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An approach based on ecosystem services for assessing progress towards sustainable development goals at both national and provincial levels in China

Ying Huang[1], Ao Kang[2], Zhuoting Jiang[2], Jin Li[3], Yingjie Ma[4]✉, Xiaoyu Gan[2] & Bo Zhou[2]

Ecosystem services (ESs), the benefits nature provides to people, are an important basis for fulfilling sustainable development goals (SDGs). Therefore, an ES-based approach will help deepen our understanding of the relationships between natural systems and human well-being and provide co-benefit pathways for sustainable development. However, monitoring progress towards achieving the SDGs based on the contributions of ESs to SDGs is lacking. Using the linkages between ESs and SDGs, this study quantified progress towards the SDGs in China from 2000 to 2020 and determined future development priorities at both the national and provincial levels. Our results indicated that (1) during the period 2000–2020, China showed decreasing trends in the 11 SDGs and SDG index scores; (2) there were significant differences in the scores for SDGs and the SDG index across 31 provinces; (3) SDG 3, SDG6, SDG11, SDG13, and SDG15 were recognized as the highest national priorities, concerning health and environment; and (4) 31 provinces faced diverse economic, social, and environmental development challenges. The ES-based approach may assist policy-makers in monitoring and comparing progress towards the SDGs in an integrated and composite way, prioritizing local action, and providing a scientific basis for formulating policies to achieve SDG implementation.

Keywords Sustainable development, Sustainable development goals, Performance assessment, Ecosystem service-based approach, China

Having noted that ecological and social issues are becoming increasingly critical and urgent, the 2030 Agenda for Sustainable Development was officially launched by the United Nations Sustainable Development Summit in September 2015. It consists of 17 universal sustainable development goals (SDGs) with 169 nested targets to ensure a balanced and sustainable future in social, economic, and environmental dimensions[1]. Several countries around the world have adopted the SDGs as a holistic framework for addressing local pressing development issues faced by humans, such as food insecurity, gender discrimination, environmental pollution, and ecological degradation[2]. To turn SDGs into problem-solving tools, it is essential to objectively assess progress towards achieving the SDGs, which can have a direct impact on tracking human efforts towards sustainability and support locally relevant policies, strategies, and programs that incorporate social, economic, and environmental dimensions[3]. In this view, SDG performance assessment is a consensus in the international community, as well as a common action.

Numerous studies have monitored the regional performance of the SDGs by constructing assessment indicator frameworks[4,5]. As an example, Allen[6] developed an SDGs assessment framework and assessed national progress towards the SDGs in Australia through 86 SDG targets and 144 corresponding indicators. Huan[7] constructed a complete indicator framework and utilized 108 indicators to assess progress towards achieving four-dimensional SDGs, including society, economy, environment, means of implementation, and cooperation, in 15 countries along the "Belt and Road". In a study by Xu[8], an framework comprising 17 SDGs and 119

[1]Art College of Chinese and Asean Arts, School of Fine Arts and Design, Chengdu University, Chengdu 610106, People's Republic of China. [2]College of Architecture and Environment, Sichuan University, Chengdu 610064, People's Republic of China. [3]School of Civil Engineering, Sichuan University of Science and Technology, Zigong 643000, People's Republic of China. [4]College of Literature and Journalism, Chengdu University, Chengdu 610106, People's Republic of China. ✉email: mayingjienew@163.com

corresponding indicators was used to measure spatio-temporal progress towards all SDGs in China during 2000–2015. However, the relevant (and available) data on which these indicators are based are mainly provided by statistical agencies, resulting in inconsistent statistical standards and methodologies[9]. As a consequence, the current SDG assessment fails to adequately reflect the potential trade-offs between the environment and human society, which in turn hinders the eventual realization of the SDGs in an integrated manner.

In recent years, several studies have demonstrated using composite indicators that integrate data from the biophysical, social, and economic spheres can help monitor the status of SDGs. As one of the composite indicators, the ecosystem service (ES) indicator is based on comprehensive environmental and socio-economic data with integrated biophysical and socio-economic characteristics in coupled human-nature systems[10,11]. ES indicators are capable of providing information about how natural resources contribute to human well-being[12,13]. Therefore, the ES-based approach can help establish linkages between natural systems and human well-being for targeted policy action[14] and should be considered in monitoring the performance of the SDGs[15–18].

A growing literature has proven the multiple linkages between ES indicators and SDGs and the delivery of one or more ESs could make important contributions to achieving 41 targets across 14 SDGs by functioning in provision, regulation, support, and culture[19,20]. In the context of more than 12 SDGs, notably SDG6 (Clean Water and Sanitation), SDG13 (Climate Action), SDG14 (Life Below Water), and SDG15 (Life on Land), the provision of food and water, carbon storage, and habitat & biodiversity contribute significantly to their achievement[21]. Moreover, even one ES (e.g. soil conservation) is found to have strong linkages to multiple SDGs (e.g. SDG 6, SDG13, and SDG15). There is a strong link between food provision and 3 SDGs, including SDG1 (No Poverty), SDG2 (Zero Hunger), and SDG13 (Climate Action)[22]. Thus, applying ES-based approaches in SDG performance assessment is therefore essential. Despite this, monitoring progress towards achieving the SDGs based on the critical roles of ESs in SDGs is still lacking, making it difficult for policymakers to incorporate them into development plans[22,23].

Despite the significance of sustainable development goals for humankind, progress in their implementation has varied from country to country. This means that the SDGs cannot be achieved simultaneously in different countries[24]. For instance, the most prioritized SDGs in Africa are those related to food security, energy, employment, and industrialization, while at the global level, the most important SDGs are also related to global climate change, ecological environment, and human health[25]. Accordingly, achieving the SDGs needs to work together from all stakeholders at local, regional, and national levels and the priorities of SDGs should be determined at different levels[26].

Over the past few decades, China has made great progress in social and economic development since the reforms and opening-up policies were implemented in 1978. There is no doubt that China has become the second-largest economy in the world[27]. In parallel, the landscape has changed dramatically, resulting in imbalances in its economy and environment[28]. Therefore, it is of strategic and practical importance to monitor the fulfillment status of the SDGs and identify the development priorities for sustainable decision-making in China. The ultimate goal of ES-based research is to provide scientific guidance and reference for decision-making to promote human well-being and achieve sustainable development[29,30]. Recently, most of these research efforts in China have been based on the quantification of the biophysical or economic values of ESs[31–35], trade-offs/synergies between ESs[36,37], ES bundles[38,39], the balance between the supply and demand of ESs[40–42], and ES flow[43,44]. For example, quantifying and mapping the spatial patterns of ESs is essential to help clarify the current situation of ESs, understand the impacts of driving forces on ESs, and develop localized ecological management[45]. Exploring the tradeoffs and synergies between different ESs can help decision-makers identify potential trade-offs, avoid unwanted and possibly irreversible effects, and offer a win–win solution[46]. Match analysis of ES supply and demand contributes to identifying hotspot and coldspot areas of ES supply and demand, determining the key areas of mismatched supply and demand of ESs, and formulating local strategies that promote the balance of supply and demand of ESs[47]. In order to efficiently manage multiple ESs, policy makers should obtain the types and distributions of the ES bundles for a better understanding of the interactions among multiple ESs[48] and capture distant interdependencies and impacts[49]. ES flow analysis is a prerequisite for further connecting production and human beneficiaries, identifying spatial dissimilarities between provisioning and benefitting areas, and enhancing the delivery of ESs to beneficiaries[50]. Numerous studies have assessed SDG progress in China at the national and subnational levels through environmental and socioeconomic indicators, however, how ES knowledge and methods can guide decision-making in regional sustainable development has not yet been thoroughly examined, rendering it difficult to effectively represent the direct link between ecosystems and human well-being. In summary, for decision-making in China, it is imperative to apply the ES-based approach to assess progress towards achieving the SDGs and differentiate the prioritized SDGs that incorporate social, economic, and environmental dimensions.

Based on the understanding of the critical roles of ESs in the SDGs, this study aimed to track progress towards the achievement of the SDGs in China from 2000 to 2020. The objectives of this work were to (1) analyze the temporal changes of ESs in China from 2000 to 2020, (2) assess the SDGs and SDG index based on the "ES-SDG linkages" at both the national and provincial levels, and (3) define national and provincial development priorities according to the SDG dashboards. The findings may assist policy-makers in monitoring and comparing progress towards the SDGs, prioritizing local action, and providing a scientific basis for formulating policies to achieve SDG implementation by 2030.

Materials and methods

Study area

China is located in eastern Asia, between 3° 51′–53° 33′ N, 73° 33′–135° 05′ E. It consists of five major regions of West, North, Southwest, Middle, and East coastal China, and covers a total area of approximately 9.6 million km^2 (Fig. 1). Vast territory forms complex topography and diverse climates in China[51]. The elevation ranges from -197

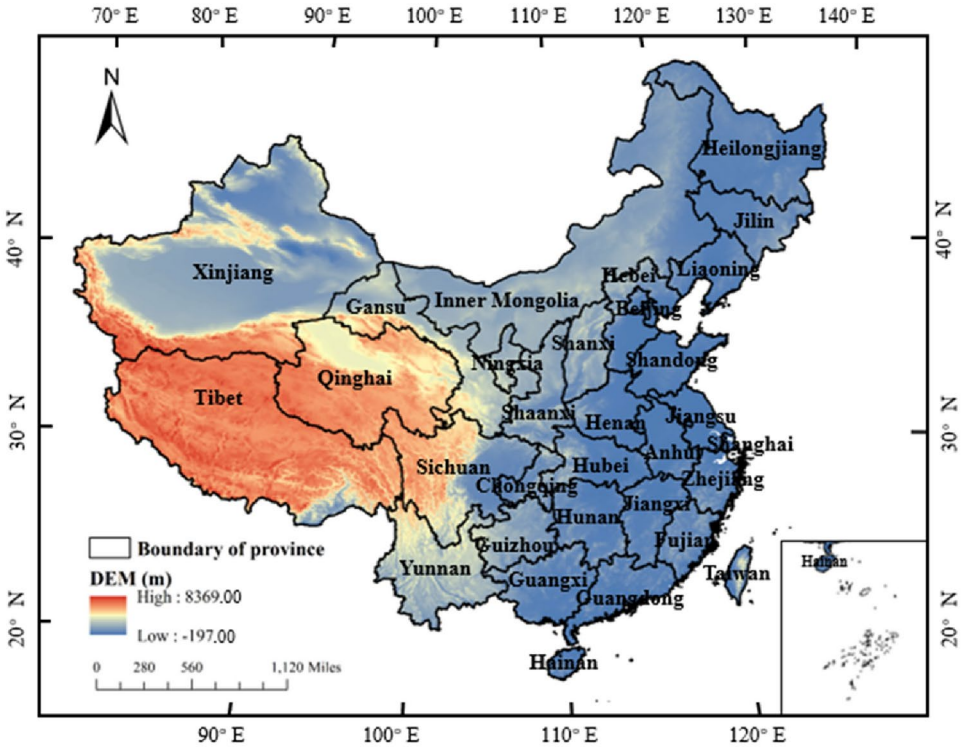

Fig. 1. Locations of study area. .

to 8369 m[52]. The terrain descends from the west to the east, forming three spatial ladder-like distributions, and it is mainly composed of mountains, hills, terraces, and plains. The climate of China belongs to the subtropical monsoon climate, temperate monsoon climate, tropical monsoon climate, temperate continental climate, and alpine climate.

Data sources and descriptions

Since the Reform and Opening-up Policy began in the late 1970s, China has been undergoing rapid economic development and industrialization[53,54]. At the end of 2021, the proportion of the urban population was 63.89%, and the area of urban construction land was 61,300 km^2 (http://www.stats.gov.cn/). Long-term high-intensity industrial development and a lack of scientific spatial management have resulted in large socioeconomic challenges such as income and gender inequality[55], and dramatic ecological issues such as air pollution, water shortages, biodiversity loss, and ecosystem destruction[56]. It is worth noting that these socioeconomic and environmental challenges within China vary substantially from region to region[57]. Therefore, there is an urgent need to assess the regional process of the SDGs in China to support the formulation of sustainable management policies and ecological civilization construction. This study used 31 provinces, except Hong Kong, Macao, and Taiwan in China as the research sample (Fig. 1).

In this study, data were obtained from the following sources.

(1) Land use and land cover data in 2000 and 2020, with a resolution of 30 m, were derived from the Resource and Environment Science and Date Center, Chinese Academy of Sciences (http://www.resdc.cn/). Accordi ng to the National Standard Land-Use Classification of China using supervised classification, the primary land use types were divided into six first-level categories, including cropland, forestland, grassland, water-body, construction land, and bare land.
(2) The digital elevation model (DEM) data came from the Geospatial Data Could Platform (http://www.gscloud.cn), and the acquired data was uniformly projected and preprocessed for cropping correction.
(3) Soil datasets (soil type, soil moisture, soil depth, soil organic carbon, and soil particle composition) with a resolution of 30 m were drawn from the Harmonized World Soil Database 1.1 (HWSD), which was constructed by the United Nations Food and Agriculture Organization (FAO) and the Vienna International Institute for Applied Systems (IIASA) (Fischer et al. 2008)[58] (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/).
(4) Meteorological datasets (temperature, precipitation, solar radiation, and evapotranspiration) were obtained from the Chinese National Meteorological Science Data Service Center (http://data.cma.cn/).
(5) The normalized difference vegetation index (NDVI) in 2000 and 2020, with a resolution of 1000 m, was supported by the Resource and Environment Science and Date Center, Chinese Academy of Sciences (http://www.resdc.cn/).

Research methods

In this study, we quantified progress towards the SDGs in China from 2000 to 2020 and determined future development priorities at both the national and provincial levels through the following steps and contents: (1) the biophysical provisions of five ESs were quantified using diverse methods (e.g. USLE, InVEST model); (2) 11 SDGs and SDG index were assessed based on the "ES-SDG linkages" at both the national and provincial levels; and (3) SDG dashboards were calculated according to the 11 SDGs scores at the national and provincial levels. The methodological framework of this study is presented in Fig. 2.

Selection and quantification of ESs

Wood[21] conducted an anonymous online survey in two rounds of 328 experts in ESs and 231 experts in development decision-making worldwide, to gather their perceptions of ES contribution to SDG and SDG targets. This work identifies that 16 ESs were closely connected to 12 SDGs and 41 targets, which could further analyze the role of specific ESs and support multiple development targets. Among them, carbon storage services, habitat maintenance services, water purification services, and water provision services were the most closely related[59]. Moreover, according to previous research[60], SDG performance assessment should also include soil retention services as ES indicators for actively safeguarding local natural resources. Therefore, five types of ESs that significantly contribute to regional ecosystem function and sustainable development in China were selected in this study, naming carbon storage, habitat maintenance, soil retention, water purification, and water provision. The specific methods of quantifying these ESs are shown in Table 1.

Calculation of the SDGs and SDG index

Normalization of ecosystem service biophysical values

To eliminate the differences in quantification methods and units between the five ES indicators, the biophysical values of each service were normalized to a value between 0 and 100 by using min–max normalization. The range normalization formula was as follows (Eq. 1):

$$\mathrm{ES_{std}} = (\mathrm{ES_{obs}} - \mathrm{ES_{min}}) / (\mathrm{ES_{max}} - \mathrm{ES_{min}}) \times 100 \quad (1)$$

where ES_{std} refers to the normalized values of each ES; ES_{obs} refers to the biophysical values of each ES; and ES_{min} and ES_{max} refer to the minimum and maximum biophysical values of each ES, respectively.

Calculation of the SDG scores

Based on the ES-SDG linkages proposed by Wood[21], some of the relationships between ESs and SDGs that are considered to provide strong support for regional sustainable development in China were chosen . As shown in Fig. 3, the contributions of five selected ESs to 11 SDGs were selected in this study: SDG1 (No Poverty), SDG2 (Zero Hunger), SDG3 (Good Health & Well-Being), SDG6 (Clean Water & Sanitation), SDG7 (Affordable & Clean Energy), SDG8 (Decent Work & Economic Growth), SDG9 (Industry, Innovation & Infrastructure), SDG11 (Sustainable Cities & Communities), SDG13 (Climate Action), SDG14 (Life Below Water) and SDG15 (Life on Land). It is evident that individual ES that releases more lifelines are more likely to strongly support

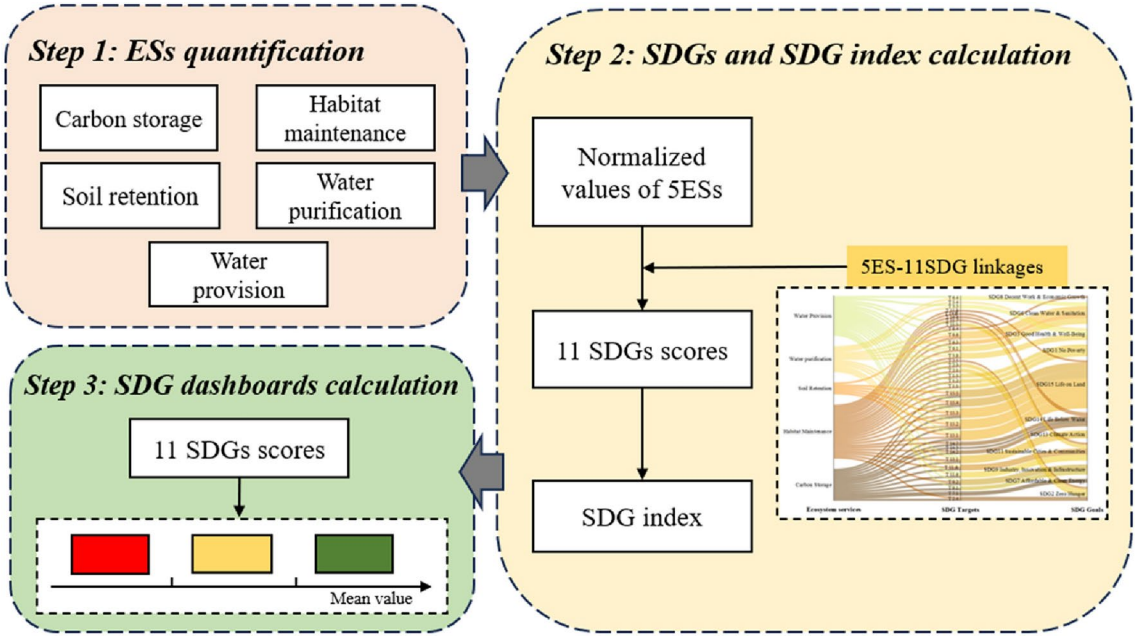

Fig. 2. Methodological framework of this study..

Ecosystem service indicators	Methods	Equation
Carbon storage	Carbon storage module	$C_{CS} = C_{above} + C_{below} + C_{soil} + C_{dead}$
		C_{CS}= total carbon storage;
		C_{above}=aboveground carbon storage;
		C_{below}= underground carbon storage;
		C_{soil}= soil carbon storage;
		C_{dead}= dead matter carbon storage
Habitat maintenance	Habitat quality module	$Q_{xj} = \left(1 - \left(\frac{D^z{}_{xj}}{D^z{}_{xj} + k^z}\right)\right)$
		Q_{xj}= habitat quality in LUCC j;
		H_j= habitat suitability in LUCC j;
		D_{xj}= total threat level in LULC j;
		k= scaling parameter
Soil retention	RUSLE model	$A = R \times K \times LS \times (1 - CP)$
		A = annual soil conservation;
		R = rainfall erosivity factor;
		K = soil erodibility factor;
		LS = slope length and steepness factor;
		C = cover-management factor;
		P = support practice factor
Water purification	Nutrient delivery ratio model	$ALV = HSS \times pol$
		ALV = adjusted output;
		HSS= hydrological sensitivity score;
		pol= output coefficient;
Water provision	Water yield module	$Y = \left(1 - \frac{AET}{P}\right) \times P$
		Y = annual water yield;
		AET = actual annual evapotranspiration;
		P = annual total precipitation

Table 1. Ecosystem service indicators related to the SDGs and quantification methods.

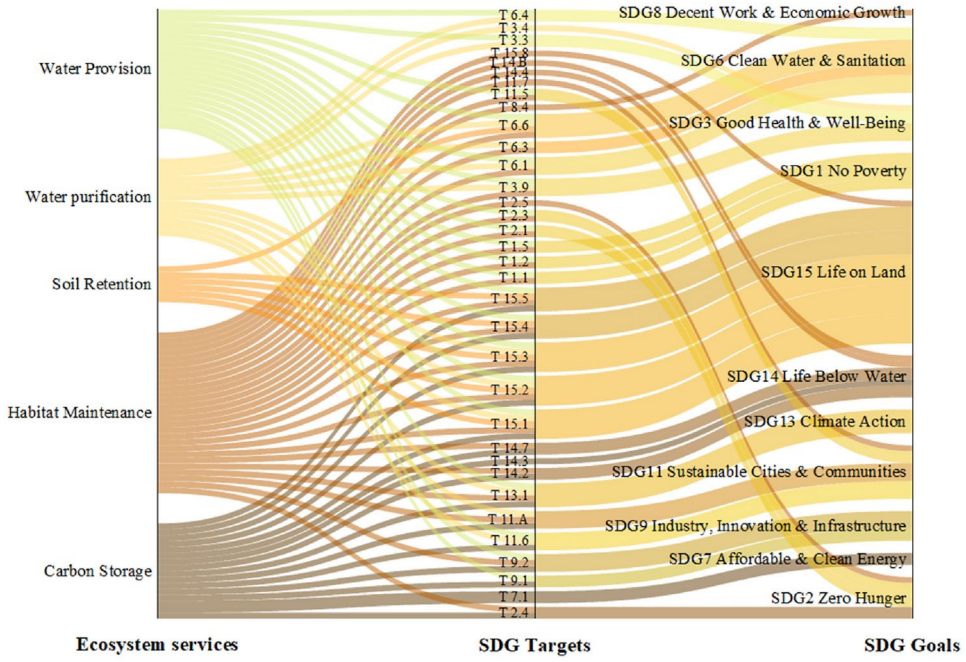

Fig. 3. The ES-SDG Target-SDG parallel linkage map.

SDGs and their targets. Hence, according to the number of ES-SDG linkages, the normalized values of the ES indicators were used to calculate the score of the SDGs using the following equation (Eq. 2):

$$SDG_j = \frac{\sum_{i=1}^{n}(ES_i \times x_i \times T_{ij} \times y_j)}{\sum_{i=1}^{n}(T_{ij})} \quad (2)$$

where SDG_j refers to the calculated scores of each SDG_j; T_{ij} refers to the number of ES-SDG linkages under $SDGj$; and x_i and y_j are the weights of ES_i and goals within SDG_j, respectively. Considering that each ES indicator plays an important role in the fulfillment of the SDGs, both x and y were set to 1. The SDG scores were also normalized from 0 to 100.

Calculation of the SDG index

The SDG index, representing the overall performance towards achieving all assessed SDGs, can be calculated using the following formula (Eq. 3):

$$SDG\ index = \frac{\sum_{j=1}^{m} SDG_j}{m} \quad (3)$$

where {m}is the number of all calculated SDGs.

Calculation of the SDG dashboards

The SDG dashboard provides comprehensive information about the average performance for each province (municipality) within each SDG. Therefore, it helps to identify those provinces that are falling behind. Furthermore, the SDG dashboard is constructed to determine the major challenges faced by each province and the implementation priorities for each province (municipality)[61]. In this study, 11 goal scores for each province in China were calculated by the weighted mean, and each goal score was divided into three levels (yellow, orange, or red) to display different progress performances for the SDGs. In detail, a province with a 'green' category (score above 50) indicates that it has achieved the goal, a province with a 'yellow' category (score below 50 and above 30) indicates that it has significant challenges, and a province with a 'red' category (score below 30) indicates that it faces major challenges.

Results

Temporal changes in ESs

Five ESs in China were quantified and their temporal change trends were analyzed at the national level (Table 1). As shown in Fig. 4, carbon storage and habitat maintenance declined in China between 2000 and 2020, while soil retention, water purification, and water provision increased to varying extents. Specifically, the mean value of carbon storage in China showed a downward trend from 11774.79 Mg/hm^2 in 2000 to 11662.12 Mg/hm^2 in 2020, which represents a 0.96% drop. The changing trend of the mean values of habitat quality in China showed

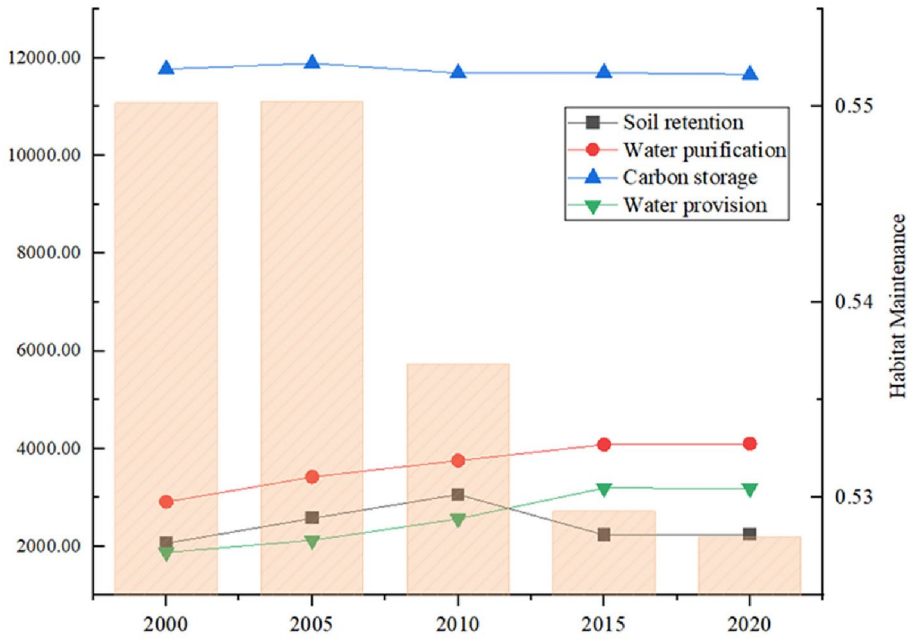

Fig. 4. The biophysical values of five ESs in China from 2000 to 2020.

a slight downward trend from 0.55 in 2000 to 0.53 in 2020, with a decrease of 4.04%. In terms of soil retention service, the values of soil retention per unit area in China increased from 2061.77 t/hm^2 in 2000 to 3060.08 t/hm^2 in 2010 and then decreased to 2238.32 t/hm^2 in 2020. Over time, it is evident that the annual average of water purification and water yield in China rose from 2.91 kg ha^{-1} in 2000 to 4.10 kg ha^{-1} and 1880.01 mm in 2000 to 3190.39 mm in 2020. There was an increase of 40.97% and 69.70%, respectively.

Temporal changes in SDGs scores

Characteristics at the national level

Figure 5 showed the scores of the SDGs and SDG index in China from 2000 to 2020 at both the national and provincial levels. Regarding individual SDG processes, all the calculated scores of the 11 SDGs in China declined at the national level. Over the past decade, the SDGs scores varied from a 0.41% drop (SDG 7, Clean energy) to a 6.56% drop (SDG 1, No Poverty). The top five SDGs were SDG 8 (Economic growth), SDG 14 (Life on water), SDG 1 (No poverty), SDG 2 (Zero hunger), and SDG 9 (Industry & Infrastructure) in 2000, while SDG 8 (Economic growth), SDG 14 (Life on water), SDG 7 (Clean energy), SDG 2 (Zero hunger), and SDG 9 (Industry& Infrastructure) in 2020. From 2000 to 2020, the top-five SDGs with the lowest decline rate were SDG 1 (No poverty), SDG 3 (Good health), SDG 9 (Industry& Infrastructure), SDG 2 (Zero hunger), and SDG 13 (Climate action).

Characteristics at the provincial level

The 11 SDGs were achieved differently by the 31 provinces at the provincial level. Specifically, all the calculated SDGs decreased in 23 of the 31 provinces from 2000 to 2020. As to the 23 degraded provinces, changes in the SDG scores ranged from 0.04% in Qinghai to 19.58% in Jiangsu. Eight other provinces improved their scores, namely, Gansu, Zhejiang, Heilongjiang, Chongqing, Hunan, Shanghai, Inner Mongolia, and Jiangxi. The SDGs

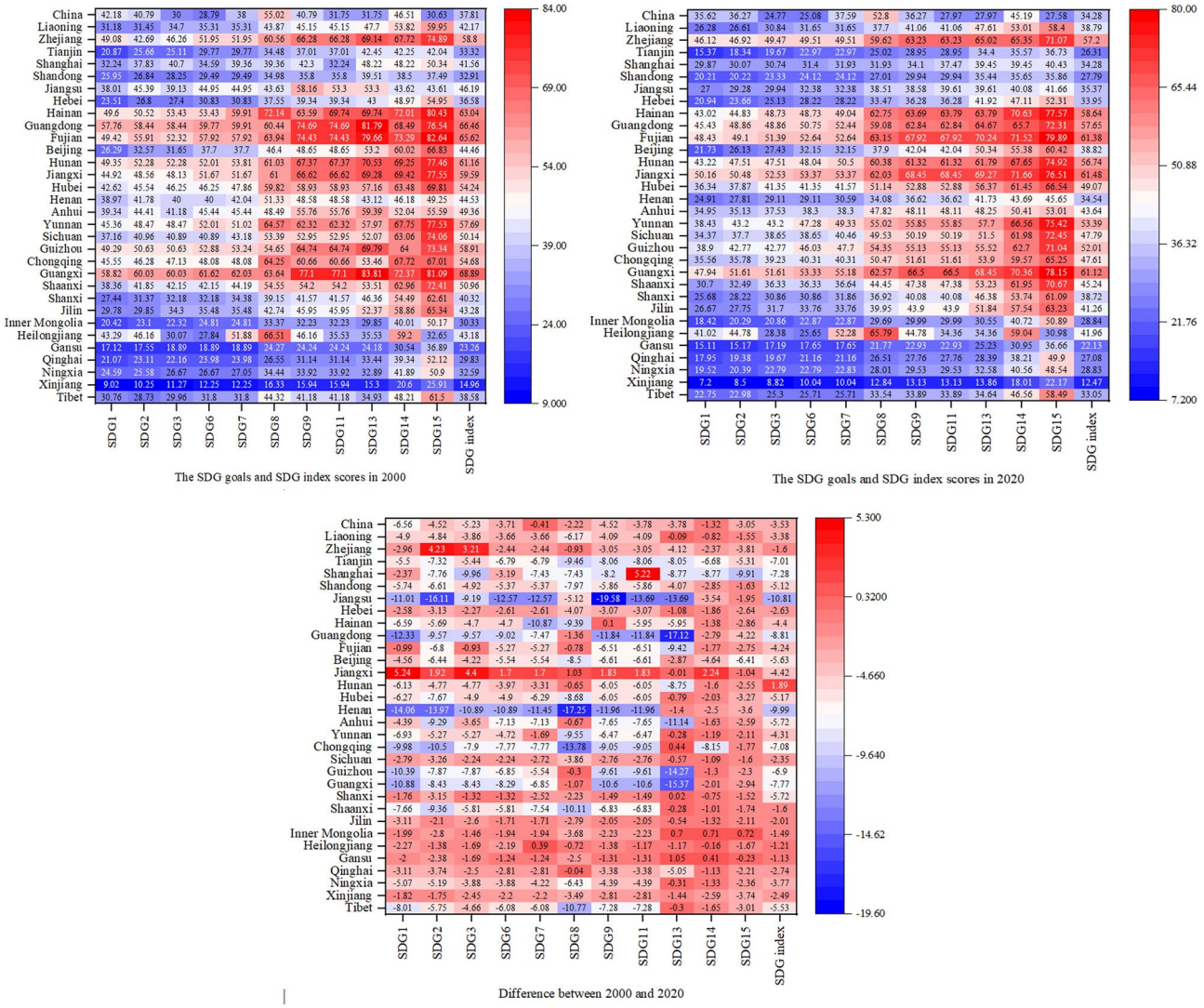

Fig. 5. The SDG goals and SDG index scores of China in 2000 and 2020, and the differences between the two periods.

scores among advanced provinces increased from a 0.39% increase (Heilongjiang) to a 5.24% increase (Jiangxi). As an example, SDG7 in Heilongjiang, SDG13 in Chongqing, and SDG11 in Shanghai increased by 0.39%, 0.44%, and 5.22%, respectively, from 2000 to 2020. Among the 11 goals in Gansu and Zhejiang, two have improved from 2000 to 20,202, namely SDG 13 and SDG 14 and SDG 2 and SDG 3. Over the period 2000–2020, SDG 13, SDG 14, and SDG 15 in Inner Mongolia showed upward trends, SDG 13, SDG 14, and SDG 15 improved in Inner Mongolia from 2000 to 2020, while the scores of the remaining 9 SDGs decreased gradually. Moreover, Jiangxi's performance on SDG 13 and SDG 15 decreased between 2000 and 2020, while its performance on all other nine SDGs improved.

Temporal changes in the SDG index

As shown in Fig. 5, at the national level, the SDG index scores declined by approximately 3.53% from 37.81 in 2000 to 34.28 in 2020, whereas at the provincial level, the SDG index scores showed significant characteristics across provinces in temporal variation. There were five provinces in East China with the highest SDG index scores: Jiangxi (61.48), Fujian (61.38), Guangxi (61.12), Hainan (58.64), and Guangdong (57.65). As for the bottom five provinces, Xinjiang (12.47), Gansu (22.13), Tianjin (26.31), Qinghai (27.08), and Shandong (27.79) were mostly located in western and northern China. These results were consistent with the findings of previous studies[61,62]. Thirty of the 31 provinces in China experienced declines in SDG index scores from 2000 to 2020, ranging from a -10.81% drop (Jiangsu) to a − 1.13% drop (Gansu). The above results indicated that compared with developed regions, the less developed provinces struggled to achieve most SDGs during our study period, contributing to the significant differences in geographic location, natural resources, and economic foundation[62].

Characteristics of SDG dashboards

Characteristics at the national level

Figures 6 and 7 showed the SDG dashboards for the 31 provinces (municipalities) in China from 2000 to 2020. In this study, according to previous research[63], the 11 SDG goals were divided into three dimensions, including the social dimension (SDG1, SDG2, SDG3, SDG11), environmental dimension (SDG6, SDG13, SDG14, SDG15), and economic dimension (SDG7, SDG8, SDG9).

There are five SDGs that were identified in China as priorities for 2000 and 2020, including SDG3 (Good Health & Well-Being), SDG6 (Clean Water & Sanitation), SDG11 (Sustainable Cities & Communities), and SDG13 (Climate Action). These findings indicated that over the study period, China had good performance in terms of fulfilling SDGs in the economic dimension, such as SDG7, SDG8, and SDG9, but still faced major challenges concerning environmental and social SDGs, such as SDG3, SDG6, and SDG15. Thus, despite great efforts made in recent decades, health and ecological conservation remain the top priorities in China.

Characteristics at the provincial level

As a result of the SDG dashboard, each province can keep track of progress towards achieving the 11 SDGs, and be able to identify the key implementation challenges that it faces. For instance, most of the western and northern provinces were challenged in all three dimensions, including Tibet, Ningxia, Xinjiang, Qinghai, Gansu, Inner Mongolia, Shandong, and Tianjin. Several provinces, including Shanxi, Henan, Hebei, Shanghai, and Liaoning, had pressing problems achieving the SDGs in the social dimension, particularly with regard to SDG1 (No Poverty), SDG2 (Zero Hunger), and SDG3 (Good Health & Well-Being). As well, from 2000 to 2020, none of the SDGs in the southwestern region (Guangxi, Guizhou, Sichuan, Chongqing, Yunnan) were red-rated. The central region of the country did not encounter great challenges in 2000, but Henan did meet some challenges in 2020, such as SDG1 (No Poverty), SDG2 (Zero Hunger), SDG3 (Good Health & Well-Being), SDG6 (Clean Water & Sanitation) and SDG 7 (Affordable & Clean Energy). Also, eastern coastal regions (Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Shandong, Shanghai, Tianjin, Zhejiang, and Liaoning) encountered several challenges, including the Sustainable Development Goals 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health & Well-Being), 6 (Clean Water & Sanitation), and 7 (Affordable & Clean Energy) in 2000 and 2020. Above all, in China, national development priorities mainly revolve around health and the environment, including SDG3 (Good Health & Well-Being), SDG6 (Clean Water & Sanitation), and SDG15 (Life on Land). However, some provincial development priorities are also related to essential material needs, such as SDG2 (Zero Hunger) and SDG1 (No Poverty). Several relevant studies have confirmed that countries, especially economically developed countries, generally perform poorly on eco-related SDGs, such as SDG11 and SDG13. This suggests that the scarcity of resources and ecological damage, as well as green transformational development, are common problems around the world.

Discussion

Advantages of the ES-based method

ESs can improve human well-being and serve as an important basis for fulfilling the SDGs[64]. Our results indicated an overall downward trend in the scores of individual SDG and the SDG index for China between 2000 and 2020. In particular, the greatest declines occurred in SDG 1, SDG 3, and SDG 2. It was identified that China has over the past two decades experienced dramatic changes in individual SDG and SDG index scores due to habitat maintenance and water provision, based on ES-SDG linkages. The results of Wood[21] also demonstrated that these two services were identified as key services that contributed to the most SDGs, 26 and 21 targets, respectively. The maintenance of habitats has contributed significantly to the achievement of 10 SDGs, including SDG1, SDG2, SDG3, SDG6, SDG8, SDG9, SDG11, SDG13, SDG14, and SDG15, while water provision significantly contributes to SDG1, SDG2, SDG3, SDG6, SDG9, SDG11, SDG13, and SDG15. This might be due to the fact that the higher the habitat quality, the more stable the ability of ecosystems to provide multiple services to human society[61]. Moreover, water provision service provides our primary needs and contributes to food security, water

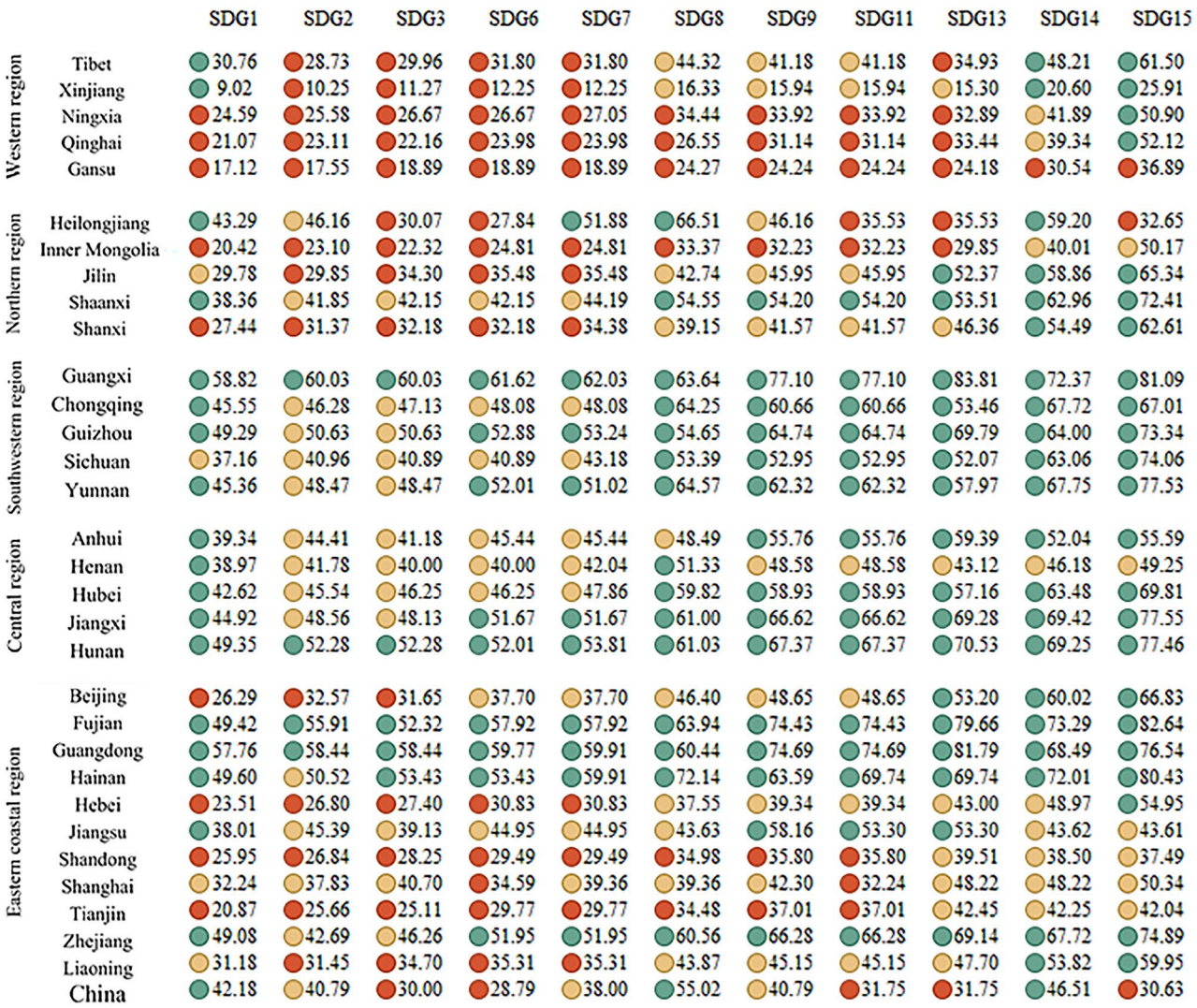

Fig. 6. The SDGs dashboard of China in 2000.

scarcity, climate change, biodiversity loss, and health threats as one of the critical services. Therefore, multiple SDGs in China were improved as a result of the increase in these two key services.

ESs connect all spheres of sustainability, from the biosphere to society and economy[19]. ESs are the foundation of sustainability, and sustainable development requires the protection and maintenance of ecosystems to ensure a long-term supply of ESs[65]. Thus, depending on the contribution of ESs to SDGs, the ES-based approach can monitor progress towards the achievement of SDGs from a more holistic and systemic perspective and provide insight into the relationships between natural systems and human well-being in coupled human-nature systems.

Implications for sustainable development management

SDG achievement requires both maintaining critical stocks of natural capital goods as well as continuous supply and sustainable usage of ESs[66,67]. ES-based solutions that combine improved benefits and human well-being derived from natural systems, and reduced costs of ecological conservation and restoration can therefore provide co-benefit pathways for the fulfillment of the SDGs[68].

In this study, we identified the most prioritized SDG at the national and provincial levels. China's 2030 Agenda for Sustainable Development is most likely to be limited by eco-related SDGs, based on our studies. Thus, the challenges of achieving SDGs in China involve taking into account the conservation and restoration of biodiversity and the aquatic environment[68,69]. Our results also support the findings of Sachs[70], who advocate the need for transformations of key investments in human well-being as well as sustainable food, land, and water. The following points should be taken into consideration by government policymakers when performing ecological preservation and planning.

First, to protect the ecological space, especially in ecologically fragile areas, we must strictly implement the ecological red line policy and prohibit all human activities within it. Second, to guarantee the stable and continuous supply of ESs for future generations, critical ecological spaces, especially those in drinking water

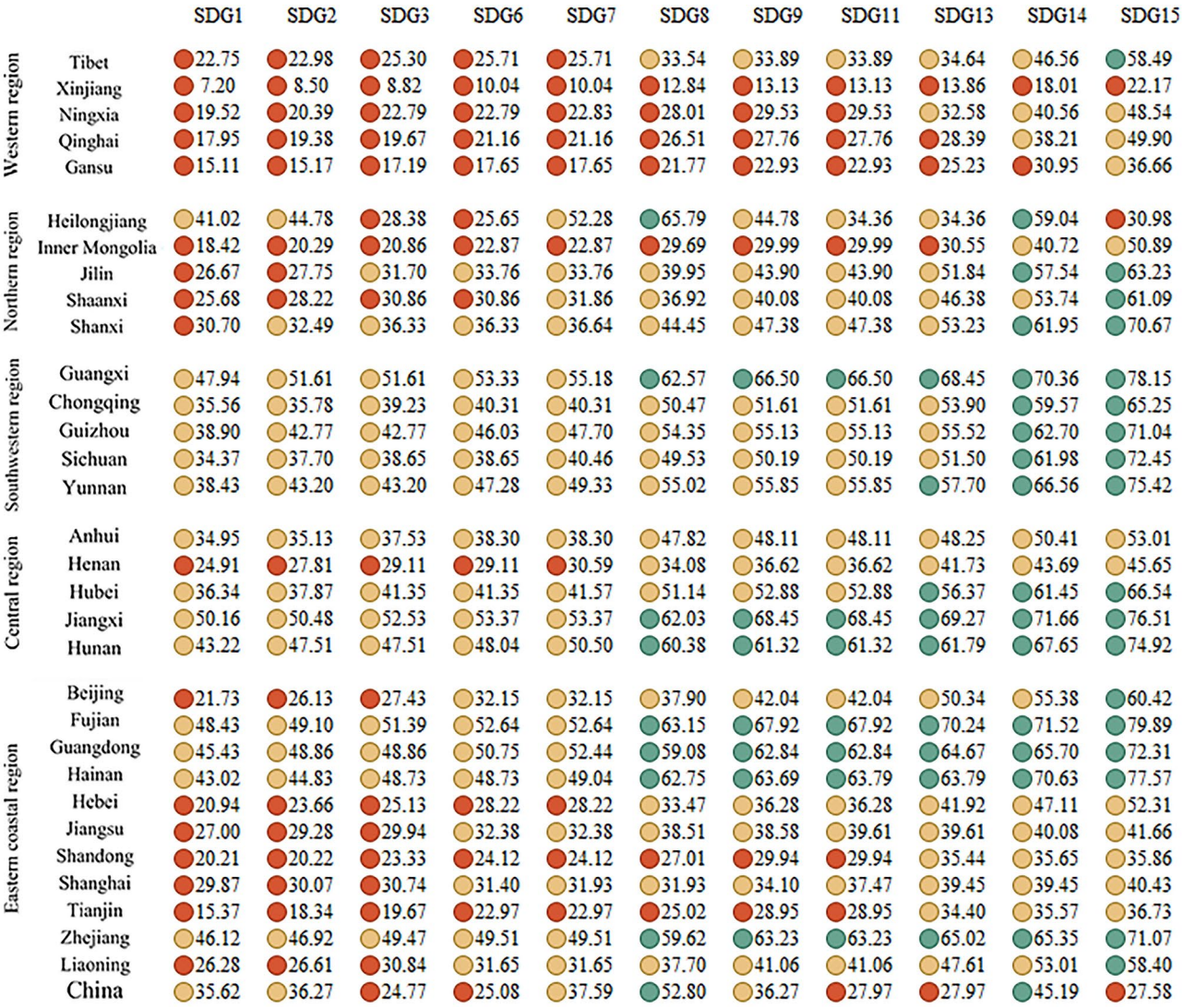

Fig. 7. The SDGs dashboard of China in 2020.

sources, must be identified and included in the ecological protection red line area for strict control and reservation. Third, it is required to strengthen ecological conservation and restoration efforts in fragile and degraded areas to restore and improve local vegetation coverage, ecosystem quality, and functions, as well as biodiversity. Fourth, the sustainable management and utilization of water resources should be strengthened. Significant investments should be made into rural toilet renovations, urban sewage treatment, and water efficiency[60]. Finally, the adoption of an ES-based approach and the realization of SDG targets and goals cannot be realized without considering the interactions across services. For this reason, strategies should focus on reconciling trade-offs or synergies among key services to better balance short-term and long-term efforts and achieve multiple SDGs simultaneously[16].

Limitations and future directions

Despite the contributions to related SDG performance assessment , several limitations remain in our study. First, because of data availability, this study only calculated five types of ESs. It will be important for future research to take into account more types of ESs to provide more accurate estimates for the current status of SDG achievement. Second, in the context of cross-regional development and regional collaboration, spillover effects were not considered in this study. Region-to-region and country-to-country spillover effects should be explored in future research[8]. Finally, the complex impact of policy on sustainable development needs to be further examined[61].

Conclusion

How to achieve the overall implementation of the SDGs remains an enormous challenge worldwide. While several studies have shown that the delivery of ESs could make important contributions to achieving SDGs; however, few studies have assessed progress towards achieving the SDGs using these connections. This study

filled this research gap by assessing the progress towards achieving the SDGs based on "ES-SDG linkages" and identifying the development priorities in terms of economic, social, and environmental dimensions in China from 2000 to 2020. The main conclusions were summarized below: (1) Regarding individual SDG processes, at the national level, all the calculated SDG scores in China showed downward trends from 2000 to 2020, while 11 SDG goals performed differently across 31 provinces. (2) The SDG index scores of China decreased from 37.81 in 2000 to 34.28 in 2020, representing a drop of 3.53%. (3) The SDG index scores showed significant differences across 31 provinces in terms of temporal variation. (4) To boost progress towards achieving SDGs in China, according to SDG dashboards, SDG 3 (Good Health & Well-Being), SDG 6 (Clean Water & Sanitation), SDG 11 (Sustainable Cities & Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land) should be prioritized. (5) 15 provinces in China faced significant challenges in meeting the SDGs, and the prioritized SDGs of 31 provinces differed across economic, social, and environmental dimensions. Our results highlighted that habitat maintenance and water provision were the critical factors that made great contributions to fulfilling the SDGs in China. This research can assist decision-makers in tracking efforts towards the achievement of the local SDGs and identifying critical development issues to facilitate the overall implementation of the SDGs in 2030. The ES-based approach will help deepen our understanding of the relationships between natural systems and human well-being and provide co-benefit pathways for sustainable development. This approach might also lay a foundation for monitoring progress in achieving SDGs in an integrated and composite way for other countries and across local to global levels.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

Y.H.: Conceptualization, methodology, formal analysis, data curation, writing-original draft, visualization. A.K.: Methodology, visualization, writing-review, and editing. Z.J.: Resources and review. J.L.: Software, validation. Y.M.: Review and editing, supervision. X.G.: Conceptualization, data curation, funding acquisition. B.Z.: Supervision, project administration, funding acquisition.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to Y.M.

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