide potentially achieving sustainable development under this scenario (Fig. 4b). Notably, Cluster II basins showed the highest sustainability potential in this regard, with six of these basins capable of achieving sustainable development in this way. However, if both the water goal (SDG 6) and the economic growth goal (SDG 8) are achieved concurrently, approximately 17 % of all transboundary basins could realize sustainable development. Furthermore, should residents in the transboundary basins concurrently attain clean water (SDG 6), rapid economic growth (SDG 8), and healthy livelihoods (SDG 3), around 38 % of all basins could achieve sustainable development. These results underscore the interconnected nature of sustainable development across the SDGs in each transboundary basin, highlighting the necessity for cooperation on multiple goals.

Scenarios in which the most critical SDG for each basin type (cluster) is achieved further revealed that achieving peace, justice, and strong institutions (SDG 16) in Cluster I also promotes the achievement of SDG 3 (healthy lives for basin residents; Fig. 3), resulting in approximately 17 additional transboundary basins achieving sustainable development compared to the baseline (Fig. 5c). For Cluster II, the achievement of SDG 6 (access to clean water and sanitation) and SDG 15 (ecosystem conservation and sustainable land use) showed synergistic effects on overall sustainable development achievement in these basins. In contrast, the achievement of SDG 8 showed divergent effects for overall sustainability achievement in Cluster III and IV basins. Notably, prioritizing environmental and ecological sustainability (SDGs 13–15), alongside food security and sustainable agriculture (SDG

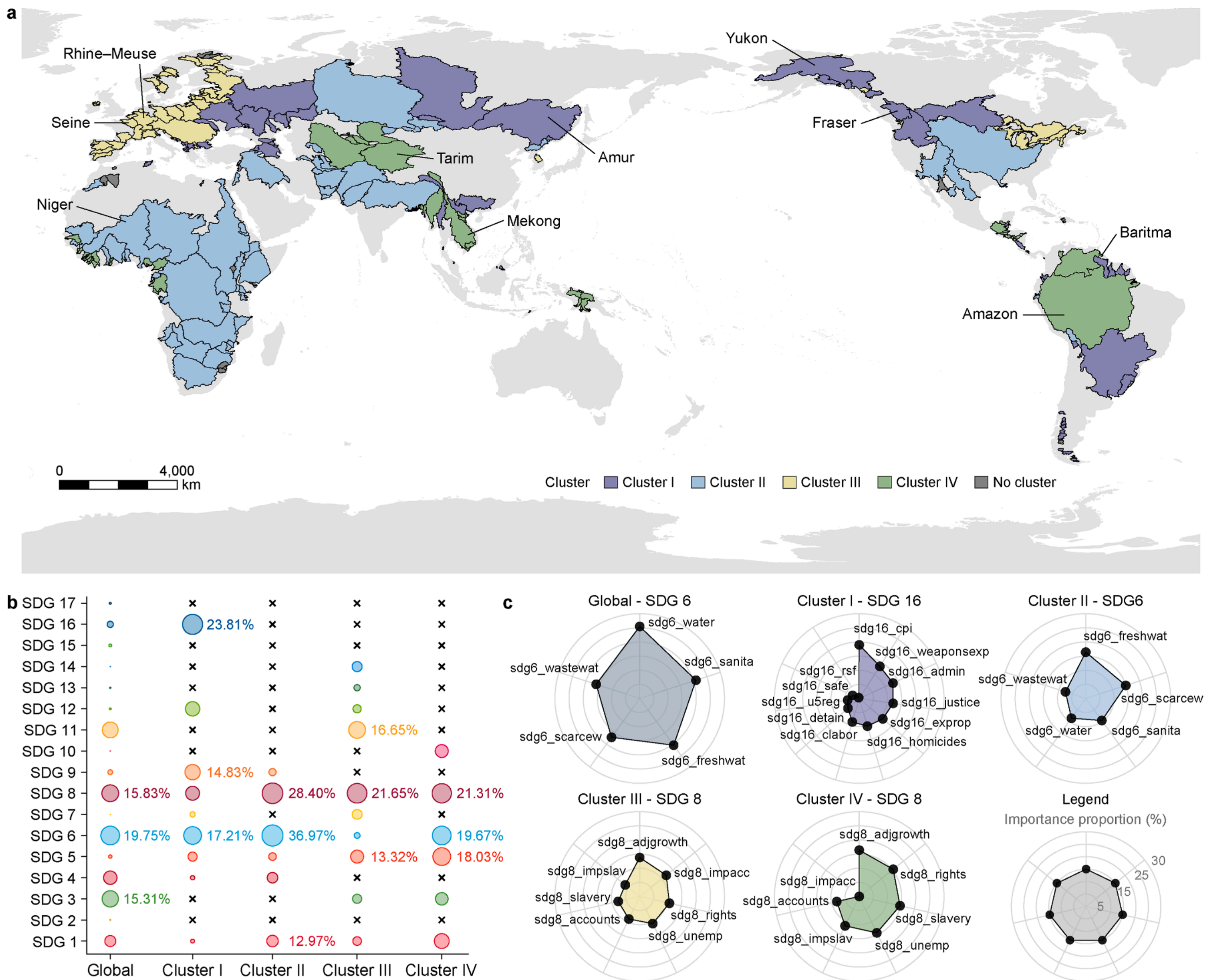

Fig. 2. Clustering patterns of transboundary basins worldwide. **a**, Distribution of transboundary basins across the four clustered types. **b**, Importance proportion for individual SDG in the different basin types (clusters). The color of each bubble represents the corresponding SDG, and the bubble size indicates the proportion of its importance. The numerical values next to the top three SDGs in each cluster indicate their relative importance rankings. **c**, Importance proportion for indicators of the most critical individual SDG for each basin type (cluster). Abbreviations for the indicators are listed in Supplementary Table S1. The importance proportion for SDGs (panel **b**) and indicators (panel **c**) are determined by the classification and regression tree model.

2), could further enhance the positioning of basins in Cluster III as general frontrunners in sustainable development. Moreover, prioritizing quality education and lifelong learning opportunities (SDG 4), along with economic growth (SDG 8), could promote overall sustainability attainment in approximately seven more transboundary basins compared to the baseline scenario. These findings underscore the need for cooperation on multiple SDGs for sustainable development in transboundary basins.

4. Discussion

4.1. Insights from the quantitative findings

This study has developed, applied, and tested a novel framework for evaluating sustainable development in transboundary basins. The spatiotemporal sustainability statuses of all 17 SDGs across 310 transboundary basins worldwide in 2020 were evaluated using this framework. The results revealed the SDG performance and challenge clustering of four main types of basins, identifying pivotal driving factors based on SDG achievement thus far. Furthermore, a scenario analysis was conducted to assess critical SDGs achievements toward achieving overall sustainability. Globally, and across most of the four basin clusters (albeit in varying orders), SDG 6 (clean water and sanitation), SDG 8 (decent work and economic growth), and SDG 16 (peace, justice, and strong institutions) emerged as key goals for achieving wider sustainability attainment.

For comparison, we also considered the 2016 United Nations Environment Programme - Danish Hydraulic Institute Centre on Water and Environment report, "*Transboundary River Basins: Status and Trends*" [11], which provides valuable insights into transboundary water management and mentions support for the SDGs. In contrast, our study quantified the overall regional SDGs status of the basins, identified areas where further progress on SDGs was

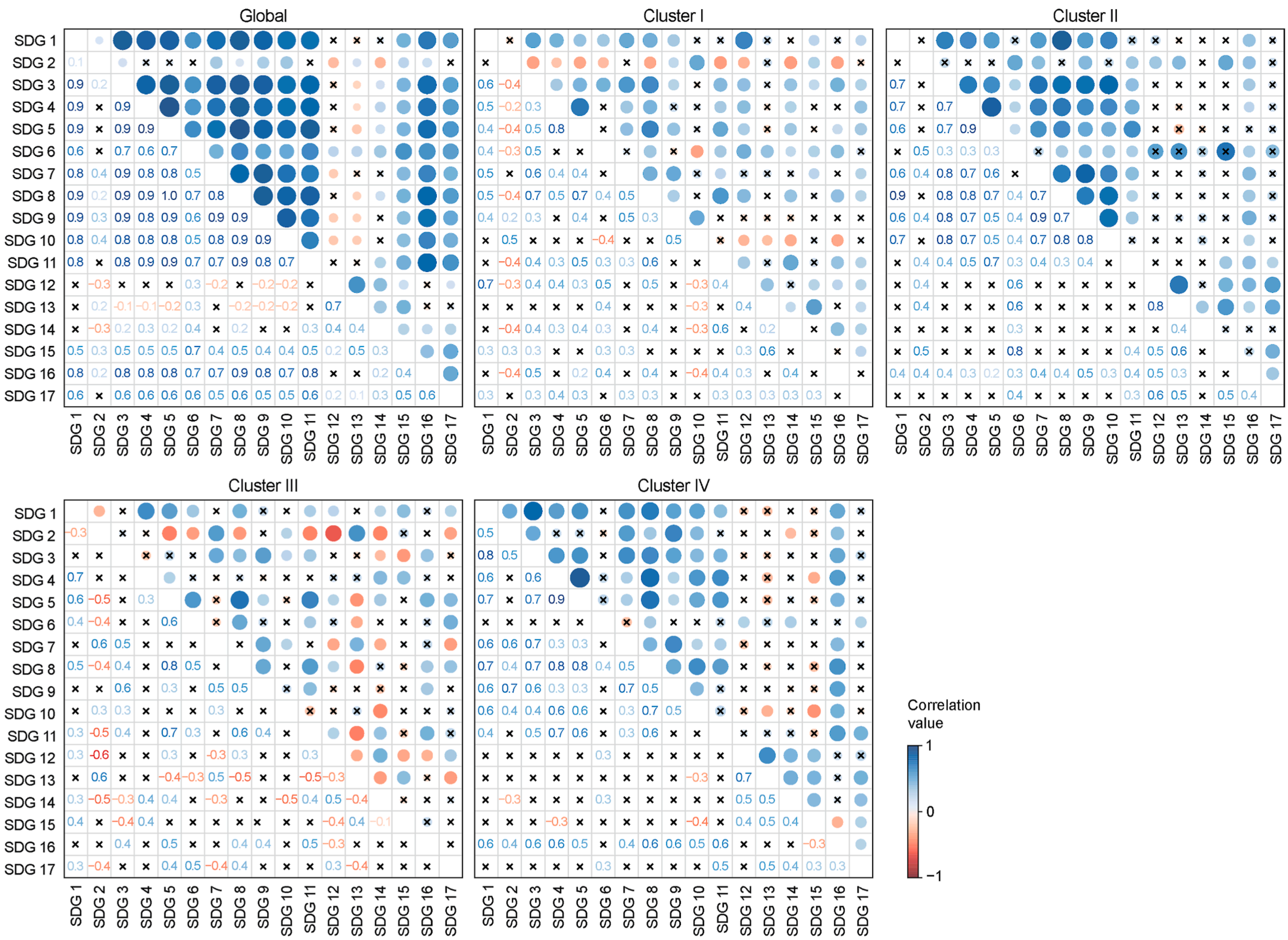

Fig. 3. SDG correlations for the four clustered types of transboundary basins. Only significant correlation coefficients ($p < 0.05$) are shown. Correlation pairs that did not pass the significance test are marked with a cross (×).

needed, and revealed emerging patterns and clustering of different types of SDG behavior across the basins. Considering, for example, SDG 6, which is emerging as the most important SDG globally, this study reveals the multifaceted interplay of factors—natural environments, stressors, management, and collaboration strategies—that determine the condition of water resources and the overall achievement of sustainable development in each transboundary basin.

For all transboundary basins defined as big (24 out of 310), the average SDG Index score was 35—that is, 7 points below the global average across all 310 basins (Supplementary Text S4). This difference highlights the importance of basin scale for overall sustainability achievement, likely due to the wider conditions and complexity ranges faced in larger basins. The following section further discusses the spatiotemporal variations in SDG achievement in and among the transboundary basins. Forthcoming research needs to delve deeper into the reasons for these variations, including cross-border and scale effects, and the synergies and trade-offs of different SDGs (Fig. 3) within transboundary basins [29,40,57,58].

4.2. Interpreting spatiotemporal variations in SDG achievement

The results of this study revealed substantial geographic variation in the average SDG Index scores of transboundary basins worldwide, with European basins notably performing better and African basins, on average, lagging considerably behind. The geographic SDGs score patterns may stem from a variety of factors, encompassing the influence of distinct regional policies, geographical attributes, climate conditions and their changes, economic dynamics, and infrastructure development [2,59–61].

For instance, Africa houses many transboundary basins (68), stemming from the historical legacy of arbitrary territorial divisions during the colonial era [62,63]. Furthermore, some transboundary basins in Africa are jointly managed by up to ten countries, amplifying the political complexities of water resource governance on the continent [1]. While this intricate situation could be one of the factors influencing the systematically lower SDG Index scores for African transboundary basins, other aspects such as economic capacity, institutional frameworks, and data availability may also play important roles. In contrast, Europe hosts the largest number of transboundary basins globally (88) and has developed one of the most comprehensive transboundary water governance systems since 1980 [64]. It is the only continent that has developed an overarching treaty framework, the United Nations Economic Commission for Europe Water Convention and its protocols [65]. With the introduction of the European Union (EU) Water Framework Directive in 2000, earlier water governance

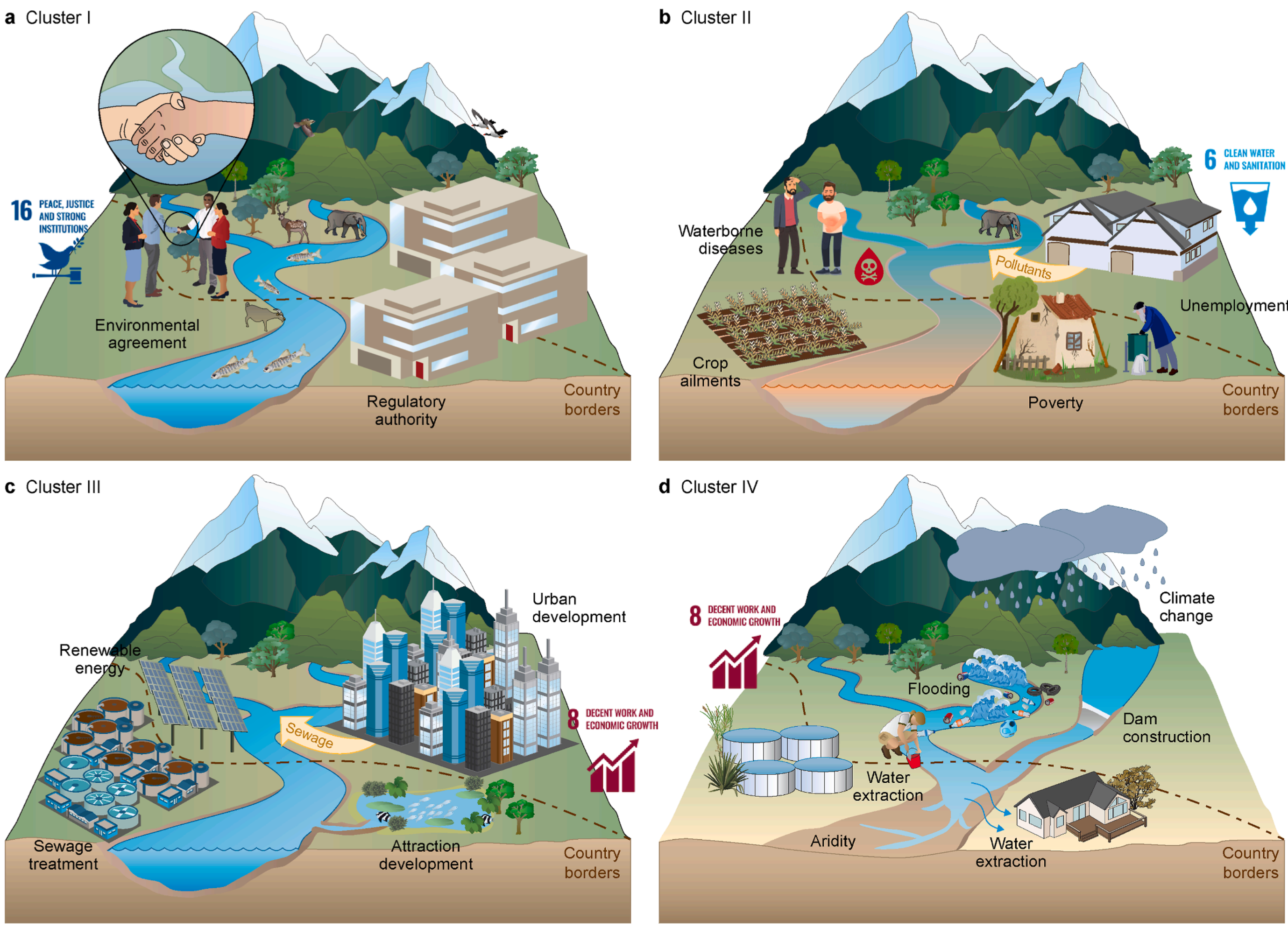

Fig. 4. Conceptual illustrations of the four basin type clusters, highlighting the most critical SDGs for each type. **a**, Cluster I (institutional governance basins) emphasizes institutional cooperation and governance with strong performance in SDG 16. **b,** Cluster II (sustained growth basins) faces multiple development challenges, including water quality, poverty, and health issues. **c,** Cluster III (inclusive growth basins) balances urban development and environmental protection with high SDG performance. **d,** Cluster IV (social coordination basins) is prone to extreme hydrological events requiring enhanced social coordination. The most critical SDGs for each cluster are labeled in the figure. For detailed information and specific cases, see Supplementary Text S3.

models in EU countries shifted toward a more comprehensive, coordinated, integrated, and universal approach—one applied to whole river basins and requiring stakeholder consultation and participation in decision-making and planning processes. Moreover, Europe experiences relatively few of the major anthropogenic pressures that are common and that significantly complicate hydropolitics elsewhere. For example, most European transboundary basins lack excessive population pressures, and both upstream and downstream countries are typically affluent, environmentally aware, and do not typically drive unilateral water development agendas [38]. Additionally, a longstanding history of cooperation characterizes most European transboundary basins, with environmental protection largely a shared political priority within the EU. Nonetheless, it is crucial to acknowledge that pollutants discharged and leaked from human activities have continuously and persistently degraded the water environment in some European basins [66], over long periods, and continue to do so [67,68]. Therefore, concerted sustainable development efforts are essential to alleviate mounting and persistent pollution pressures on the inland and coastal waters of these basins [69–71].

Crises and disasters occurring at various times can significantly impact sustainable development in transboundary basins, as in other parts of the world. For example, in 2019, a crisis emerged—the COVID-19 pandemic—that resulted in substantial excess mortality worldwide, with approximately 14.83 million deaths recorded between 2020 and 2021 [72]. This pandemic led to various challenges, including groundwater shortages resulting from increased water usage [73], difficulties accessing drinking water due to epidemic lockdowns, and sanitation issues stemming from inadequate facilities for informal settlement populations [74]. Indicator SDG 6 (population using at least basic drinking water services) (Fig. 2c) highlights the significant challenges of managing these multifaceted issues and the difficulties in transboundary basins that may already be facing long-term water security crises [75]. While societies and economies have resumed their development following the normalization of the pandemic, some lingering adverse impacts may persist, hindering sustainable development.

Some studies have indicated that certain transboundary basins in North America, particularly the Mississippi River Basin (SDG Index score 30) and the Nelson–Saskatchewan River Basin (36), have specific factors contributing to their relatively low SDG Index scores. These include limited forest cover, resulting in poor carbon sequestration capacity [76], significant intercontinental and

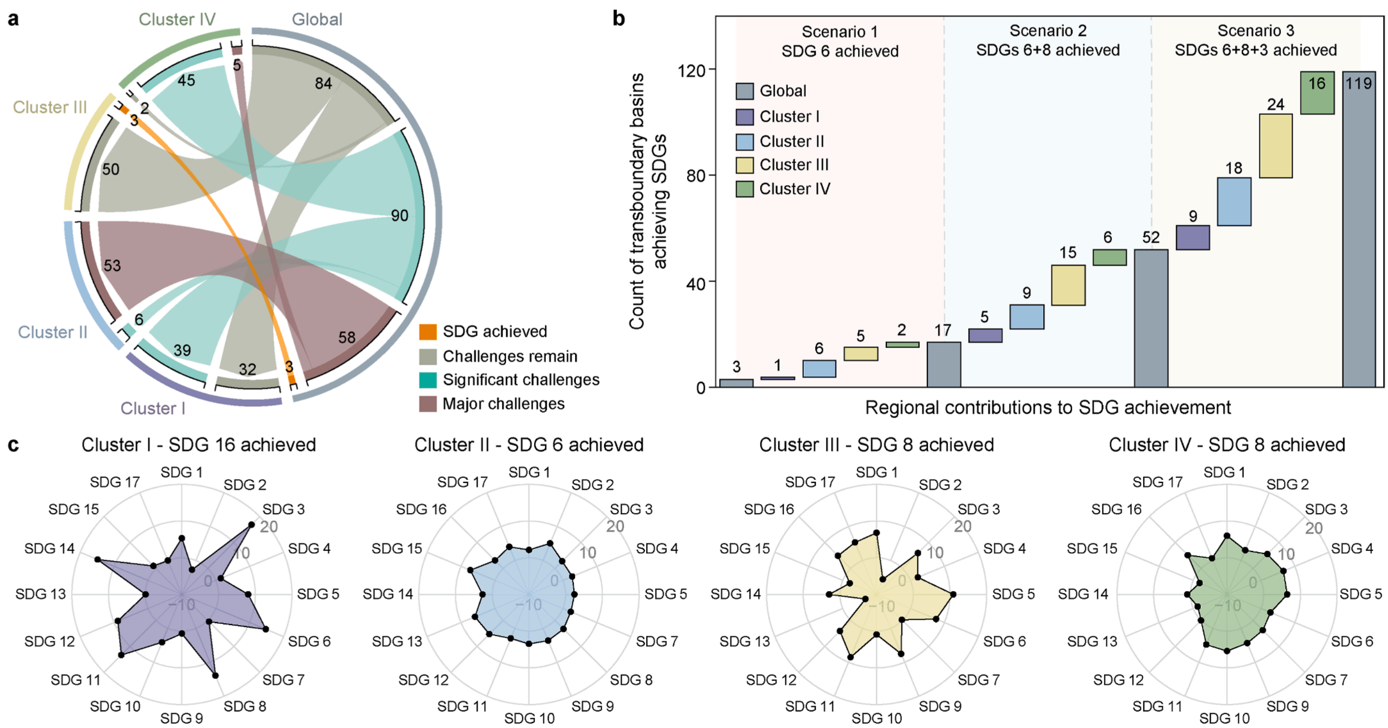

Fig. 5. Scenario analysis for promoting SDG achievement in transboundary basins. **a**, The number of transboundary basins at each level of SDG achievement globally and across the four cluster types in 2020. The numbers indicate the count of transboundary basins achieving each status. For detailed information, see Supplementary Table S8 **b**, The number of transboundary basins in the four cluster types for different scenarios of SDG achievement; the bars in different colors represent the number of transboundary basins achieving sustainable development. **c**, Additional numbers of transboundary basins achieving each individual SDG under different scenarios compared to the baseline, considering the achievement of the most critical SDGs for each cluster.

international resource distribution issues [77], and severe water pollution problems [78–80]. As such, although the North American SDG Index scores are relatively high overall, some transboundary basins in this region still face major challenges in sustainable development.

4.3. Study limitations and calls for further research

We combined the 2020 *Sustainable Development Report* data with the EGC approach to calculate the sustainable development dataset for transboundary basins. The selection of different SDG indicators, as well as the methods used for measuring SDG performance and clustering basins into different types, affected the results [40].

Furthermore, due to methodological and data collection limitations, the data in the *Sustainable Development Report* could not be directly compared across consecutive years [40]. We chose 2020 as the analysis year for this study, consistent with prior research that similarly evaluated the state of sustainable development using data exclusively from that year [81]. This limitation prevented a temporal analysis of SDG progress and its relationship with EGC over time. Moreover, while we used the EGC approach to allocate resources in other sectors based on the distribution of water resources, there is a need to examine the temporal relationship between EGC values and SDGs progress in greater depth.

For a comprehensive understanding of SDG progress, forthcoming research needs to delve deeper into variations in sustainable development progress over time and within smaller subbasins (more finely resolved basic calculation units) to quantify the variation ranges and decipher their causes within and among transboundary basins. Further exploration should also address how variations in sustainability development relate to various types of national development status (e.g., developed versus developing countries). Additionally, efforts should be directed toward improving and refining data and methodologies for examining the interactions between the upstream and downstream sections of transboundary basins. Greater consideration should also be given to regional downscaling of planetary boundaries [82–84] and the roles and interactions of such boundaries with the various SDGs.

4.4. Three complementary key qualitative aspects

Unlike prior studies that focused mainly on national or administratively/politically structured regional SDG achievements [85–87], this study integrated transboundary basin and EGC perspectives in assessing the natural–physical structuring (topographically determined bounding) of these basins and the associated regional sustainability achievements and inequalities, thereby offering a novel lens to evaluate disparities in SDG progress. The findings of this study complement the key insights gained from more qualitative global sustainability assessments. In particular, a heightened focus and emphasis are needed on the three main complementary aspects of sustainability.

Firstly, although SDG 5 (gender equality) did not emerge as the most critical factor for any basin type (cluster), its importance ranked among the top three for inclusive growth basins (Cluster III) and social coordination basins (Cluster IV) (Fig. 2b). Therefore, it is essential to enhance women's representation and capacity within the public administrative organizations involved in transboundary water management. Whereas previous research has underscored the importance of including women in negotiation and inclusivity efforts for fragile transboundary basins [88], we further highlight a persistent disparity in this context: although women are often responsible for household water security, they remain underrepresented in decision-making processes. This underrepresentation not only affects SDG 5 but also hampers progress toward the globally most important SDG 6 (clean water and sanitation), since women's participation in water governance is critical for sustainable water management. Furthermore, in regions prone to extreme hydrological events, women disproportionately bear additional responsibilities, such as collecting water during crises, highlighting the need for further improvement in achieving inclusive and sustainable water management [89,90].

Second, multiparty cooperation (SDG 16) remains a pivotal element for resolving water disputes. For instance, studies examining the Syr Darya Basin have highlighted that adhering to cooperation agreements benefits all basin countries [91]. However, our findings suggest considerable variations in cooperation effectiveness depending on governance structures and geopolitical contexts, with power asymmetries among riparian states often dictating the form and extent of collaboration. Another example is the Mekong River, which falls under the oversight of the Mekong River Commission. During a downstream drought in spring 2016, upstream countries released emergency reservoir water, which mitigated the crisis downstream and fostered regional cooperation [92]. In February 2024, UN Water conducted the Global Workshop on Droughts in Transboundary Basins, which emphasized that droughts are projected to become more frequent due to the impacts of climate change, with collaborative efforts in transboundary basins becoming increasingly imperative to sustainably meet—as well as mitigate and adapt to—these changes [93]. Currently, scholars are investigating transboundary cooperation to improve our understanding of stakeholders' strategies and behaviors [2,94], thereby supporting the design of more effective cooperation mechanisms that are crucial for transboundary SDG management.

Lastly, effective management of transboundary basins requires not only enhanced governance skills among professionals but also increased awareness of sustainable development among residents in these areas [95] (SDG 4). Douven et al. [96] indicated that the training of riparian professionals leads to improved implementation capacities. However, the sustainable development of transboundary basins cannot rely solely on the efforts of a few individuals. It also requires continuing public awareness and education. Adopting approaches such as role-playing or games in transboundary basin governance can foster awareness of sustainable development requirements from an early age and across a range of stakeholders [97,98]. Through such activities, diverse participants can assume roles different from their own, thereby nurturing various abilities for policy sensitivity, resource management, decision-making, and conflict mediation. This will also reinforce SDG 17 (partnerships for the goals) by fostering collaborative efforts across different sectors and stakeholders to achieve sustainable basin management.

5. Conclusions

This study developed and applied a systematic framework to assess SDGs progress across 310 transboundary basins worldwide. On average, these basins scored significantly lower than individual countries, reflecting their more complex socioenvironmental and governance conditions. We identified substantial regional disparities and grouped the basins into four types, each facing distinct sustainability challenges. Clean water (SDG 6), economic growth (SDG 8), and health (SDG 3) emerged as key goals associated with overall progress, particularly in 38 % of the basins, where targeted improvements in these areas could drive broader sustainability gains. The results also highlighted varying synergies and trade-offs among SDGs across basin types, underscoring the need for context-specific strategies. While the framework cannot address all the complexities of transboundary SDGs assessment, it provides a structured lens for understanding regional dynamics that are often overlooked in national evaluations. These findings can support future research and policy dialog on transboundary water governance and sustainable development.

CRediT authorship contribution statement

Yiqi Zhou: Writing – original draft, Visualization, Methodology, Conceptualization, Formal analysis. **Yanfeng Di:** Data curation, Writing – review & editing. **Xianjin Huang:** Writing – review & editing, Supervision. **Shilin Fu:** Writing – review & editing. **Xinxian Qi:** Methodology, Conceptualization, Formal analysis, Visualization, Writing – original draft. **Chao He:** Writing – review & editing. **Georgia Destouni:** Writing – review & editing, Supervision.

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.

Acknowledgements

Funding support for this work has been provided by the Major Projects of the National Social Science Foundation of China (23&ZD099), National Natural Science Foundation of China (42201301), Special Foundation of Science and Technology Innovation of Carbon Peak and Carbon Neutrality in Jiangsu Province (BK20220037), the “GeoX” Interdisciplinary Research Funds for the Frontiers Science Center for Critical Earth Material Cycling, Nanjing University (0209/14380116), the Special Fund of Jiangsu Province Carbon Peak and Carbon Neutral Technology Innovation (BK20220037), the Postgraduate Research & Practice Innovation Program of Jiangsu Province (KYCX24_0198), and the Swedish Research Council (VR, project 2022–04672).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ese.2025.100611.

References

[1] L. De Stefano, Jacob D. Petersen-Perlman, Eric A. Sproles, Jim Eynard, Aaron T. Wolf, Assessment of transboundary river basins for potential hydro-political tensions, Glob. Environ. Change (2017) 35–46, https://doi.org/10.1016/j.gloenvcha.2017.04.008, 2017.
[2] Adriano Vinca, Simon Parkinson, Keywan Riahi, Edward Byers, Afreen Siddiqi, Abubakr Muhammad, Ansir Ilyas, Nithiyanandam Yogeswaran, Barbara Willaarts, Piotr Magnuszewski, Muhammad Awais, Andrew Rowe, Djilali Ned, Transboundary cooperation a potential route to sustainable development in the Indus basin, Nat. Sustain. (2021) 331–339, https://doi.org/10.1038/s41893-020-00654-7, 2021.
[3] J. Eliasson, The rising pressure of global water shortages, Nature (2015) 6, https://doi.org/10.1038/517006a, 2015.
[4] W.W. Immerzeel, A.F. Lutz, M. Andrade, A. Bahl, H. Biemans, T. Bolch, S. Hyde, S. Brumby, B.J. Davies, A.C. Elmore, A. Emmer, M. Feng, A. Fernández, U. Haritashya, J.S. Kargel, M. Koppes, P.D.A. Kraaijenbrink, A.V. Kulkarni, P. A. Mayewski, S. Nepal, P. Pacheco, T.H. Painter, F. Pellicciotti, H. Rajaram, S. Rupper, A. Sinisalo, A.B. Shrestha, D. Viviroli, Y. Wada, C. Xiao, T. Yao, J.E. M. Baillie, Importance and vulnerability of the world's water towers, Nature (2020) 364–369, https://doi.org/10.1038/s41586-019-1822-y, 2020.
[5] Ahmed Munia Hafsa, Joseph H.A. Guillaume, Naho Mirumachi, Yoshihide Wada, Matti Kummu, How downstream sub-basins depend on upstream inflows to avoid scarcity: typology and global analysis of transboundary rivers, Hydrol. Earth Syst. Sci. (2018) 2795–2809, https://doi.org/

10.5194/hess-22-2795-2018, 2018.
[6] WWAP, The United Nations World Water Development Report 2015: Water for a Sustainable World, UNESCO, 2015.
[7] S.L. Pimm, C.N. Jenkins, R. Abell, T.M. Brooks, J.L. Gittleman, L.N. Joppa, P. H. Raven, C.M. Roberts, J.O. Sexton, The biodiversity of species and their rates of extinction, distribution, and protection, Science (2014), https://doi.org/10.1126/science.1246752, 2014.
[8] J. Best, Anthropogenic stresses on the world's big rivers, Nat. Geosci. 2019 (2019) 7–21, https://doi.org/10.1038/s41561-018-0262-x.
[9] David E.H. J. Gernaat, Patrick W. Bogaart, Detlef P. Van Vuuren, Hester Biemans, Robin Niessink, High-resolution assessment of global technical and economic hydropower potential, Nat. Energy (2017) 821–828, https://doi.org/10.1038/s41560-017-0006-y, 2017.
[10] Malgorzata Blicharska, Richard J. Smithers, Grzegorz Mikusiński, Patrik Rönnbäck, Paula A. Harrison, Måns Nilsson, William J. Sutherland, Lantbruksuniversitet Sveriges, Biodiversity's contributions to sustainable development, Nat. Sustain. (2019) 1083–1093, https://doi.org/10.1038/s41893-019-0417-9, 2019.
[11] UNEP and UNEP-DHI, Transboundary river basins: status and trends, United Nations Environ. Prog. 3 (2016) 1–2.
[12] Sujata Budhathoki, Prabin Rokaya, Karl-Erich Lindenschmidt, Impacts of future climate on the hydrology of a transboundary river basin in northeastern North America, J. Hydrol. (2022) 127317, https://doi.org/10.1016/j.jhydrol.2021.127317, 2022.
[13] Leila Eamen, Brouwer Roy, Saman Razavi, Integrated modelling to assess the impacts of water stress in a transboundary river basin: bridging local-scale water resource operations to a river basin economy, Sci. Total Environ. 2021 (2021) 149543, https://doi.org/10.1016/j.scitotenv.2021.149543.
[14] Nina Rholan Houngué, Kingsley Nnaemeka Ogbu, Adrian Delos Santos Almoradie, Mariele Evers, Evaluation of the performance of remotely sensed rainfall datasets for flood simulation in the transboundary mono river catchment, Togo and Benin, J. Hydrol. Reg. Stud. (2021) 100875, https://doi.org/10.1016/j.ejrh.2021.100875, 2021.
[15] Elisie Kåresdotter, Gustav Skoog, Haozhi Pan, Zahra Kalantari, Water-related conflict and cooperation events worldwide: a new dataset on historical and change trends with potential drivers, Sci. Total Environ. (2023) 161555, https://doi.org/10.1016/j.scitotenv.2023.161555, 2023.
[16] Bernard Baah-Kumi, Frank A. Ward, Transboundary water treaty design for poverty reduction and climate adaptation, J. Hydrol. (2022) 127409, https://doi.org/10.1016/j.jhydrol.2021.127409, 2022.
[17] Bronwyn Wake, Water wars, Nat. Clim. Change (2021) 84, https://doi.org/10.1038/s41558-021-00997-9, 2021.
[18] Daniel Althoff, Georgia Destouni, Global patterns in water flux partitioning: irrigated and rainfed agriculture drives asymmetrical flux to vegetation over runoff, One Earth (2023) 1246–1257, https://doi.org/10.1016/j.oneear.2023.08.002, 2023.
[19] Mohammed Basheer, Victor Nechifor, Alvaro Calzadilla, Solomon Gebrechorkos, David Pritchard, Nathan Forsythe, Jose M. Gonzalez, Justin Sheffield, Hayley J. Fowler, Julien J. Harou, Cooperative adaptive management of the Nile river with climate and socio-economic uncertainties, Nat. Clim. Change (2023) 48–57, https://doi.org/10.1038/s41558-022-01556-6, 2023.
[20] Georgia Destouni, Fernando Jaramillo, Carmen Prieto, Hydroclimatic shifts driven by human water use for food and energy production, Nat. Clim. Change (2013) 213–217, https://doi.org/10.1038/nclimate1719, 2013.
[21] F. Destouni G. Jaramillo, Local flow regulation and irrigation raise global human water consumption and footprint, Science (2015) 1248–1251, https://doi.org/10.7910/DVN/29779, 2015.
[22] Melissa McCracken, Chloé Meyer, Monitoring of transboundary water cooperation: Review of sustainable development goal indicator 6.5.2 methodology, J. Hydrol. (2018) 1–12, https://doi.org/10.1016/j.jhydrol.2018.05.013, 2018.
[23] Cameron Allen, Graciela Metternicht, Thomas Wiedmann, Matteo Pedercini, Greater gains for Australia by tackling all SDGs but the last steps will be the most challenging, Nat. Sustain. (2019) 1041–1050, https://doi.org/10.1038/s41893-019-0409-9, 2019.
[24] Pietro Gennari, Jose Rosero-Moncayo, Francesco N. Tubiello, The FAO contribution to monitoring SDGs for food and agriculture, Nat. Plants 2019 (2019) 1196–1197, https://doi.org/10.1038/s41477-019-0564-z.
[25] Yali Liu, Jianqing Du, Yanfen Wang, Xiaoyong Cui, Jichang Dong, Pan Gu, Hao Yanbin, Kai Xue, Hongbo Duan, Anquan Xia, Yi Hu, Zhi Dong, Bingfang Wu, Jürgen P. Kropp, Bojie Fu, Overlooked uneven progress across sustainable development goals at the global scale: challenges and opportunities, Innov. Amsterdam (2024) 100573, https://doi.org/10.1016/j.xinn.2024.100573, 2024.
[26] Yali Liu, Jianqing Du, Yanfen Wang, Xiaoyong Cui, Jichang Dong, Hao Yanbin, Kai Xue, Hongbo Duan, Anquan Xia, Yi Hu, Zhi Dong, Bingfang Wu, Xinquan Zhao, Bojie Fu, Evenness is important in assessing progress towards sustainable development goals, Natl. Sci. Rev. (2021) (2021) nwaa238, https://doi.org/10.1093/nsr/nwaa238.
[27] Felipe P.L. Melo, Luke Parry, Pedro H.S. Brancalion, Severino R.R. Pinto, Joaquim Freitas, Adriana P. Manhães, Paula Meli, Gislene Ganade, Robin L. Chazdon, Adding forests to the water–energy–food nexus, Nat. Sustain. (2021) 85–92, https://doi.org/10.1038/s41893-020-00608-z, 2021.
[28] S.D. Sasmito, M. Basyuni, A. Kridalaksana, M.F. Saragi-Sasmito, C.E. Lovelock, D. Murdiyarso, Challenges and opportunities for achieving sustainable development goals through restoration of Indonesia's mangroves, Nat. Ecol. Evol. (2023) 62–70, https://doi.org/10.1038/s41559-022-01926-5, 2023.
[29] M. Wang, A.B.G. Janssen, J. Bazin, M. Strokal, L. Ma, C. Kroeze, Accounting for interactions between sustainable development goals is essential for water pollution control in China, Nat. Commun. 2022 (2022) 730, https://doi.org/10.1038/s41467-022-28351-3.
[30] X. Wu, B. Fu, S. Wang, S. Song, D. Lusseau, Y. Liu, Z. Xu, J. Liu, Bleak prospects and targeted actions for achieving the sustainable development goals, Sci. Bull. (2023) 2838–2848, https://doi.org/10.1016/j.scib.2023.09.010, 2023.
[31] Huijuan Xiao, Sheng Bao, Jingzheng Ren, Zhenci Xu, Transboundary impacts on SDG progress across Chinese cities: a spatial econometric analysis, Sustain. Cities Soc. (2023) (2023) 104496, https://doi.org/10.1016/j.scs.2023.104496.
[32] Huijuan Xiao, Zhenci Xu, Jingzheng Ren, Ya Zhou, Ruojue Lin, Sheng Bao, Long Zhang, Shengfang Lu, Carman K.M. Lee, Jianguo Liu, Navigating Chinese cities to achieve sustainable development goals by 2030, Innov. Amsterdam (2022) 100288, https://doi.org/10.1016/j.xinn.2022.100288, 2022.
[33] Q. Xing, C. Wu, F. Chen, J. Liu, P. Pradhan, B.A. Bryan, T. Schaubroeck, L. R. Carrasco, A. Gonsamo, Y. Li, X. Chen, X. Deng, A. Albanese, Y. Li, Z. Xu, Intranational synergies and trade-offs reveal common and differentiated priorities of sustainable development goals in China, Nat. Commun. (2024) (2024) 2251, https://doi.org/10.1038/s41467-024-46491-6.
[34] Zhenci Xu, Towards carbon neutrality in China: a systematic identification of China's sustainable land-use pathways across multiple scales, Sustain. Prod. Consum. (2024) 167–178, https://doi.org/10.1016/j.spc.2023.12.008, 2024.
[35] Zhenci Xu, N. Sophia, Chau, Xiuzhi Chen, Jian Zhang, Yingjie Li, Thomas Dietz, Jinyan Wang, Julie A. Winkler, Fan Fan, Baorong Huang, Shuxin Li, Shaohua Wu, Anna Herzberger, Ying Tang, Dequ Hong, Yunkai Li, Jianguo Liu, Assessing progress towards sustainable development over space and time, Nature (2020) 74–78, https://doi.org/10.1038/s41586-019-1846-3, 2020.
[36] T.S. Amjath-Babu, Bikash Sharma, Roy Brouwer, Golam Rasul, Shahriar M. Wahid, Nilhari Neupane, Utsav Bhattarai, Sieber Stefan, Integrated modelling of the impacts of hydropower projects on the water-food-energy nexus in a transboundary Himalayan river basin, Appl. Energy (2019) 494–503, https://doi.org/10.1016/j.apenergy.2019.01.147, 2019.
[37] Mehebub Sahana, Md Kutubuddin Dhali, Sarah Lindley, Global disparities in transboundary river research have implications for sustainable management, Commun. Earth Environ. 2024 (2024), https://doi.org/10.1038/s43247-024-01928-0.
[38] Jianqing Du, Yali Liu, Zhenci Xu, Hongbo Duan, Minghao Zhuang, Yi Hu, Qiao Wang, Jichang Dong, Yanfen Wang, Bojie Fu, Global effects of progress towards sustainable development goals on subjective well-being, Nat. Sustain. (2024) 360–367, https://doi.org/10.1038/s41893-024-01270-5, 2024.
[39] Guido Schmidt-Traub, Christian Kroll, Katerina Teksoz, David Durand-Delacre, Jeffrey D. Sachs, National baselines for the sustainable development goals assessed in the SDG index and dashboards, Nat. Geosci. (2017) 547–555, https://doi.org/10.1038/ngeo2985, 2017.
[40] Xutong Wu, Bojie Fu, Shuai Wang, Shuang Song, Yingjie Li, Zhenci Xu, Yongping Wei, Jianguo Liu, Decoupling of SDGs followed by re-coupling as sustainable development progresses, Nat. Sustain. (2022) 452–459, https://doi.org/10.1038/s41893-022-00868-x, 2022.
[41] Yingchun Ge, Xin Li, Ximing Cai, Xiangzheng Deng, Feng Wu, Zhongyuan Li, Wenfei Luan, Converting UN sustainable development goals (SDGs) to decision-making objectives and implementation options at the river basin scale, Sustainability (2018) 1056, https://doi.org/10.3390/su10041056, 2018.
[42] A. Druckman, T. Jackson, Measuring resource inequalities: the concepts and methodology for an area-based Gini coefficient, Ecol. Econ. (2008) 242–252, https://doi.org/10.1016/j.ecolecon.2007.12.013, 2008.
[43] Yongqiang Zhang, Congcong Li, Francis H.S. Chiew, David A. Post, Xuanze Zhang, Ning Ma, Jing Tian, Dongdong Kong, L. Ruby Leung, Qiang Yu, Jiancheng Shi, Changming Liu, Southern Hemisphere dominates recent decline in global water availability, Science (American Association for the Advancement of Science) (2023) 579–584, https://doi.org/10.1126/science.adh0716, 2023.
[44] Arunima Malik, Manfred Lenzen, Mengyu Li, Camille Mora, Sarah Carter, Stefan Giljum, Stephan Lutter, Jorge Gómez-Paredes, Polarizing and equalizing trends in international trade and sustainable development goals, Nat. Sustain. (2024) 1359–1370, https://doi.org/10.1038/s41893-024-01397-5, 2024.
[45] Yuantao Yang, Shen Qu, Bofeng Cai, Sai Liang, Zhaohua Wang, Jinnan Wang, Ming Xu, Mapping global carbon footprint in China, Nat. Commun. (2020), https://doi.org/10.1038/s41467-020-15883-9, 2020.
[46] Carsten F. Dormann, Jane Elith, Sven Bacher, Carsten Buchmann, Gudrun Carl, Gabriel Carré, Jaime R. García Marquéz, Bernd Gruber, Bruno Lafourcade, Pedro J. Leitão, Tamara Münkemüller, Colin McClean, Patrick E. Osborne, Björn Reineking, Boris Schröder, Andrew K. Skidmore, Damaris Zurell, Sven Lautenbach, Collinearity: a review of methods to deal with it and a simulation study evaluating their performance, Ecography (2013) 27–46, https://doi.org/10.1111/j.1600-0587.2012.07348.x, 2013.
[47] Wenjun Wu, Peiqi Gao, Qiming Xu, Tianlong Zheng, Jie Zhang, Jinnan Wang, Nianlei Liu, Jun Bi, Yuanchun Zhou, Hongqiang Jiang, How to allocate discharge permits more fairly in China?-A new perspective from watershed and regional allocation comparison on socio-natural equality, Sci. Total Environ. (2019) 390–401, https://doi.org/10.1016/j.scitotenv.2019.05.104, 2019.

[48] Tao Sun, Hongwei Zhang, Yuan Wang, Xiangming Meng, Chenwan Wang, The application of environmental Gini coefficient (EGC) in allocating wastewater discharge permit: the case study of watershed total mass control in Tianjin, China, Resour. Conserv. Recycl. (2010) 601–608, https://doi.org/10.1016/j.resconrec.2009.10.017, 2010.
[49] Yu Sen, Li He, Hongwei Lu, An environmental fairness based optimisation model for the decision-support of joint control over the water quantity and quality of a river basin, J. Hydrol. (2016) 366–376, https://doi.org/10.1016/j.jhydrol.2016.01.051, 2016.
[50] J.D. Sachs, From millennium development goals to sustainable development goals, Lancet (2012) 2206–2211, 2012.
[51] J.D. Sachs, G. Schmidt-Traub, Global fund lessons for sustainable development goals, Science (2017) 32–33, https://doi.org/10.1126/science.aai9380, 2017.
[52] Halidu Abu-Bakar, Leon Williams, Stephen H. Hallett, Quantifying the impact of the COVID-19 lockdown on household water consumption patterns in England, npj Clean Water (2021) 1–9, https://doi.org/10.1038/s41545-021-00103-8, 2021.
[53] Alma Yunuen Raya-Tapia, Xate Geraldine Sánchez-Zarco, Brenda Cansino-Loeza, César Ramírez-Márquez, José María Ponce-Ortega, A typology country framework to evaluate the SDG progress and food waste reduction based on clustering analysis, Trends Food Sci. Technol. 2024 (2024) 104304, https://doi.org/10.1016/j.tifs.2023.104304.
[54] Flannery Dolan, Jonathan Lamontagne, Robert Link, Mohamad Hejazi, Patrick Reed, Jae Edmonds, Evaluating the economic impact of water scarcity in a changing world, Nat. Commun. (2021) 1915, https://doi.org/10.1038/s41467-021-22194-0, 2021.
[55] Yiqi Zhou, Shan Zou, Weili Duan, Yaning Chen, Kaoru Takara, Yanfeng Di, Analysis of energy carbon emissions from agroecosystems in Tarim river basin, China: a pathway to achieve carbon neutrality, Appl. Energy (2022) 119842, https://doi.org/10.1016/j.apenergy.2022.119842, 2022.
[56] Haiyang Shi, Geping Luo, Hongwei Zheng, Chunbo Chen, Olaf Hellwich, Jie Bai, Tie Liu, Shuang Liu, Jie Xue, Peng Cai, Huili He, Friday Uchenna Ochege, Tim Van de Voorde, Philippe de Maeyer, A novel causal structure-based framework for comparing a basin-wide water–energy–food–ecology nexus applied to the data-limited Amu Darya and Syr Darya river basins, Hydrol. Earth Syst. Sci. (2021) 901–925, https://doi.org/10.5194/hess-25-901-2021, 2021.
[57] Francesco Fuso Nerini, Julia Tomei, Long Seng To, Iwona Bisaga, Priti Parikh, Mairi Black, Aiduan Borrion, Catalina Spataru, Vanesa Castán Broto, Gabrial Anandarajah, Ben Milligan, Yacob Mulugetta, Mapping synergies and trade-offs between energy and the sustainable development goals, Nat. Energy (2018) 10–15, https://doi.org/10.1038/s41560-017-0036-5, 2018.
[58] H. Xiao, S. Bao, J. Ren, Z. Xu, S. Xue, J. Liu, Global transboundary synergies and trade-offs among sustainable development goals from an integrated sustainability perspective, Nat. Commun. (2024) 500, https://doi.org/10.1038/s41467-023-44679-w, 2024.
[59] Thomas Bernauer, Tobias Böhmelt, International conflict and cooperation over freshwater resources, Nat. Sustain. (2020) 350–356, https://doi.org/10.1038/s41893-020-0479-8, 2020.
[60] Bojie Fu, Xutong Wu, Shuai Wang, Wenwu Zhao, Scientific principles for accelerating the sustainable development goals, Geogr. Sustain. (2024) 157–159, https://doi.org/10.1016/j.geosus.2024.01.005, 2024.
[61] Jianguo Liu, Vanessa Hull, H. Charles J. Godfray, David Tilman, Peter Gleick, Holger Hoff, Claudia Pahl-Wostl, Zhenci Xu, Min Gon Chung, Jing Sun, Shuxin Li, Nexus approaches to global sustainable development, Nat. Sustain. (2018) 466–476, https://doi.org/10.1038/s41893-018-0135-8, 2018.
[62] Claudious Chikozho, Pathways for building capacity and ensuring effective transboundary water resources management in Africa: revisiting the key issues, opportunities and challenges, Phys. Chem. Earth, Parts A/B/C (2014) 72–82, https://doi.org/10.1016/j.pce.2014.11.004, 2014.
[63] Geert-Jan Nijsten, Greg Christelis, Karen G. Villholth, Eberhard Braune, Cheikh Bécaye Gaye, Transboundary aquifers of Africa: review of the current state of knowledge and progress towards sustainable development and management, J. Hydrol.: Reg. Stud. 2018 (2018) 21–34, https://doi.org/10.1016/j.ejrh.2018.03.004.
[64] Y. Mylopoulos, E. Kolokytha, E. Kampragou, D. Vagiona, Combined methodology for transboundary river basin management in Europe. Application in the Nestos-Mesta catchment area, Water Resour. Manag. (2008) 1101–1112, https://doi.org/10.1007/s11269-007-9214-8, 2008.
[65] Stella Tsani, Phoebe Koundouri, Ebun Akinsete, Resource management and sustainable development: a review of the European water policies in accordance with the United Nations' sustainable development goals, Environ. Sci. Pol. (2020) 570–579, https://doi.org/10.1016/j.envsci.2020.09.008, 2020.
[66] Tim van Emmerik, Caspar Roebroek, Winnie de Winter, Paul Vriend, Marijke Boonstra, Merijn Hougee, Riverbank macrolitter in the Dutch Rhine-Meuse delta, Environ. Res. Lett. (2020) 104087, https://doi.org/10.1088/1748-9326/abb2c6, 2020.
[67] Jacopo Cantoni, Zahra Kalantari, Georgia Destouni, Legacy contributions to diffuse water pollution: data-driven multi-catchment quantification for nutrients and carbon, Sci. Total Environ. (2023) (2023) 163092, https://doi.org/10.1016/j.scitotenv.2023.163092.
[68] Georgia Destouni, Jacopo Cantoni, Zahra Kalantari, Distinguishing active and legacy source contributions to stream water quality: comparative quantification for chloride and metals, Hydrol. Process. (2021), https://doi.org/10.1002/hyp.14280, 2021.
[69] Nandita B. Basu, Kimberly J. Van Meter, Danyka K. Byrnes, Philippe Van Cappellen, Brouwer Roy, Brian H. Jacobsen, Jerker Jarsjö, David L. Rudolph, Maria C. Cunha, Natalie Nelson, Bhattacharya Ruchi, Georgia Destouni, Søren Bøye Olsen, Managing nitrogen legacies to accelerate water quality improvement, Nat. Geosci. (2022) 97–105, https://doi.org/10.1038/s41561-021-00889-9, 2022.
[70] Georgia Destouni, Ida Fischer, Carmen Prieto, Water quality and ecosystem management: data-driven reality check of effects in streams and lakes, Water Resour. Res. (2017) 6395–6406, https://doi.org/10.1002/2016WR019954, 2017.
[71] Georgia Destouni, Jerker Jarsjö, Zones of untreatable water pollution call for better appreciation of mitigation limits and opportunities, Wiley Interdiscip. Rev. Water (2018), https://doi.org/10.1002/wat2.1312, 2018.
[72] William Msemburi, Ariel Karlinsky, Victoria Knutson, Serge Aleshin-Guendel, Somnath Chatterji, Jon Wakefield, The WHO estimates of excess mortality associated with the COVID-19 pandemic, Nature (London) (2023) 130–137, https://doi.org/10.1038/s41586-022-05522-2, 2023.
[73] Sayeed Abu, Md Hafizur Rahman, Jochen Bundschuh, Indika Herath, Fahad Ahmed, Prosun Bhattacharya, Mohammad Raihan Tariq, Faujhia Rahman, Md Tarikul Islam Joy, Mohammad Tazrian Abid, Nondo Saha, M. Tasdik Hasan, Handwashing with soap: a concern for overuse of water amidst the COVID-19 pandemic in Bangladesh, Groundw. Sustain. Dev. (2021) 100561, https://doi.org/10.1016/j.gsd.2021.100561, 2021.
[74] Nishat Shermin, Sk Nafiz Rahaman, Assessment of sanitation service gap in urban slums for tackling COVID-19, J. Urban Manag. (2021) 230–241, https://doi.org/10.1016/j.jum.2021.06.003, 2021.
[75] Bellie Sivakumar, COVID-19 and water, Stoch. Environ. Res. Risk Assess. (2021) 531–534, https://doi.org/10.1007/s00477-020-01837-6, 2021.
[76] Jinglan Cui, Miao Zheng, Zihao Bian, Naiqing Pan, Hanqin Tian, Xiuming Zhang, Ziyue Qiu, Jianming Xu, Baojing Gu, Elevated CO2 levels promote both carbon and nitrogen cycling in global forests, Nat. Clim. Change (2024) 511–517, https://doi.org/10.1038/s41558-024-01973-9, 2024.
[77] Leandro E. Miranda, Giancarlo Coppola, Hunter R. Hatcher, Matthew B. Jargowsky, Zachary S. Moran, Michael C. Rhodes, A bird's-eye view of reservoirs in the Mississippi basin tips a need for large-scale coordination, Fish Fish. (2021) 128–140, https://doi.org/10.1111/faf.12509, 2021.
[78] Katie Meehan, Jason R. Jurjevich, Lucy Everitt, Nicholas M.J. W. Chun, Sherrill Justin, Urban inequality, the housing crisis and deteriorating water access in US cities, Nat. Cities (2025) 93–103, https://doi.org/10.1038/s44284-024-00180-z, 2025.
[79] J. Tom Mueller, Stephen Gasteyer, The widespread and unjust drinking water and clean water crisis in the United States, Nat. Commun. (2021), https://doi.org/10.1038/s41467-021-23898-z, 2021.
[80] Sarah Stackpoole, Robert Sabo, James Falcone, Lori Sprague, Long-term Mississippi river trends expose shifts in the river load response to watershed nutrient balances between 1975 and 2017, Water Resour. Res. (2021), https://doi.org/10.1029/2021WR030318, 2021.
[81] Xutong Wu, Bojie Fu, Shuai Wang, Yanxu Liu, Ying Yao, Yingjie Li, Zhenci Xu, Jianguo Liu, Three main dimensions reflected by national SDG performance, Innov. Amsterdam (2023) 100507, https://doi.org/10.1016/j.xinn.2023.100507, 2023.
[82] Anita D. Bayer, Sven Lautenbach, Almut Arneth, Benefits and trade-offs of optimizing global land use for food, water, and carbon, Proc. Natl. Acad. Sci. (2023), https://doi.org/10.1073/pnas.2220371120, 2023.
[83] K. Richardson, W. Steffen, W. Lucht, J. Bendtsen, S.E. Cornell, J.F. Donges, M. Druke, I. Fetzer, G. Bala, W. von Bloh, G. Feulner, S. Fiedler, D. Gerten, T. Gleeson, M. Hofmann, W. Huiskamp, M. Kummu, C. Mohan, D. Nogues-Bravo, S. Petri, M. Porkka, S. Rahmstorf, S. Schaphoff, K. Thonicke, A. Tobian, V. Virkki, L. Wang-Erlandsson, L. Weber, J. Rockstrom, Earth beyond six of nine planetary boundaries, Sci. Adv. (2023) eadh2458, https://doi.org/10.1126/sciadv.adh2458, 2023.
[84] Arne Tobian, Dieter Gerten, Ingo Fetzer, Sibyll Schaphoff, Lauren Seaby Andersen, Sarah Cornell, Johan Rockström, Climate change critically affects the status of the land-system change planetary boundary, Environ. Res. Lett. (2024) 54060, https://doi.org/10.1088/1748-9326/ad40c2, 2024.
[85] Cameron Allen, Michael Reid, John Thwaites, Rod Glover, Tahl Kestin, Assessing national progress and priorities for the Sustainable Development Goals (SDGs): experience from Australia, Sustain. Sci. (2020) 521–538, https://doi.org/10.1007/s11625-019-00711-x, 2020.
[86] Lone Kørnøv, Ivar Lyhne, Juanita Gallego Davila, Linking the UN SDGs and environmental assessment: towards a conceptual framework, Environ. Impact Assess. Rev. 2020 (2020) 106463, https://doi.org/10.1016/j.eiar.2020.106463.
[87] Emilia Ravn Boess, Lone Kørnøv, Ivar Lyhne, Maria Rosário Partidário, Integrating SDGs in environmental assessment: unfolding SDG functions in emerging practices, Environ. Impact Assess. Rev. 2021 (2021) 106632, https://doi.org/10.1016/j.eiar.2021.106632.
[88] Sam Wong, A post-critical perspective to community participation in transboundary water governance – a case study of the Volta river basin in West Africa, Geoforum (2016) 83–92, https://doi.org/10.1016/j.geoforum.2016.10.012, 2016.
[89] Lynette de Silva, Jennifer C. Veilleux, J. Marian, Neal the Role of Women in Transboundary Water Dispute Resolution, Springer International Publishing, Cham, 2018.

[90] Martina Klimes, David Michel, Elizabeth Yaari, Phillia Restiani, Water diplomacy: the intersect of science, policy and practice, J. Hydrol. (2019) 1362–1370, https://doi.org/10.1016/j.jhydrol.2019.02.049, 2019.
[91] Rebecca L. Teasley, Daene C. McKinney, Calculating the benefits of transboundary river basin cooperation: syr Darya basin, J. Water Resour. Plan. Manage. ASCE (2011) 481–490, https://doi.org/10.1061/(ASCE)WR.1943-5452.0000141, 2011.
[92] Yu Yang, Pingzhong Tang, Jianshi Zhao, Bo Liu, Dennis Mclaughlin, Evolutionary cooperation in transboundary river basins, Water Resour. Res. (2019) 9977–9994, https://doi.org/10.1029/2019WR025608, 2019.
[93] Lukas Hermwille, Adis Dzebo, Gabriela Ileana Iacobuţă, Wolfgang Obergassel, Global stocktake and the SDG midterm review as opportunities for integration, Nat. Clim. Change (2023) 1002–1004, https://doi.org/10.1038/s41558-023-01813-2, 2023.
[94] Shlomi Dinar, David Katz, Lucia De Stefano, Brian Blankespoor, Do treaties matter? Climate change, water variability, and cooperation along transboundary river basins, Polit. Geogr. (2019) 162–172, https://doi.org/10.1016/j.polgeo.2018.08.007, 2019.
[95] Paul G. Bain, Pieter M. Kroonenberg, Lars-Olof Johansson, Taciano L. Milfont, Charlie R. Crimston, Tim Kurz, Ekaterina Bushina, Carolina Calligaro, Christophe Demarque, Yanjun Guan, Joonha Park, Public views of the sustainable development goals across countries, Nat. Sustain. (2019) 819–825, https://doi.org/10.1038/s41893-019-0365-4, 2019.
[96] W. Douven, M.L. Mul, B. Fernández-Álvarez, S. Lam Hung, N. Bakker, G. Radosevich, P. van der Zaag, Enhancing capacities of riparian professionals to address and resolve transboundary issues in international river basins: experiences from the Lower Mekong river basin, Hydrol. Earth Syst. Sci. (2012) 3183–3197, https://doi.org/10.5194/hess-16-3183-2012, 2012.
[97] Pieter Bots, Els van Daalen, Functional design of games to support natural resource management policy development, Simulat. Gaming (2007) 512–532, https://doi.org/10.1177/1046878107300674, 2007.
[98] W. Douven, M.L. Mul, L. Son, N. Bakker, G. Radosevich, A. Hendriks, Games to create awareness and design policies for transboundary cooperation in river basins: lessons from the shariva game of the Mekong River commission, Water Resour. Manag. (2014) 1431–1447, https://doi.org/10.1007/s11269-014-0562-x, 2014.