Big Earth Data in Support of the Sustainable Development Goals

Chinese Academy of Sciences

International Research Center of Big Data for Sustainable Development Goals

September 2022

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CONTENTS

Preface

The 2030 Agenda for Sustainable Development provides an ambitious vision for global sustainable development in three dimensions: economic, social and environmental. It has, however, run into major challenges posed by such problems as the lack of data, unbalanced progress, and trade-offs between the Sustainable Development Goals (SDGs). At the same time, ravaging climate change, the lingering COVID-19 pandemic, and rising regional tensions make realizing the 2030 Agenda much more difficult. At the 76th session of the UN General Assembly in 2021, President Xi Jinping proposed the Global Development Initiative to accelerate the implementation of the 2030 Agenda and promote stronger, greener, and healthier development.

As clearly pointed out in the *UN Sustainable Development Goals Report 2021*, data are strategic assets for rebuilding and accelerating the implementation of the SDGs, and availability of and timely access to high-quality data is more important than ever before. To this end, the UN Secretary General has proposed the Data Strategy to "get more relevant, disaggregated and timely data to track, predict and accelerate SDG progress," to turn data and information into insights, and to change and improve decision-making on development issues.

With digitalization picking up speed worldwide, data comparability and availability have improved globally. However, there are still gaps in the geographical coverage and timeliness of SDG data in various fields, and innovative methods are urgently needed to close these gaps. The Big Earth Data technology, which integrates earth science, information science, and space science and technologies, is capable of macro-level and dynamic monitoring, can significantly improve the data acquisition capacities, thus providing much-needed support for SDG implementation.

President Xi Jinping announced on September 22, 2020, at the 75th UN General Assembly, that China was to set up the International Research Center of Big Data for Sustainable Development Goals (CBAS). CBAS, formally established on September 6, 2021, is the world's first international scientific institution to serve the UN 2030 Agenda with big data. Over the past year, CBAS has developed a big data platform system for sustainable development, launched and operated the world's first science satellite for sustainable development – SDGSAT-1, and researched into technologies and methodologies for Big Earth Data in support of SDGs. It has provided data, information, and services for monitoring and evaluating SDG indicators globally, contributing to implementing the 2030 Agenda.

For three years in a row, the Chinese Academy of Sciences (CAS) has led the preparation of the annual reports on *Big Earth Data in Support of the Sustainable Development Goals*, which have contributed 64 cases cumulatively on monitoring, assessment, and demonstration, including 53 data products, 33 methods and models, and 42 decision support, and demonstrated China's exploration and practice of using Big Earth Data technology to support SDGs globally and regionally.

The 2022 report continues to focus on six SDGs, i.e., Zero Hunger, Clean Water and Sanitation, Sustainable Cities and Communities, Climate Action, Life below Water, and Life on Land, and on interactions and integrated evaluations among SDG indicators as well. At the same time, this year's report includes a new chapter on SDG 7 – Affordable and Clean Energy, and presents demonstrations of regional-level comprehensive evaluation that accommodates different regional features. With a continued focus on China's ecological and environmental changes, this report comprehensively evaluates 56 environmental-related indicators, both in innovative ways and on the strength of case studies from the past four years, to monitor the progress in China's implementation of SDGs.

Over 170 scientists from more than 40 research institutions and universities were involved in drafting this report, which draws on the best and latest scientific research results concerning big data on SDGs. We would also like to express our heartfelt thanks to the headquarters of CAS for their strong support and the drafting team for their extraordinary hard work.

Guo Huadong

Director of the International Research Center of Big Data for Sustainable Development Goals

Member of the UN 10-Member Group to support the TFM for SDGs (2018-2021)

Executive Summary

This report presents 42 cases where Big Earth Data was used to monitor and evaluate 25 targets under 7 SDGs- SDG 2 Zero Hunger, SDG 6 Clean Water and Sanitation, SDG 7 Affordable and Clean Energy, SDG 11 Sustainable Cities and Communities, SDG 13 Climate Action, SDG 14 Life below Water and SDG 15 Life on Land, and to study the interactions among SDG indicators and their integrated evaluations. These cases demonstrate SDG monitoring and assessment outcomes at global, regional, national and local scales from three aspects of data products, methods and models and decision support. They can inform decisions and represent innovative practice of using big data to advance the implementation of SDGs.

In the context of SDG 2 Zero Hunger, the report focuses on improving agricultural productivity and sustainable food production. It produces a 30 m resolution global cropping intensity product for 2020, the spatial-temporal change in soil organic carbon density of cropland and the data product of carbon emissions by cropping system in counties at the Chinese scale, and a saline-alkali soil identification and classification model, which can be used to retrieve the saline-alkali soil in Northeast China for the past 35 years. Based on analysis of the above data, it is found that in 2020, about 85.2% of the world's arable land was under the single cropping pattern. If cropping intensity can achieve its full potential, then grain production can increase by 230 million tons, or 6.4% of the current global total. In the western part of the black soil region in Northeast China, which is one of the world's three largest soda salt alkali lands, a series of restoration projects like "Vegetation of Saline and Alkali Land" and "Major Project in West Jilin Province" have reduced the area of saline and alkali land by 63.3% since 2000, and promoted grain production. From 2015 to 2020, the soil organic carbon density of cropland increased by 3.4%. Agricultural carbon emission per unit value has declined over the recent decade, with high emission per unit area in the Jianghuai Region, Hanjiang Plain and Sichuan Basin.

In the context of SDG 6 Clean Water and Sanitation, the report discusses improving water environment, improving water-use efficiency, integrated water resources management, and change in water-related ecosystems, and presents SDG 6 progress at the provincial level in China through monitoring and assessment based on multiple sources of data, including site observations, statistical surveys and remote sensing monitoring. The study found that the groundwater environment and agricultural water-use efficiency have significantly improved, the overall water stress level has been on a downward trend, and tools for water resources management have been notably optimized; the water surface area of reservoirs was on an upward trend while the declining rate of groundwater storages slowed down. However, from the perspective of provincial level administrative divisions, there are notable spatial differences in the achievement of various indicators, due to varying geographical conditions, resource endowments and level of economic development. The developed regions generally face challenges from water environment and water-related ecosystems, while less developed regions are typically low on water-use efficiency. The results of the study help gauge the progress in SDG 6 implementation and identify problems and gaps at the Chinese provincial level, and can inform the formulation and revision of strategies to accelerate the achievement of SDG 6.

In the context of SDG 7 Affordable and Clean Energy, the report discusses access to electricity, renewable energy and international energy cooperation. At the global scale, the electrification of built-up areas was monitored by remote sensing. At the Chinese scale, data products developed include the dataset of photovoltaic power plants extracted by remote sensing monitoring, the dataset on the impact of China's international energy cooperation projects on SDG 7 progress in developing countries and the statistical dataset on China-sponsored international training programs on solar energy utilization. The development of renewable energy in China was investigated, and China's progress in three indicators concerning renewable energy and international energy cooperation was evaluated. Based on analysis of the above data, the study found that globally electrified built-up areas increased remarkably from 2014 to 2020, up by nearly two percentage points as a share. In China, the transformation to green and low-carbon energy has made notable progress, with installed renewable energy capacity and electricity generated from renewable sources in 2021 being 2.12 and 1.79 times that of 2015. China has helped developing countries achieve SDG 7 through international energy cooperation, increasing per capita electricity consumption in 80 countries. China-sponsored international training programs on solar power utilization have benefited 133 countries (regions).

In the context of SDG 11 Sustainable Cities and Communities, the report details efforts concerning the urbanization process monitoring and evaluation, World Heritage protection, urban disasters and response, urban green space and the multiple targets monitoring for SDG 11 at community scale. The data products developed by the study include, at the Chinese scale, the dataset on the monitoring of SDG 11.5 progress in prefecture-level cities and the data product on functional classification of communities, enabling the calculation and evaluation of four SDG 11 indicators; and at the global scale, the dataset on the world's major urban built-up areas, data on World Heritage boundary vector, the dataset on losses due to extreme weather and climate disasters and the dataset on the trend of global greenness. Based on analysis of the above data, the study found that global urbanization developed in a more balanced way from 2000 to 2020; the land cover change in World Cultural Heritage sites was generally less than 1% and overall protection was good from 2015 to 2020. The implementation of *Sendai Framework for Disaster Risk Reduction (2015-2030)* has made some progress both in China and globally. China accounts for 19% of the world's urban built-up areas, but 28% of the world's significant greening urban areas. Chinese population benefiting from significant greening urban areas accounts for about 47% of the global beneficiary population. The implementation of SDG 11.1, SDG 11.2 and SDG 11.3 in China is generally good at the community scale.

In the context of SDG 13 Climate Action, the report discusses the four themes of disaster monitoring and reduction action, long-term early warning for climate change, global terrestrial/oceanic carbon sink estimation, and climate change education. Studies led to data products on soil moisture content, and disaster prevention and reduction policies, findings on the state of climate change education, and the calculation and evaluation of four SDG 13 indicators in China. At a global scale, datasets of heat wave distribution, ocean heat content and salinity, and global terrestrial/oceanic carbon sinks were developed. Analyses based on the above data led to the following findings: farmland in China suffered serious water-logging in summer and autumn of 2021, but grain yields were not affected thanks to scientific field management; China and its provincial governments have set up fairly full-fledged disaster reduction systems through a series of policies and measures; China has a relatively sound climate change education system but there is room for improvement in curriculum design and hands-on activities; as global land temperature increases, the frequency and intensity of heat waves, ocean heat content, salinity contrast and vertical stratification are also increasing; global terrestrial and oceanic carbon sinks have been increasing in the past 20 years.

In the context of SDG 14 Life below Water, the focus is on three themes – reducing marine pollution, protecting marine ecosystems and protecting coastal areas. At the Chinese scale, data products have been developed such as the distribution of nutrient concentrations in the coastal waters of Eastern China from 1978 to 2019, spatial distribution of China's coastal tidal flats in 2016 and 2020, coastal wetlands' typhoon protection value from 2010 to 2020, and dynamic monitoring of returning mariculture enclosures to the sea and wetlands in China's coastal areas from 2010 to 2020 and a multi-source remote sensing inversion model of green tide biomass has been proposed. In the regional scale, the 3D computational model for the thermal environment of coral reef bleaching has been proposed and the thermal environmental early warning system for coral reef bleaching in China-ASEAN seas has been developed. Based on the above products, models and system applications, analysis shows the following findings: the nutrient concentrations in China's coastal waters have decreased significantly in the recent decade and more; the main reason for the decrease of dissolved inorganic nitrogen and dissolved inorganic phosphorus concentrations in China's coastal water is the reduction of the terrestrial nitrogen and phosphorus input; China's coastal wetlands play a significant role in defending against typhoons and mitigating losses from disasters and the total value provided by coastal wetlands for typhoon protection is continuously increasing; the thermal environment early warning system for coral reef bleaching serves as strong scientific and technological support for regional countries' timely understanding of the bleaching environment faced by coral reefs and formulation measures for coral reef protection; and the pace of returning mariculture enclosures to the sea and wetlands in coastal China has consistently increased and China made notable progress in coastal reclamation control and management from 2010 to 2020.

In the context of SDG 15 Life on Land, the report focuses on three themes – combating desertification and land degradation, protecting mountain ecosystems, and prevention, control and management of invasive alien species. At the Chinese scale, assessment was conducted on desertification control and carbon sink benefits, on black soil degradation status and risk in Northeast China, on the status of biodiversity conservation in mountainous areas, and on the risk, prevention, control and management of invasive alien species. At the global scale, products developed include the global sand dunes (lands) dynamics product and the big data online tool for the Great Green Wall of Africa which provides high-resolution land productivity dynamics products covering 11 member countries of the Pan African Agency of the Great Green Wall and 26 key technologies for land degradation control. Based on the above data and analysis, we found that China has achieved remarkable results in land degradation management, with visible carbon sink effect by desertification control; a large proportion of mountain ecosystems in China are under protection, with their spatial layout being further optimized; and it has achieved remarkable outcomes in the prevention and control of major invasive alien species with a scalable prevention and control technology system put in place.

Regarding interactions among SDGs and regional integrated evaluations, analysis is carried out on synergistic and trade-off relationships among SDGs at the provincial scale in China. The findings show that significant spatial and temporal changes have occurred in such relationships at the provincial level over the past 20 years. In most provincial administrative regions, SDG 6 and SDG 15 are more susceptible to trade-offs from other SDGs. Of all these regions, relationships of about 27% of the trade-off indicator pairs have changed to synergistic ones, and about another 18% of the trade-off indicator pairs have seen their trade-off intensity mitigated. The findings of the SDG regional integrated evaluation on typical provinces and cities in China show that since 2015, Hainan Province has made big progress in ecological civilization construction, with high scores on SDG 15, and significant improvement in SDG 2 and SDG 11. A total of 81% of the 70 indicators evaluated in Lincang, Yunnan Province saw progress made or were close to the target. The sustainable development index for eco-tourism in the Lijiang River Basin of Guilin, Guangxi rose from 0.46 in 2010 to 0.71 in 2020. The average annual growth rate of Gross Ecosystem Product in Shenzhen, Guangdong Province was 2.29%. The above analytical results can inform efforts in Chinese regions with different characteristics in setting priority development goals and mitigating the SDG indicator trade-offs that exist in development.

Introduction

The 17 Sustainable Development Goals (SDGs) adopted by the United Nations as part of the 2030 Agenda constitute a global framework for achieving sustainable development. They have become a strategic priority and focus of action for countries worldwide. However, almost halfway into the 2030 Agenda process, its implementation has been seriously hindered by climate change and the COVID-19 pandemic with global progress in individual goals even facing setbacks. The Goals will not be achieved by 2030 unless the implementation is accelerated. In 2021, about one-tenth of the world's population went hungry; more than three billion people were at health risk due to scarce data on the water quality of rivers, lakes, and groundwater; globally, 733 million people still lacked access to electricity; cities were hard hit by COVID-19; four key climate change indicators- global greenhouse gas concentrations, sea-level rise, ocean heat, and ocean acidification – hit record highs; increasing ocean acidification, eutrophication, and plastic pollution put the livelihoods of billions of people at risk; continued global deforestation, land and ecosystem degradation, and loss of biodiversity posed major threats to human survival and sustainable development (UN, 2022; Sachs *et al.* , 2022).

Science, technology, and innovation can help address these major challenges, primarily to support assessment at national and local scales and inform policy-making by enhancing data capacity for SDG monitoring and evaluation. The *Sustainable Development Goals Report 2022* points out that the pandemic has delayed the development of new national statistical plans worldwide, and there are still considerable gaps in the geographical coverage and timeliness of global data on indicators (UN, 2022). Meanwhile, the current indicator data are primarily of coarse-grained statistical values, with the time resolution mostly being "year" and the spatial resolution mostly "country", incapable of disaggregation by geographical location, population distribution, and environmental differences, which is crucial to thoroughly assessing the regional differences in SDG progress and identifying those lagging. Thus they are not enough to effectively inform sub-national governments' decision-making. According to estimates from the Organization for Economic Cooperation and Development, 105 out of the 169 SDG targets will be challenging to achieve without sufficiently engaging sub-national governments (OECD, 2020). Many are environmental targets sensitive to spatial and temporal changes among these targets.

As the core of the digital technology, big data has become one of the important engines of digital transformation across societies. The Big Earth Data, a key part of big data, mainly composed of Earth observation and geospatial data, has the advantages of easy acquisition, timely update, more objective results, and higher resolution. Moreover, it covers different spatial scales and geographical locations free from administrative fragmentation, allowing a more accurate assessment of SDG indicator progress and prompt problem detection. In addition, its role in analyzing the complex interactions and co-evolution between nature and social systems will contribute to the overall understanding and realization of SDGs.

Relying on its multiple disciplinary strengths, the Chinese Academy of Sciences (CAS) has gathered a wide variety of Big Earth Data, including satellite remote sensing images, geospatial data, social media data, and statistical data on seven SDGs, including Zero Hunger, Clean Water and Sanitation, Affordable and Clean Energy, Sustainable Cities and Communities, Climate Action, Life below Water and Life on Land, which are closely related to the Earth surface environment and human activities. CAS has developed innovative technologies and methods for big data processing and analysis based on cloud computing, such as the production of global public data products, the monitoring and evaluation of SDG indicators at multiple scales, and multi-indicator trade-off-and-synergy analysis, to provide data, methods, and information for SDG-related progress assessment, multi-disciplinary research, and multi-level decision making (Figure 1-1).

The reports on *Big Earth Data in Support of the Sustainable Development Goals* were released annually since 2019. In terms of filling the data gap, the reports provide high-quality data products previously lacking for monitoring

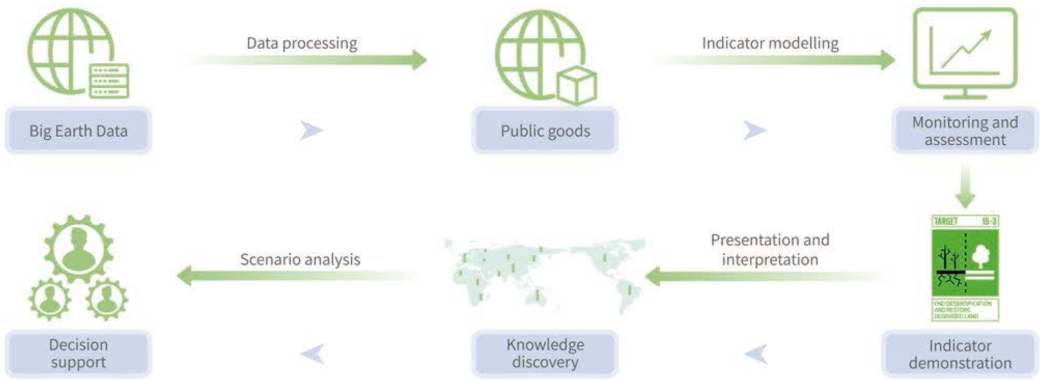


Figure 1-1. Scientific demonstration flowchart of Big Earth Data supporting SDGs

SDG indicators, for example, the dataset on the prevalence of stunting among Chinese children under five. They also provide additional background and analytical data for a deeper understanding of the progress in and drivers for indicators, such as long-term-series data products of the global land use classification. In terms of methods and models, the reports offer new ways for more timely and detailed assessment and prediction of SDG indicators, such as the high-precision inversion model of global crop intensity and rapid extraction method of global urban impervious surface. The reports also present scientific evidence for decision support, including the tracking and assessment of China's land degradation neutrality and its contribution to the world, and the assessment of dynamic change of water body in Ramsar sites, which can inform policy-making on improving the global synergy and comparability of indicators and addressing cross-border sustainable development issues. In 2022, in the context of climate change, the report adds a chapter that looks at SDG 7 – Affordable and Clean Energy and its monitoring and evaluation based on Big Earth Data, and explores the interactions between climate change and food systems, the carbon sequestration effect of desertification control, and the change of marine physical environment under global warming.

Based on the datasets from the 2019-2022 reports, with reference to the explicit thresholds in SDGs and targets, and quantitative targets defined by UN agencies and international organizations, the report assesses China's progress in 56 environmental SDG indicators between 2010 and 2021 (UNEP, 2021a) (Figure 1-2). Some quantitative findings on the progress are exploratory results of applying critical big data processing, analytics and other innovative methods. The results show that between 2010 and 2015, 38 indicators improved continuously, and five deteriorated. Between 2016 and 2021, 42 indicators improved continuously. In 2015, 10 indicators were close or achieved; by 2021, that number had risen to 26. Among all the indicators assessed, China stands out in disaster prevention and mitigation, safe drinking water, renewable energy, road traffic, and forest protection, and needs to do more regarding greenhouse gas emission and biodiversity protection.

In summary, by the end of 2021, China's environmental indicators had improved substantially compared with 2015 (the starting year of the 2030 Agenda). Almost at mid-point on the way to 2030, nearly half of the 56 assessed environmental indicators have been met ahead of schedule, laying a good foundation for achieving all SDGs by 2030.

With a deep commitment to sustainable development and experience-sharing, China has been promoting a balanced, coordinated, open, and inclusive new stage of global development. In September 2021, Chinese President Xi Jinping proposed a Global Development Initiative, calling for all-round cooperation in priority areas including poverty alleviation, food security, climate change and green development, and connectivity, and ensuring no one is left behind in these areas aligned with the 2030 Agenda. According to the list of deliverables attached to the Chair's Statement of the High-level Dialogue on Global Development held in June 2022, China will launch a Sustainable Development Satellite Constellation Plan, and develop and share data and information for SDG monitoring, which will be an important contribution to advancing global SDG cooperation in coordinated Earth observation, data sharing and application, and accelerating the implementation of the 2030 Agenda.

As the mid-term evaluation of the 2030 Agenda approaches, the United Nations will comprehensively review and adjust its SDG indicator framework globally. In the context of lacking enough indicator monitoring data, properly adding easily accessible and internationally comparable big data indicators will effectively improve the existing condition of SDG monitoring and evaluation, and effectively support decision-making on global sustainable development.

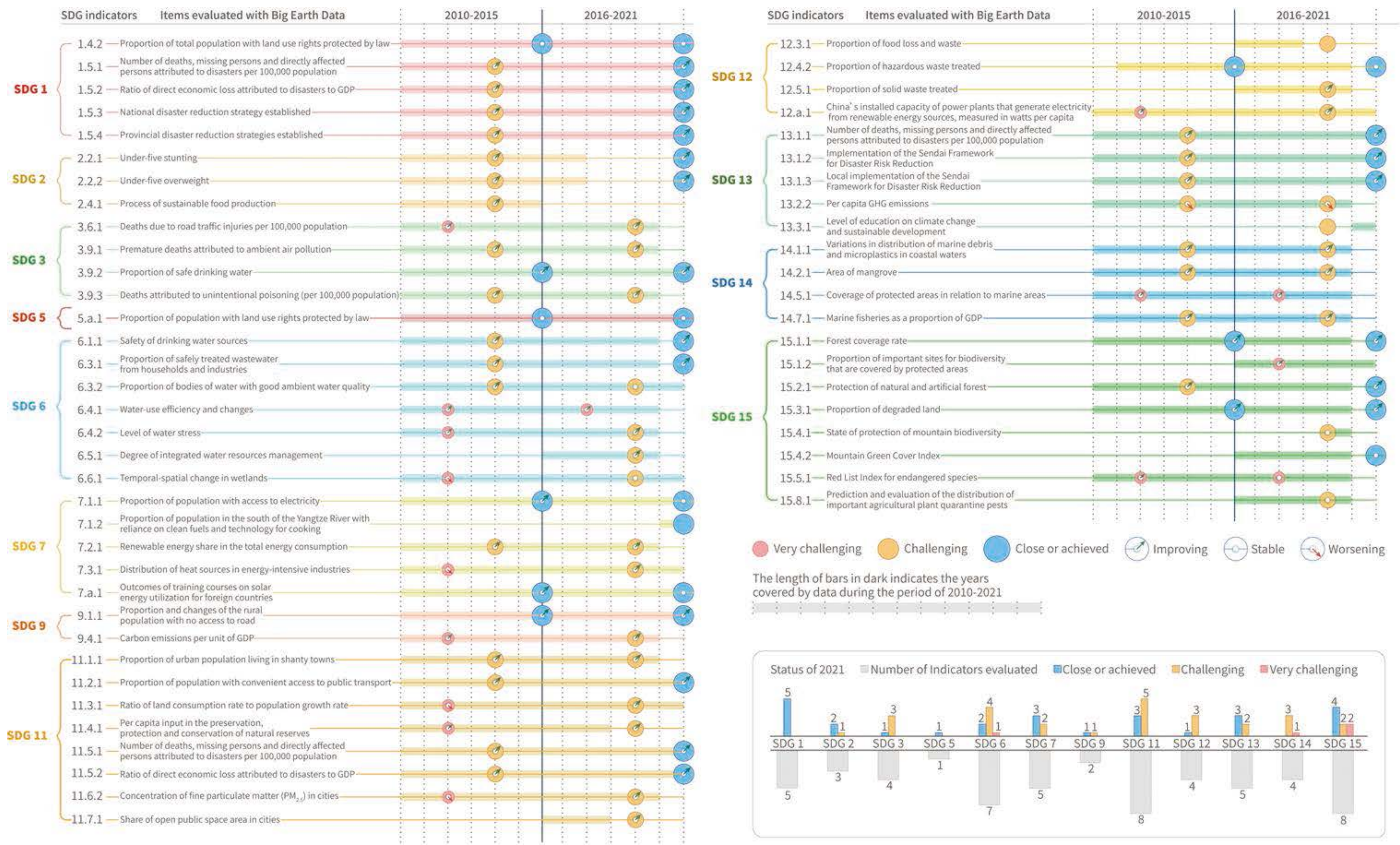


Figure 1-2. Evaluation of China's Progress in SDGs Based on Big Earth Data (2010-2021)


SDG2

SDG 2
Zero Hunger

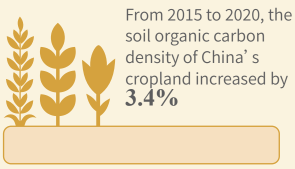
Highlights

Improving Agricultural Productivity

There is potential for improving the global crop intensity. Marked progress has been made in managing the saline-alkali land in the black soil region in Northeast China. In 2020, about 85.2% of global arable land was under single cropping. Grain production is expected to increase by 230 million tons, or 6.4% of the current global production, if the cropping intensity potential at rainfed conditions is achieved. In the western part of the black soil region in Northeast China, which is one of the world's three largest soda salt alkali lands, a series of restoration projects like "Vegetation Restoration in Saline-sodic Soil" and "Major Projects in West Jilin Province" have reduced the area of salt alkali land by 63.3% since 2000, and promoted grain production.

Promoting Sustainable Grain Production

China's cropping systems have the potential for reducing carbon emission and reaching carbon neutrality. From 2015 to 2020, the soil organic carbon density of cropland increased by 3.4%; carbon emission per unit value of the cropping system has declined over the recent decade, albeit higher emission per unit area in the Jianghuai Region, Jianghan Plain, and Sichuan Basin.



Background

Zero Hunger constitutes the foundation for sustainable development. Today, implementation of SDG 2 is off track globally, leaving much to be desired. After being stable for five consecutive years, in 2020 alone, the global population facing hunger increased from 8.4% to 10.4% (FAO, 2021). Malnutrition in different forms remains a challenge, with the ratio of the malnourished rising from 8.0% in 2019 to 9.8% in 2021. Global food insecurity has been exacerbated due to the growing frequency of regional conflicts, worsening climate change, and economic slowdown (FAO, *et al.*, 2022). Furthermore, impacted by large-scale and intensive resource consumption and development, the food systems are threatening the global water resources, biodiversity, and critical ecosystems.

The United Nations convened the Food Systems Summit in September 2021 to, among others, build a global consensus on the importance of improving food system transformation, which, as the Summit pointed out, will promote human health and improve the environment, thus helping with the realization of all SDGs. The UN Secretary-General said at the Summit that transforming food systems will help drive global recovery from the COVID-19 pandemic. The five action tracks for the transformations are identified as ensuring access to safe and nutritious food for all, shifting to sustainable consumption patterns, promoting production that has a positive impact on nature, promoting equitable livelihoods, and building resilience to vulnerability, shocks, and stress, and in this process innovation serves as an important lever of change on all the action tracks. Improving agricultural productivity and sustainable food production, two areas where innovation can make a great impact, represent effective ways to ensuring access to nutrition and promoting harmony between man and nature, and are critical to reducing the risk of hunger and achieving global food security.

Supported by the Big Earth Data technology, the Report in the past three years presented national-scale long-term spatiotemporal analyses and pathway analyses of stunting among children, sustainable and intensification of cultivated land, and sustainable food production in China. This year, centering on SDG 2.3 and SDG 2.4 with a continued focus on improving agricultural productivity and sustainable food production, the report details the monitoring methods for cropping intensity and soil salinization, two important factors affecting agricultural productivity, and analysis of sustainable food production against the background of climate change, with a view to providing data products, methods, and decision-making support in identifying food-system problems and promoting food-system transformation.

2 ZERO HUNGER

Main Contributions

This chapter evaluates the progress of SDG 2.3 and SDG 2.4 through four cases at global, national, and local scales. The main contributions are as follows (Table 2-1).

Table 2-1 Cases and Their Main Contributions

Subject	Target	Case	Contributions
Improving Agricultural Productivity	SDG 2.3	Spatial pattern of cropping intensity and gaps at global scale	**Data product:** Global 30 m resolution cropping intensity of 2020 **Method and model:** Global high-resolution remote sensing extraction model for cropping intensity **Decision support:** Identifying areas with large cropping intensity gap in the world to inform decisions on global grain output increase
	SDG 2.3 SDG 2.4	Variations in the area of the saline-alkali land of the black soil region in Northeast China and the driving factors	**Data product:** Dataset of soil salinization degree in black soil saline area in Northeast China in 1985-2020 **Method and model:** Soil electrical conductivity inversion model based on ensemble classification algorithm and machine learning **Decision support:** Providing data to support the improvement, utilization and reclamation of saline-alkali land, and inform the development and classification assessment of agricultural production potential
Promoting Sustainable Food Production	SDG 2.4	The assessment of potential for cropland carbon sequestration in China under global change	**Data product:** Carbon density of Chinese cropland soil in 2015 and 2020 and its future spatial pattern **Method and model:** Spatial big data-driven Agro-C model **Decision support:** Informing decisions on the sustainable production of crop farming aligned with carbon goals
		Temporal and spatial variations of carbon emissions for cropping systems in China	**Data product:** Carbon emission volumes of cropping system at Chinese county-scale in 2010, 2015 and 2020 **Method and model:** Quantitative estimation of carbon emission by the crop production systems at the county scale in China through integration of multi-source data and machine learning **Decision support:** Informing the understanding of the current state of agricultural carbon emission at county scale and future polices on carbon emission reduction

2 ZERO HUNGER

Thematic Studies

Improving Agricultural Productivity

Improving agricultural productivity is the most direct route to ensure food security. Expanding the area of arable land, increasing farming intensity, and boosting unit yield by technological means are the three ways to raise agricultural output. However, potential is limited in developing reserve arable land in many regions of the world and, at the same time, arable land, already limited in area, is under the pressures of industrialization and urbanization. Given that, higher grain output in the future will have to rely on sustainable agricultural technologies, such as protective farming and soil fertility enrichment, and on top of that, multi-cropping and intensive utilization of cultivated land, which can directly improve agricultural productivity. Meanwhile, rehabilitating degraded soil and increasing arable land reserves is another important way to raise agricultural productivity. This section, focusing on multiple cropping and saline-alkali land management, offers technical support to and informs policy-making on raising agricultural productivity, based on Big Earth Data-enabled extraction of global large-scale multi-cropping on cultivated land and the long-term monitoring of changes in saline-alkali land in key regions.

Spatial pattern of cropping intensity and gaps at global scale

Target: 2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

According to the phenological information of the Agro-ecological Zones, starting dates and ending dates of monitoring were determined. Based on all available Landsat-8 and Sentinel-2 imageries at 10-30 m resolution at the global scale from the monitoring period, Normalized Difference Vegetation Index (NDVI) from multiple satellite images was harmonized and integrated into a time series dataset. Whittaker smoother was employed to fill the gap and reconstruct the smoothed NDVI time series. Using a binary crop phenophase profile indicating growing and non-growing periods (Liu *et al.*, 2020; Zhang *et al.*, 2021), 30 m resolution global cropping intensity product for 2020 was generated and the spatial pattern was analyzed. Cropping intensity product was also overlapped with the potential cropping intensity data to derive cropping intensity gaps.

In 2020, about 85.2% of global cropland was in the single cropping pattern, and the double cropping pattern mainly concentrated in the Indo-Gangetic Plain, North China Plain, Parana River Basin, Mato Grosso Plateau and Nile Delta. The cropping intensity index averaged 115% globally in 2020, with 85.2% of cropland in single cropping, 14.4% in double cropping, and only 0.4% in triple cropping or above. Cropland in multiple cropping patterns is mainly in East Asia, South Asia, South America, and the Nile Delta (Figure 2-1), and triple cropping is only 0.4% scattered in tropical and subtropical regions. Double cropping is most concentrated in the Indo-Gangetic Plain, North China Plain, Parana River Basin, Mato Grosso Plateau, and Nile Delta, where cropping intensity is higher than in other areas at the same latitude. There are significant differences in cropping intensity among continents, with the highest average cropping intensity in South America at 134%. The average cropping intensity in Asia is 121%, slightly lower than in South America. Europe and Africa are observed with average cropping intensity of 110%, higher than those in North America and Oceania, with the lowest cropping intensity at 105% and 103%, respectively.

Grain production is expected to increase by 230 million tons, or 6.4% of the current global production, if the cropping intensity gaps at rainfed conditions are achieved. The climate conditions are favorable to multiple cropping in Central America, Southeast Asia, and Africa's equatorial region, where the cropping intensity gaps are larger than in other regions. The cropping intensity gaps of most countries in the above-mentioned regions exceed 0.75 cropping season when climate conditions are fully utilized. Globally, grain production is expected to increase by 230 million tons, or 6.4% of the current global total grain production, by closing the cropping intensity gaps. In China, larger cropping intensity gaps are observed in the south of Yangtze River, with robust economic development and significant labor migration from rural to urban areas. Land use intensification can be further improved in the south through better coordination between economic and agricultural development, and through innovation and technology.

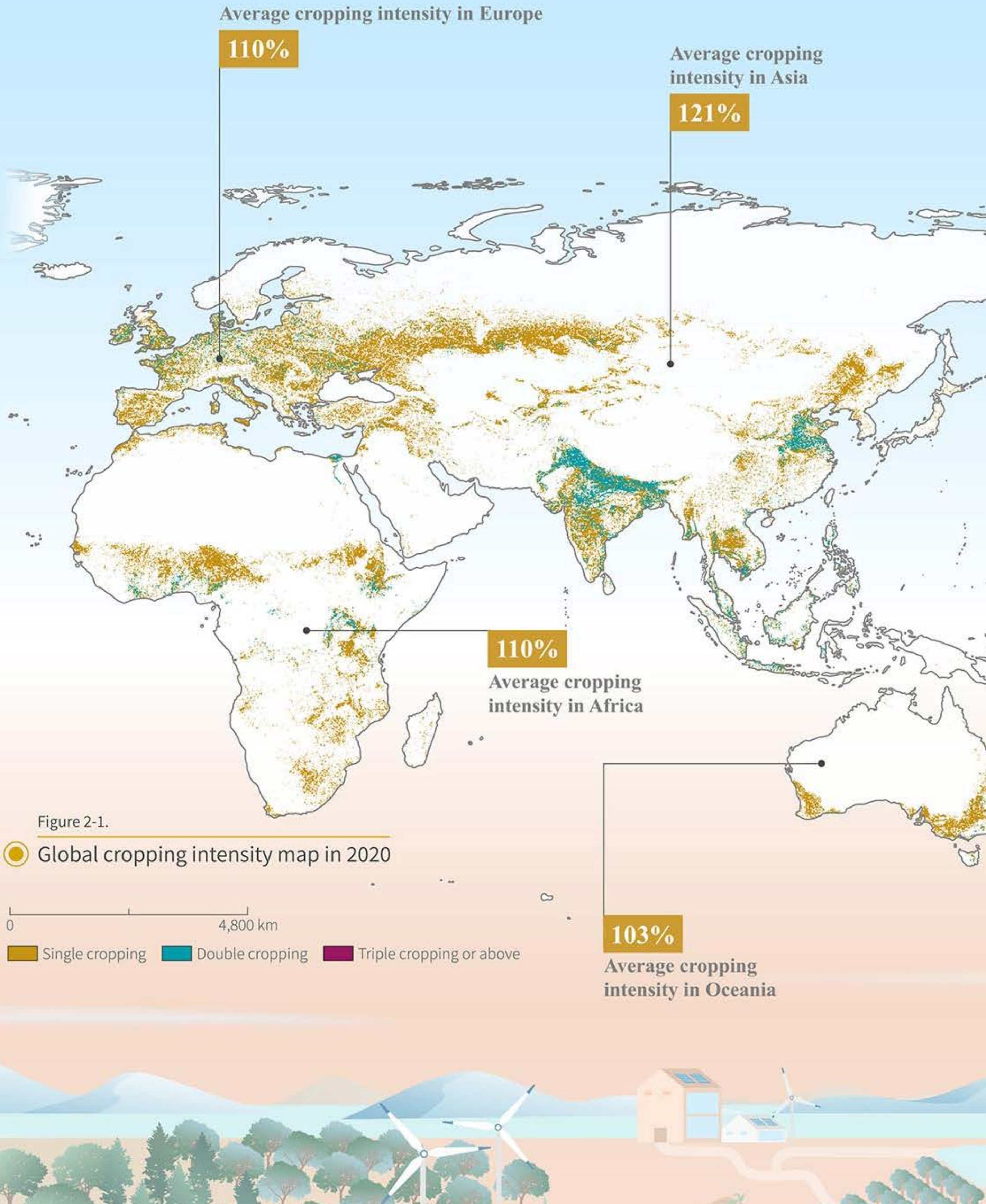
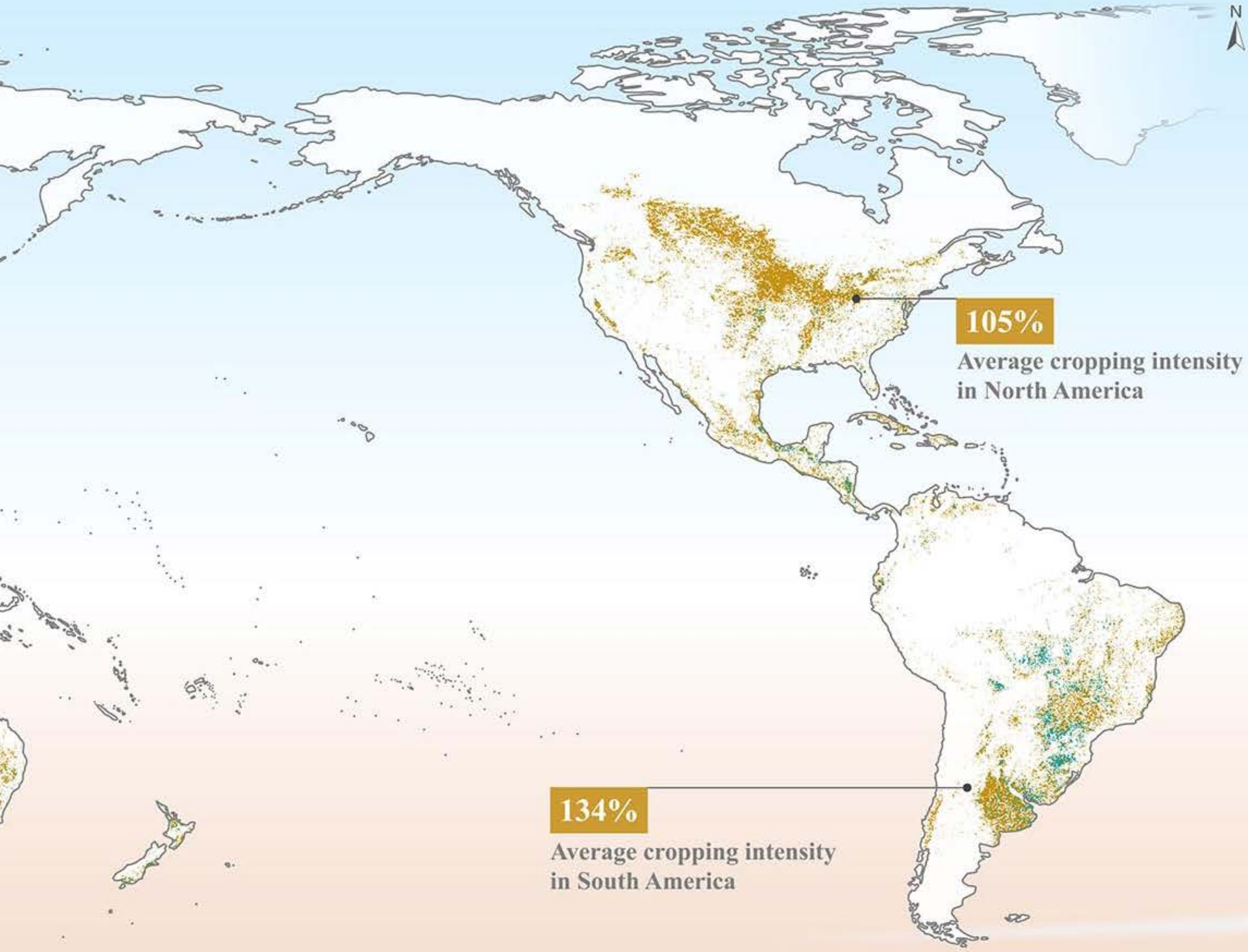


Figure 2-1.

Global cropping intensity map in 2020


N
105%
Average cropping intensity in North America
134%
Average cropping intensity in South America

Variations in the area of the saline-alkali land of the black soil region in Northeast China and the driving factors

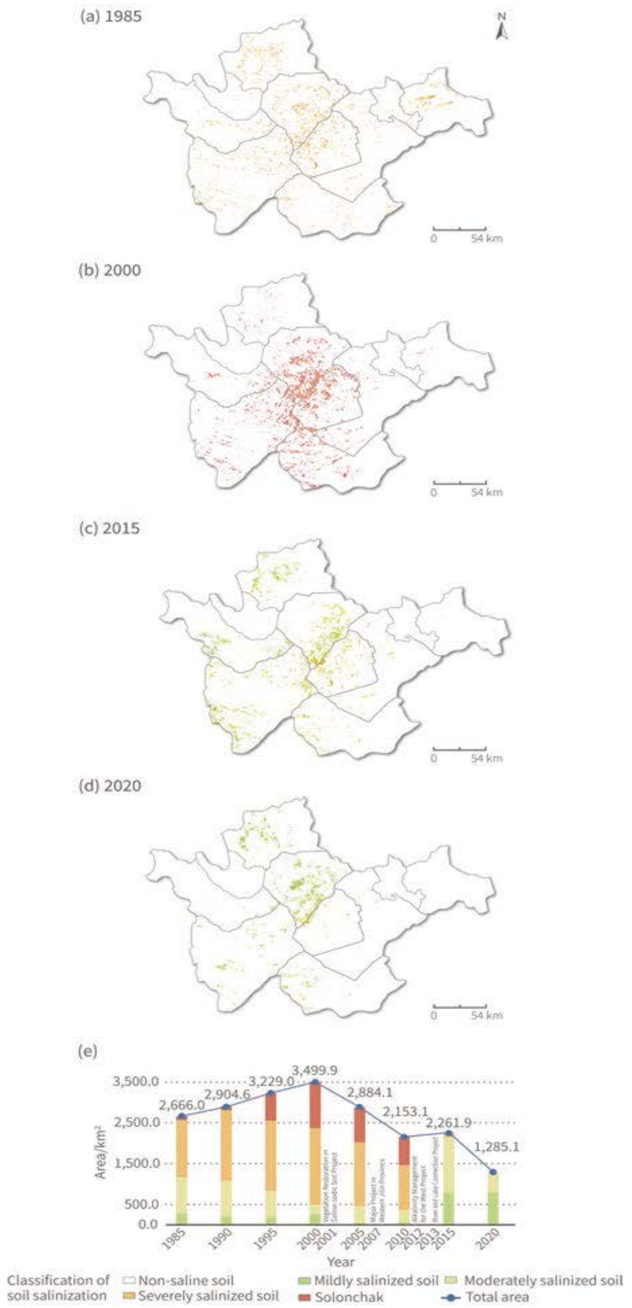
Target: 2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

In the west of Jilin province, China has one of the world's three largest soda saline-alkali lands. It accounts for 19% of the total area of the black soil in northeast China and over 80% of the saline-alkali area on the black soil, and is a top priority in black soil protection. Based on the Landsat 5/7/8 data, this study proposes a remote sensing model and the corresponding method that retrieves the long-term variations of the area of saline-alkali lands in west Jilin. Moreover, with multi-year data collected from the field, this study establishes and verifies a model for identifying soil salinization and retrieving the electrical conductivity of lands. Changes in soil salinization and the driving factors are then discussed in light of government policies.

This study proposes a saline-alkali land identification algorithm and classification model for the monitoring of the degree of soil salinization in the salina concentrated area in west Jilin from 1985 to 2020. This study establishes a long-term temporal soil electrical conductivity inversion model (Li *et al.,* 2022) by using the big data and the processing programs on the cloud platform, the classification algorithm and machine learning model, the multi-year data collected from the field and the remote sensing data captured by satellites for multiple periods, and through such methods as Box-Cox transformation, spectral parameter selection, machine learning modeling, and accuracy verification. Under this model, soil salinization in the west of Northeast China from 1985 to 2020 is identified and classified (Figure 2-2). And as the results show, the area of saline-alkali lands in west Jilin province expanded before it shrank, and salinization worsened before it lessened.

Soil salinization has been effectively reduced through the implementation of the Vegetation Restoration in Saline-sodic Soil Project and the Major Projects in Western Jilin Province, with the area of saline-alkali lands on the black soil shrinking by 63.3%, contributing to increased grain yield. The monitored period was divided into the natural state (1985-2000) and rehabilitation state (2000-2020) according to the area of saline-alkali lands and the period of government-sponsored improvement projects. During the natural state period, the total area of saline-alkali lands increased by 31.3%, and the degree of salinization deteriorated. In contrast, during the rehabilitation period, the total area of saline-alkali lands decreased by 63.3%,



↑ Figure 2-2. Temporal-spatial distribution of saline-alkali lands in west Jilin and change in area from 1985 to 2020 and the degree of salinization lessened (Figure 2-2). Further analysis revealed that 57% of the increased saline-alkali lands were converted from grassland and dryland during the natural state period, negatively impacting animal husbandry and agriculture. During the rehabilitation period, the implementation of the project "Vegetation Restoration in Saline-sodic Soil" and "Major Projects in Western Jilin Province" converted a large area of saline-alkali lands into dryland (55.6%) and grassland (23.5%), reversing the trend of saline-alkali land expansion and significantly boosting grain yield.

Promoting Sustainable Food Production

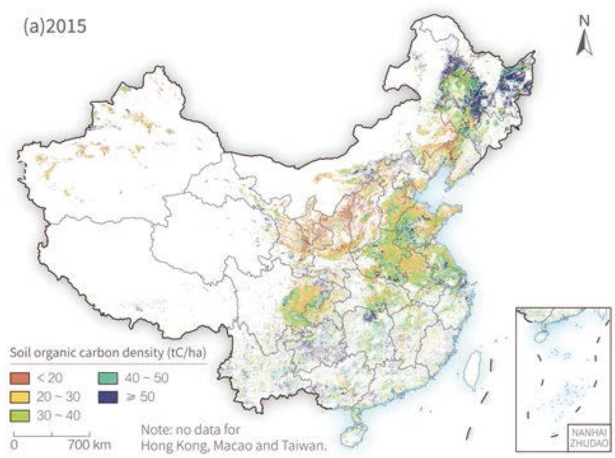
Sustainable grain production lies at the core of SDG 2.4 and is also an effective means of tackling global challenges such as climate change and land degradation. Sustainable food production means a green and low-carbon pattern that mitigates the impact of food production on climate change through adaptation. Studies show that the food production systems are responsible for nearly one-third of global greenhouse gas emissions, but well-managed cropland soil can become an important carbon sink and provide healthier and more sustainable conditions for crops. Centering on the food production systems under climate change, this section will present two cases that summarize the current and future carbon changes of cropland soil and carbon emissions of the food production systems, to inform decisions on sustainable food production under climate change.

The assessment of potential for cropland carbon sequestration in China under global change

Target: 2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

Agro-C is a process-based model that assesses the carbon cycle in agricultural ecosystems independently developed by Chinese scientists. Calibrated and validated by crop yield statistics of four grain crops (rice, wheat, corn, and soybean) in China, the model simulated the spatial pattern of soil carbon density in relation to the growing processes of the four grain crops in 2015 and 2020. Meanwhile, using four future climate change scenarios (SSP126/SSP245/SSP370/SSP585) of the FGOALS-g3 model (Flexible Global Ocean-Atmosphere-Land System Model-Grid Point Version 3), this case evaluates the temporal and spatial changes of carbon sequestration in Chinese cropland soils under baseline and optimized management practices from the present to 2060.

The soil organic carbon in Chinese cropland increased by 3.4% from 2015 to 2020. Agro-C model simulation shows that from 2015 to 2020, the national average soil organic carbon density of cropland increased from 41.3 t C/ha to 42.7 t C/ha, an increase of 3.4%. Spatially, Northeast China had the highest, followed by the North China Plain, which was slightly higher than the Sichuan Basin (Figure 2-3). In terms of temporal change, some parts of the Northeast experienced a downward trend, while the North China



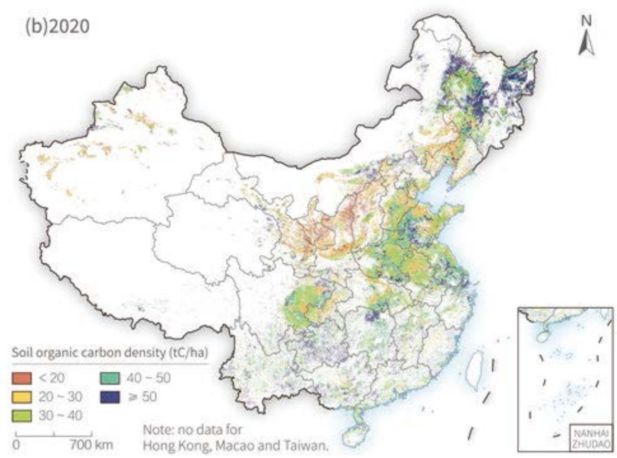


Figure 2-3. Spatial pattern of soil organic carbon density of Chinese cropland in 2015 and 2020

plain saw a significant increase, mainly attributable to the higher yield of the rotation of winter wheat and summer corn and more straw return-to-field as a result of machine harvesting of vast areas of winter wheat.

Future scenarios show that Chinese cropland soils will continue to serve as a carbon sink, but with weakening intensity. Under both the baseline scenarios where straw return-to-field ratio, cropland organic fertilizer application and no-tillage practices remain at the level of 2020, and the optimized scenario where management practices are continuously improved, the Agro-C model simulation shows that Chinese cropland soils will continue to serve as a carbon sink, but with weakening intensity. The impact of management practices on cropland soil carbon sequestration is greater than that of climate change. Under the baseline scenario, the carbon sequestration of Chinese cropland soils is above 15 TgC/a; under the optimized scenario, it exceeds 20 TgC/a. The optimized management practices in Chinese cropland can increase crop yield, which in turn improves the amount of crop straw and roots returning to the field. This positive feedback can reduce the adverse effects of global warming on soil carbon storage.

Temporal and spatial variations of carbon emissions for cropping systems in China

Target: 2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, help maintain ecosystems, strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and progressively improve land and soil quality.

The potential for agricultural greenhouse gas emission reduction varies across regions (Powlson *et al.,* 2011), and a clear understanding of the differences is essential for sustainable grain production and emission reduction. The Big Earth Data technology can reveal the spatiotemporal patterns of the carbon emissions from the cropping systems at a high-resolution scale to inform global warming mitigation efforts in the agricultural system (Guo, 2019).

Using the Big Earth Data and machine learning method, carbon emission data for cropping systems in China was produced at the county scale for 2010, 2015 and 2020, enabling the monitoring of carbon emissions with high temporal and spatial resolution. Using a detailed dataset on China's provincial-level carbon emissions from cropping systems from 1978 to 2016, considering emissions from a full range of agricultural activities related to crop farming, including crop residue open burning, cropland emissions, machinery use, nitrogen fertilizer production, and pesticide production, based on machine learning method, this case evaluates the impact of natural and human factors on carbon emissions for cropping systems at the provincial scale and identifies the main factors at play, extending the monitoring of provincial emissions to 2020. Taking the provincial-scale carbon emissions as the dependent variable and the main influencing factors as the independent variables and using the random forest algorithm, a down-scaling model of carbon emissions estimation is constructed to monitor cropping systems emissions at the county level in China.

2) In the past ten years, China's agricultural carbon emission per unit value has continued to decline, with a drop of about 45.9%, while carbon emission per unit yield has remained stable. Higher carbon emission per unit area is observed in the Yangtze-Huai River Basin, Jianghan Plain, and Sichuan Basin. China's carbon emissions from cropping systems display a distinct spatial pattern of higher in the north and east and lower in the west and south (Figure 2-4). Higher carbon emissions per unit area are observed in Jiangsu, Henan, Hubei, Hunan, Sichuan, and Guangdong. Regions where such emissions exceed 200 tCO_2-eq/km^2 include the Yangtze-Huai River Basin, Jianghan Plain, and Sichuan Basin. Despite the increasing trends for both crop yield and the output value of the planting industry between 2010 and 2020, carbon emissions per unit value have shown a downward trend (Figure 2-4d), with a decline of 0.09 tCO_2-eq/(10^4·a) since 2017, while carbon emissions per unit yield have largely unchanged over the same period.

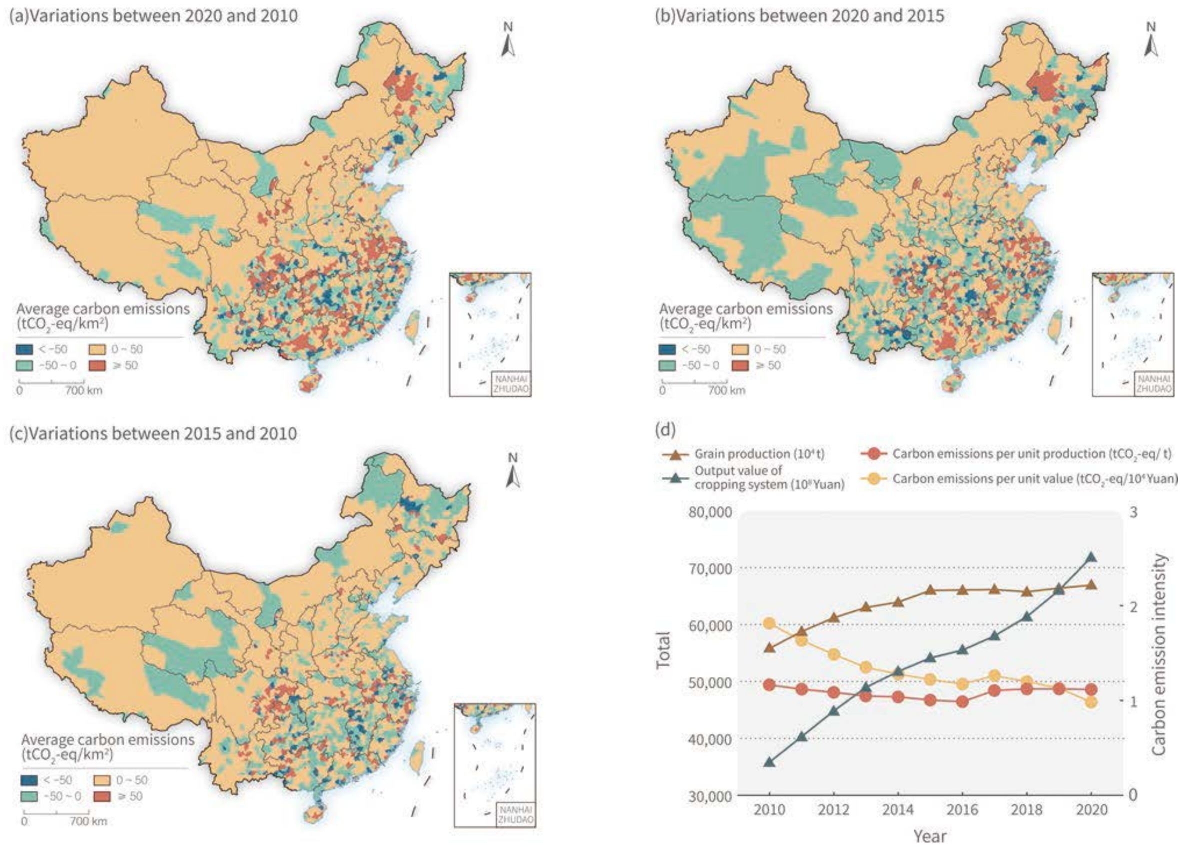


Figure 2-4. Carbon emissions by China's cropping systems and spatial distribution and time series of variations from 2010 to 2020

Recommendations and Outlook

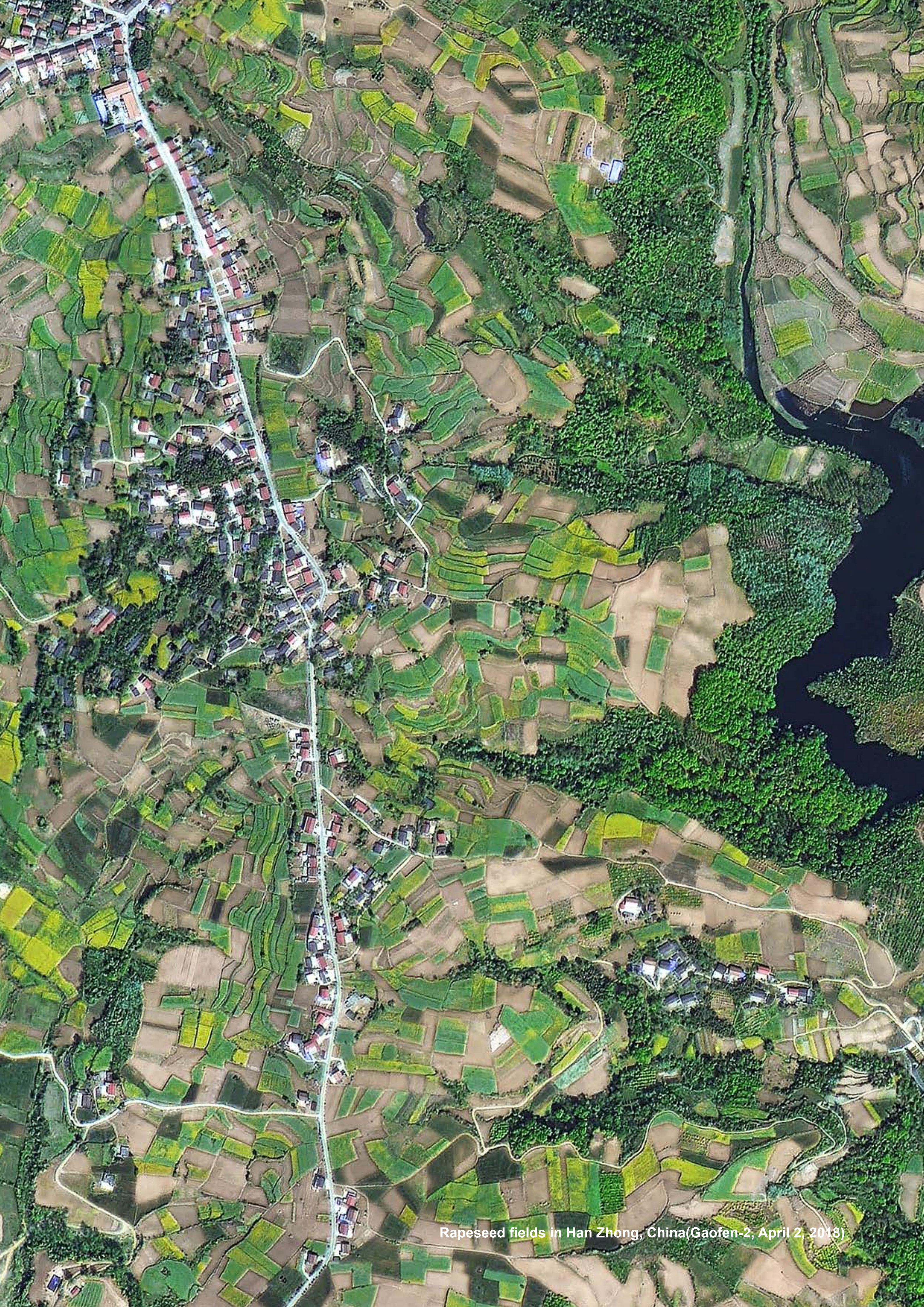
In this chapter, two topics under Zero Hunger are discussed, e.g., improving agricultural productivity and sustainable food production, through cases at the global, national, and local scales. Compared with the reports of the past three years, this chapter includes the monitoring of SDG 2.4.1 (related to soil degradation and soil fertility) at the regional scale, and studies sustainable food production under SDG 2.4 at the Chinese national scale in the context of climate change. In the meantime, the extraction method of cropping intensity has been expanded to the global scale.

Based on the above studies, we offer the following recommendations:

(1) Regarding SDG 2.3.1 referring to improving agricultural productivity, the study on the global cropping intensity spatial distribution and potential reveals that the greatest potential for cropping intensity in the world is found in the tropical and subtropical regions. If their climate conditions of light, temperature and water are used to the fullest extent, these regions can further raise the level of cropping intensity and make greater contributions to meeting the Zero Hunger Goal. In China, both the degree and potential of cropping intensity are higher than the global average, with significantly greater potential for closing the cropping intensity gap in the south than in the north. In the future, sustainable economic development and the cultivation of high-standard farmland should be pursued in parallel at the regional scale, with more intensive utilization of agricultural resources for stable grain production.

(2) Regarding SDG 2.4.1 referring to sustainable food production, the study shows that climate change is impacting and impacted at the same time by food production systems; sustainable crop production management, especially increases in no-tillage and straw return-to-field and strengthened management of fertilizers and pesticides, can help food production systems cope with climate change and also mitigate it through carbon emission reduction and carbon neutrality.

Efforts will continue in exploring ways of using Big Earth Data to monitor and evaluate progress in food security and Zero Hunger and identifying sensitive areas and constraints, with a view to finding a science-based path to achieve Zero Hunger Goal.



Rapeseed fields in Han Zhong, China(Gaofen-2, April 2, 2018)


SDG 6

SDG 6

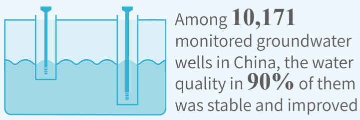
Clean Water and Sanitation

Multi spectral remote sensing image of the Yellow River Estuary (SDGSAT-1, November 12, 2021)

Highlights

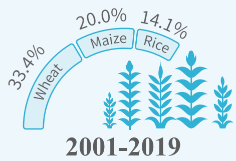
Improving Water Environment

The groundwater environments have improved significantly in China. From 2019 to 2021, the comprehensive evaluation results of water quality of 10,171 monitored groundwater wells in China are mainly class IV, and the proportion of water quality in stable or improved is 90%.



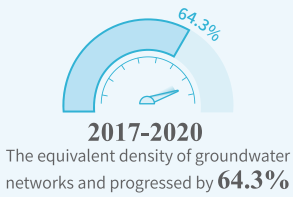
Improving Water-use Efficiency

The agricultural water-use efficiency in China has improved notably, and overall water stress has been on a downward trend. From 2001 to 2019, the water-use efficiency of wheat, maize, and rice in China increased by 33.4%, 20.0%, and 14.1%, respectively; from 2015 to 2020, overall water stress decreased from 66% to 58%, belonging to the medium category.



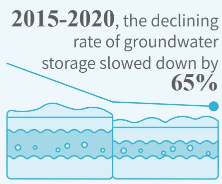
Integrated Water Resources Management

Remarkable progress has been made in optimizing the tools for water resources management. From 2017 to 2020, the equivalent density of groundwater networks and hydrological networks progressed by 64.3% and 13.3% respectively.



Changes in Water-related Ecosystems

Significant changes have occurred in the extent of inland water bodies and groundwater storage in China. The water surface area of reservoirs increased by about 7% in 2020 compared with 2015. The change rate of groundwater storage in China from 2005 to 2020 is -2.556±3.28 billion m^3/a. The declining rate of groundwater storage in China as a whole and the North China Plain from 2015 to 2020 slowed down by 65% and 37%, respectively, compared with that from 2005 to 2014.



6 CLEAN WATER AND SANITATION

Background

"Ensuring availability and sustainable management of water and sanitation for all" is at the core of SDG 6. UN Water pointed out in its comprehensive assessment report issued in 2021 that the world was already off track on SDG 6 even before the outbreak of COVID-19 (UN Water, 2021). There are still 2 billion people worldwide without access to safely managed drinking water and 3.6 billion without safe sanitation facilities. In addition, 2.3 billion people lack soap and basic hand washing facilities at home. Most of the wastewater is untreated before being discharged. One fifth of the world's river basins are experiencing rapid changes, and 80% of wetland ecosystems have been lost. In the next nine years, we need to move four times faster in some fields to meet SDG 6 on time (Harlin *et al.,* 2021).

In the SDG 6 Progress Reports, released by UN Water in 2021, on individual indicators – wastewater treatment (SDG 6.3.1), ambient water quality (SDG 6.3.2), change in water-use efficiency (SDG 6.4.1), level of water stress (SDG 6.4.2), integrated water resources management (SDG 6.5.1), transboundary water cooperation (SDG 6.5.2), and freshwater ecosystems (SDG 6.6.1), the progress in SDG 6 implementation worldwide is systematically reviewed and analyzed. However, there are still huge gaps in the data used in the report. In addition, national level data is inadequate in accurately informing decision-making. Therefore, urgent actions need to be taken in the following two aspects: first, to strengthen data collection at the national and local levels; second, to inform decision makers on practical actions.

Big Earth Data technology, making rapid advances in recent years, has dramatically improved the capacities for monitoring and evaluating SDG 6. Through remote sensing, regular revisits, and rapid information extraction, such technology enables high spatial-temporal resolution monitoring of relevant indicators, producing more accurate and comprehensive evaluation results at a lower cost and shorter time (Lu *et al.,* 2021). In the past three years, with the support of Big Earth Data, national-scale monitoring was successively carried out of the water quality improvement, water-use efficiency improvement, integrated water resources management, and change in water related ecosystems, and the evaluation was done of the effectiveness of the implementation of integrated management of water quality, water quantity and water ecosystems in China. Nevertheless, the role of these studies in informing policies is weakened due to the lack of understanding of the differences in indicator progress in different administrative regions within the country. So this year's report systematically evaluates the provincial level implementation of SDG 6 in China, covering ambient water quality, water-use efficiency, level of water stress, integrated water resources management, freshwater ecosystems, and integrated assessment. The results are of great value for understanding the provincial implementation of SDG 6, identifying problems and gaps, and informing strategies for accelerating the realization of SDG 6 indicators.

6 CLEAN WATER AND SANITATION

Main Contributions

This chapter evaluates progress of SDG 6.3, SDG 6.4, SDG 6.5, and SDG 6.6 individually and collectively at China's provincial level from 2015 to 2020 through six cases. The main contributions are as follows (Table 3-1).

Table 3-1 Cases and Their Main Contributions

Theme	Target	Case	Contributions
Improving Water Environment	SDG 6.3	Assessment of groundwater quality changes in China	**Decision support:** Inform the evaluation of effectiveness of groundwater quality control at the provincial level in China
Improving Water-use Efficiency	SDG 6.4	Evaluation of water-use efficiency changes of three major grain crops in China	**Data product:** Dataset of water-use efficiency of three major grain crops in China between 2001-2019, by year, with 1 km spatial resolution **Method and model:** Evaluation method based on multi-source data and combined with crop growth process
		Analysis on the changes and driving forces of water stress level in China from 2010 to 2020	**Data product:** China water stress dataset, between 2010-2020, by month, with spatial resolution 0.5 ° **Decision support:** Inform industrial restructuring policies under the scenarios of climate change and water resource constraints
Integrated Water Resources Management	SDG 6.5	Assessment of data supporting capacity for provincial integrated water resources management in China	**Method and model:** Quantitative evaluation method for data supporting capacity of integrated water resources management **Decision support:** Inform the assessment of data support capacity for China's provincial level integrated water resources management
Change in Water Ecosystems	SDG 6.6	Assessment of change in surface water and groundwater volume in Chinese provinces	**Data products:** Datasets (2015 and 2020) of Chinese reservoirs' distribution; Dataset of changes in Chinese groundwater storage between 2005-2020, by month, with spatial resolution 0.5 ° **Method and model:** A collaborative forward modeling integrating gravity satellite and groundwater level data **Decision support:** Inform the assessment of the exploitation and utilization of surface water and groundwater resources at Chinese provincial level
Comprehensive Evaluation	SDG 6.1 SDG 6.3 SDG 6.4 SDG 6.5 SDG 6.6	Comprehensive evaluation of China's SDG 6 progress from 2015 to 2020	**Method and model:** Sustainability index of water resources development and protection **Decision support:** Inform the assessment of progress in clean water and sanitation facilities at provincial level in China

Thematic Studies

Improving Water Environment

In the past 40 years, amidst the vigorous development of industrialization and urbanization in China, there have been frequent water pollution incidents caused by industrial, agricultural, and domestic sewage discharge, which has become a potential risk factor to people's health, sustainable development, and social stability. However, since 2006, China has implemented the National Project of Science and Technology for Water Pollution Control and Treatment. As a result, the surface and groundwater environments have significantly improved. This section analyzes the groundwater quality changes. It evaluates the progress in implementing water quality improvement (SDG 6.3) at the Chinese provincial level.

Assessment of groundwater quality changes in China

Target: 6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally.

Based on 2019, 2020, and 2021 water quality data from the monitoring stations under the National Groundwater Monitoring Project, according to the Standard for Groundwater Quality (National Standards of the People's Republic of China) (GB/T14848-2017), each water quality index of the monitoring stations is assessed to produce the F value for the comprehensive evaluation of the groundwater quality at the monitoring stations (I: <0.8; II: 0.8-2.5; III: 2.5-4.25; IV: 4.25-7.2; V≥7.2), by the Nemerow index method (Ni and Feng, 2018). The evaluation results show that Class I-III groundwater has relatively low chemical component and is suitable as a centralized drinking water source and industrial and agricultural water. These are defined in this study as "excellent." Class IV groundwater, which has a high chemical component content, is suitable for agriculture and some industrial use and can be used as domestic drinking water after proper treatment. It is defined as "good" in this study. Class V groundwater is not suitable for drinking and is defined as "inferior."

Table 3-2. Proportions of water quality by class at groundwater monitoring sites in China

Class		Excellent			Good	Inferior
		Class I	Class II	Class III	Class IV	Class V
Year	2019	2.5%	10.3%	1.6%	66.9%	18.8%
	2020	3.1%	9.4%	1.0%	68.8%	17.7%
	2021	3.4%	10.2%	1.1%	67.8%	17.4%

From 2019 to 2021, more than 90% of monitoring sites saw stable level of underground water quality or improvement. Groundwater quality assessment results from the 10,171 monitoring wells show that most were Class IV, accounting for around 67.8%, the second largest group was Class V, taking approximately 17.9%, while Class I-III were about 14.2% (Table 3-2). During those three years, groundwater quality was stable with improvement. 11.8% of monitoring sites observed improvement, 9.9% saw deterioration, and 78.3% remained stable. In this water quality evaluation system, "improved" refers to the upgrading from Class IV or V to Class I-III, or from Class

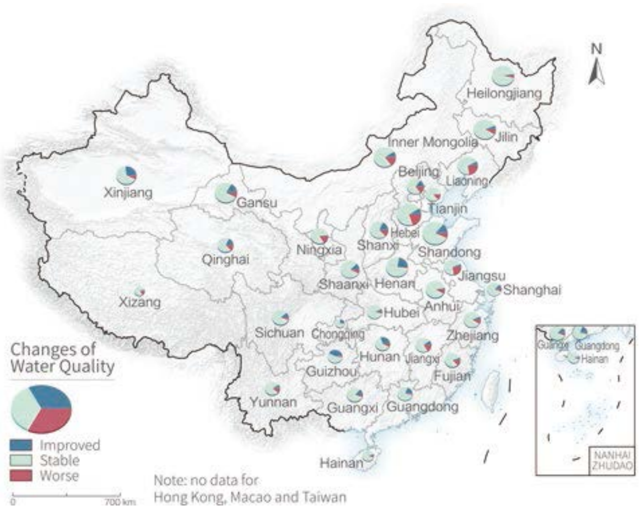


Figure 3-1. Change in assessment results at groundwater monitoring sites at provincial level between 2019 and 2021

V to class IV; "worse" means downgrading from Class I-III to Class IV or Class V, or from Class IV to Class V; "stable" means no change in the evaluation results of a single monitoring site.

From 2019 to 2021, the water quality evaluation results of groundwater monitoring stations in all the provinces in China were mainly "stable". The provinces with large changes are distributed in North China, East China, and parts of northwest and southwest China (Fig. 3-1).

Improving Water-use Efficiency

According to Food and Agriculture Organization of the United Nations (FAO) and UN water reports, the global water-use efficiency increased by 9% from 2015 to 2018, including 15% for industry and 8% for agriculture and service industry (FAO and UN Water, 2021a). However, 10% of the world's population still lives in countries with high or extremely high water stress (FAO and UN Water, 2021b). The imbalance between the supply and demand of water resources in China has eased recently (Chen *et al.,* 2022), but an objective evaluation was still impossible due to the lack of accurate, complete, and up-to-date data. This section evaluates China's progress in implementing SDG 6.4 – improving water efficiency – at the regional and provincial levels using data from satellite remote sensing, statistical investigation, and model simulation.

Evaluation of water-use efficiency changes of three major grain crops in China

Target: 6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

The crop yield is estimated based on the crop Gross Primary Productivity (GPP) dataset from the remote sensing EF-LUE (Evaporative Fraction–Light Use Efficiency) model (Du *et al.,* 2022), combined with crop phenology and provincial crop yield statistical data. The evapotranspiration water consumption of crops (Evapotranspiration, ET) is calculated by applying the ETMonitor model (Hu *et al.,* 2015; Zheng *et al.,* 2019) to the corresponding multi-source remotely sensed data and atmospheric reanalysis data ERA5 (the fifth generation ECMWF reanalysis for the global climate and weather). The crop yield ratio to ET is used to estimate and analyze the spatial and temporal pattern of water-use efficiency (WUE) of three major grain crops (wheat, corn, and rice) in China.

Water-use efficiency of the three major grain crops in China showed an obvious increasing trend. From 2001 to 2019, water-use efficiency was on an obvious upward trend for all 3 main grain crops, with an increase of 33.4% (0.024 kg • m^{-3} • a^{-1}) for wheat, 20.0% (0.016 kg • m^{-3} • a^{-1}) for corn, and 14.1% (0.014 kg • m^{-3} • a^{-1}) for rice (Figure 3-2a). The water-use efficiency of the three major grain crops in different geographical regions mostly showed an upward trend but varying degrees. The WUE of wheat increased by a bigger margin in the north, east, and central China (Figure 3-2b); the WUE of corn rose relatively fast in the north, northeast, and northwest (Figure 3-2c); the WUE of rice showed an overall increasing trend in the east and south (Figure 3-2d) while displaying little change in the northeast and central China.

Water-use efficiency improvement was mainly attributable to increase in crop yield. The analysis of the contribution rate change in ET and per unit yield to the trend of water-use efficiency reveals that, the change in water-use efficiency of the three major grain crops in China as a whole and in major geographical regions, is mainly driven by the increase of per unit yield of crops. Although ET also shows an upward trend, the increase range is relatively small, and thus its contribution to the change in crop water-use efficiency is smaller than that of per unit yield (Figure 3-3). The grain yield increases significantly, but the water consumption per unit area does not increase equally, thanks to advances in agricultural science and technology and the significant improvement in agricultural infrastructure, water-saving irrigation and agricultural water management technique, all factors conducive to the sustainable development of food production in China.

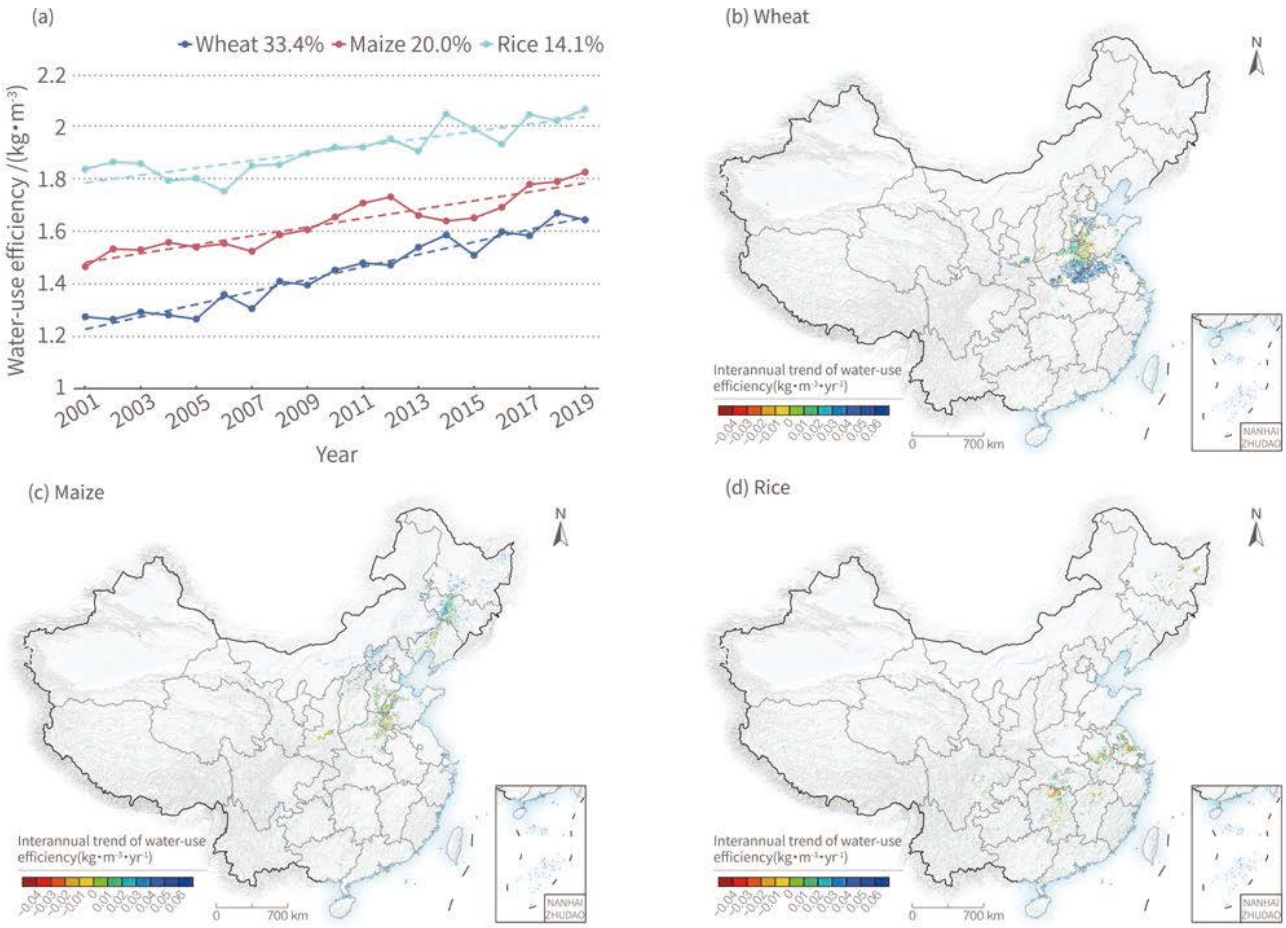


Figure 3-2. Interannual change in water-use efficiency of three main grain crops in China (a) and spatial distribution (b, c and d) from 2001 to 2019 (The percentages in 3-2a show the increase rates between 2001 and 2019)

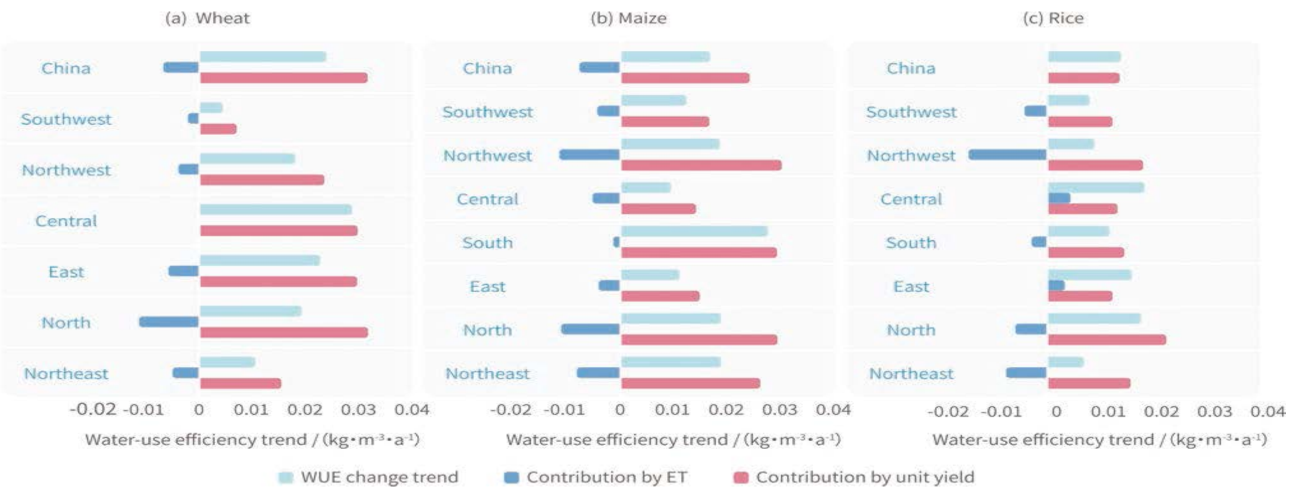


Figure 3-3. Yield and ET to WUE trend from 2001 to 2019 for three major grain crops

(Note: the positive contribution of yield indicates that the trend of yield is consistent with that of water-use efficiency, while the negative value indicates opposite trends. The positive value of ET contribution indicates that the trend of ET is opposite to that of water-use efficiency, while the negative value indicates consistent trends. If the absolute value of the contribution of yield is greater than that of ET, it means that the contribution of change in yield to WUE trend is larger; otherwise, the contribution of change in ET to WUE trend is larger)

Analysis on the changes and driving forces of water stress level in China from 2010 to 2020

Target: 6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

The level of water stress (SDG 6.4.2) is defined by FAO as the ratio between total freshwater withdrawn by major economic sectors and available freshwater resources (taking into account environmental water requirements) (FAO, 2018). It falls into the following categories: 0-25% no stress; 25-50% low; 50-75% medium; 75-100% high; >100% extremely high. Based on the remote sensing data, statistical data, model-simulated data, and the ratio of available water resources in the Level One water resources district in China, this case calculates the level of water stress for each province in China and evaluates the change in water stress from 2010 to 2020. The contributions of the climate factor and water-use factor to the change in water stress level are analyzed by the factor decomposition method.

From 2010 to 2020, China's water stress level showed a downward trend. The level of water stress in China in 2020 was 58%, on a downward trend from 66% in 2015, but still in the medium category. Extremely high water stress level of more than 100% was observed in Beijing, Tianjin, Hebei, Shanxi, Shandong, and Henan provinces in the north, Jiangsu province and Shanghai in the east, and Xinjiang and Ningxia in the northwest, a level that indicates the natural water resources in these regions cannot meet the demand for water use. The water stress level was either declining or not growing significantly in all provinces except Hainan province, where a notable increase was seen. The climate factor was the dominant driver behind the change in water stress levels for most provinces, except for Jiangsu, Zhejiang, Fujian, and Guangdong provinces in the southeast, where the reduction in water use was the main driver (Figure 3-4). The contributions of climate wetting and water-use reduction to the overall decrease of water stress in China were 70% and 30%, respectively.

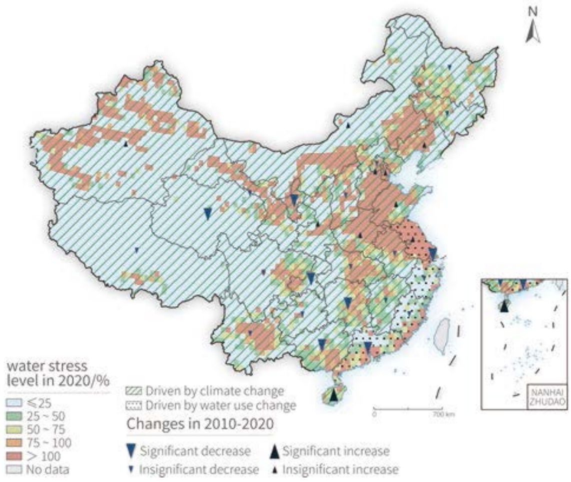


Figure 3-4. Spatial distribution of water stress level in China and changes

Technological progress is the main inhibitor of water-use increase. In terms of contributions to water use by sector, the change in water use in the northeast and the south of the Yangtze River is mainly driven by the decline of industrial water use, with a contribution rate above 50% in Jilin, Heilongjiang, Shanghai, Fujian, Hubei, Hunan, Guangdong. In most northern provinces, the main driver is the decrease in agricultural water use, and the contribution rate is more than 50% in Hebei, Liaoning, Shandong, Qinghai provinces and Ningxia (Figure 3-5a). In terms of population, economics and the technological factor, the latter two are the dominant drivers behind the change in water use, with economic development driving up water use while technological progress inhibiting the increase in water use (Figure 3-5b). Overall, technological progress is the dominant factor inhibiting the increase in water use.

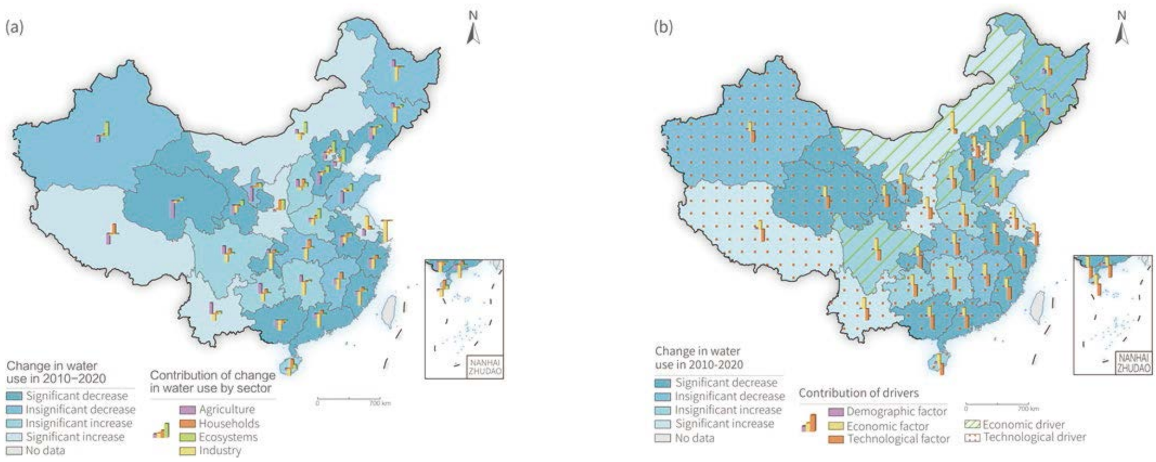


Figure 3-5. Contribution by driver to change in water use in China. (a) Contribution by sector, (b) Contribution by demographic, economic and technological factors

Integrated Water Resources Management

According to the UNEP assessment report (UNEP, 2021a), the implementation rate of integrated water resources management is far lower than expected globally. Therefore, the SDG 6.5 will not be met unless doubling the effort. In recent years, China has deepened its integrated water resources management, gradually implementing sound institutional and administrative systems to support it. In terms of management tools, China has implemented the strictest system for managing water resources, accelerated progress in setting targets for ecological flows, water-use quotas for provinces sharing rivers and controls on groundwater, tightened measures mandating a feasibility study on water resources for construction project and water intake license, tightened the monitoring and measurement system, and carried out statistical surveys on water use. This section evaluates the progress in implementing the integrated water resources management (SDG 6.5) at the provincial level from the perspective of data supporting capacity for such management.

Assessment of data supporting capacity for provincial integrated water resources management in China

Target: 6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.

Drawing references from UNEP's "step-by-step methodology for monitoring integrated water resources management (6.5.1)" (UNEP, 2017) and in light of the statistics on the monitoring of hydrology and water resources and the contents of water resources management in China, an index set was constructed for the assessment of data supporting capacity for integrated water resources management in five aspects, namely water availability, water use, water sources, aquifer, and data validity. Based on this index set, data supporting capacity for integrated water resources management in 2017 and 2020 at both national and provincial levels was evaluated. The data on hydrologic stations and groundwater stations come from *National Hydrologic Statistics Annual Report*; the data on total water supply and consumption come from *China Water Resources Bulletin*.

The Supporting capacities of all kinds of data for integrated water resources management improved to varying degrees in China from 2017 to 2020. The equivalent density of groundwater networks increased from 8.4 stations/10^3 km^2 in 2017 to 13.8 stations/10^3 km^2 in 2020, with a progress degree of 64.3%. The equivalent density of hydrological networks progressed by 13.3%.

Obvious differences in data supporting capacity among provinces. In 2020, all major water sources in China were monitored for water quality, with little difference among provinces in terms of the completeness of reporting by monitoring sites of all categories, notwithstanding inter-provincial imbalances in other indicators. The equivalent density of hydrological networks was observed to be large in the southeast and small in the northwest, with the largest value in Shanghai and the smallest value in Qinghai province. The equivalent density of groundwater networks was large in the north and small in the south, with the largest value in Beijing and the smallest value in Xinjiang. The differences in data supporting capacity in different provinces are closely related to their water resources endowment conditions, socio-economic development status, and the features of water resources development and utilization.

Change in Water Ecosystems

According to the latest UNEP assessment, nearly one-fifth of the surface water area of the world's watersheds has changed significantly over the past five years, including new water surfaces created by floods and reservoir construction, and lakes, wetlands, and floodplains lost to drought (UNEP, 2021b). During this period, China's inland water bodies have changed notably, evidenced by the main increase in artificial water bodies as a result of the construction of hydrological projects (Wang *et al.,* 2022), a remarkable rise in the area of most natural lakes on the Qinghai-Tibetan Plateau under the influence of climate change, and a decline in lakes on the Inner Mongolia Plateau (Tao *et al.,* 2020). This section assesses the progress in China's implementation of the conservation and restoration of water-related ecosystems (SDG 6.6) from the perspective of change in surface-subsurface water reserves.

Assessment of change in surface water and groundwater volume in Chinese provinces

Target: 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.

The surface water area of Chinese reservoirs in 2015 was extracted using manual visual interpretation based on monthly water distribution data from the European Commission's Joint Research Centre (JRC); while the surface water area of Chinese reservoirs in 2020 was extracted using the random forest classification method based on Sentinel-1 imagery (Li and Niu, 2022); a coordinated forward model that reconciles Gravity Recovery and Climate Experiment (GRACE) satellite and groundwater level data was developed based on Chen *et al.* (2009) and Pan *et al.* (2017) for mapping groundwater storage changes in China.

Surface water area of China's reservoirs increased by about 7% from 2015 to 2020. The surface water area of Chinese reservoirs was 22,500 km^2 in 2015 and 24,100 km^2 in 2020, increasing by about 7%. The largest increase happened in reservoirs in inland river basins, accounting for 5% of the total growth. In comparison, a decline of 4% was observed in the Pearl River basin, and the change in other basins was within 1% to 2%.

According to 2020 results, China's reservoirs are mainly located in the Yangtze River Basin, accounting for about 50%; the Huai River and Pearl River basins each account for more than 10%; about 25% are in the southeastern river basins, Songhuajiang-Liaohe Basin, Yellow River Basin, Hai River Basin, inland and southwestern river basins.

Groundwater reduction during 2015-2020 slowed down by 65% from 2005-2014. The rate of groundwater storage change was -2.556±3.284 billion m^3/a during 2005-2020. Areas experiencing significant ($p<0.05$) decrease, accounting for 27% of the national territory, were mainly found in the north of the Yangtze River, such as the Yellow-Huai-Hai Plain, central Inner Mongolia, west Liao River Basin, and north of Tian Mountain; while areas of significant increase, accounting for 45% of the territory, were mainly in the south of the Yangtze River, such as the Sichuan Basin and Yunnan-Guizhou Plateau (Figure 3-6a). During 2015-2020, the groundwater storage change rates in China as a whole and in the North China Plain slowed down by 65% and 37% respectively, compared with that in the period of 2005-2014. The plain area of Beijing saw a reversal from an annual average decline of 0.11±0.004 billion m^3 to an annual average increase of 0.07±0.01 billion m^3/a) (Figure 3-6b).

The changes mentioned above in groundwater storage and the total area and number of reservoirs show fairly consistent spatial characteristics. Groundwater storage is increasing in areas with many reservoirs, such as the Yangtze River, Songhuajiang-Liaohe, and Pearl River basins, while in areas with few reservoirs, such as the Hai River, Yellow River, and southwestern river basins, the groundwater storages are on a decreasing trend.

Figure 3-6.

(a)Spatial distribution of groundwater storage change rate in 2005-2020

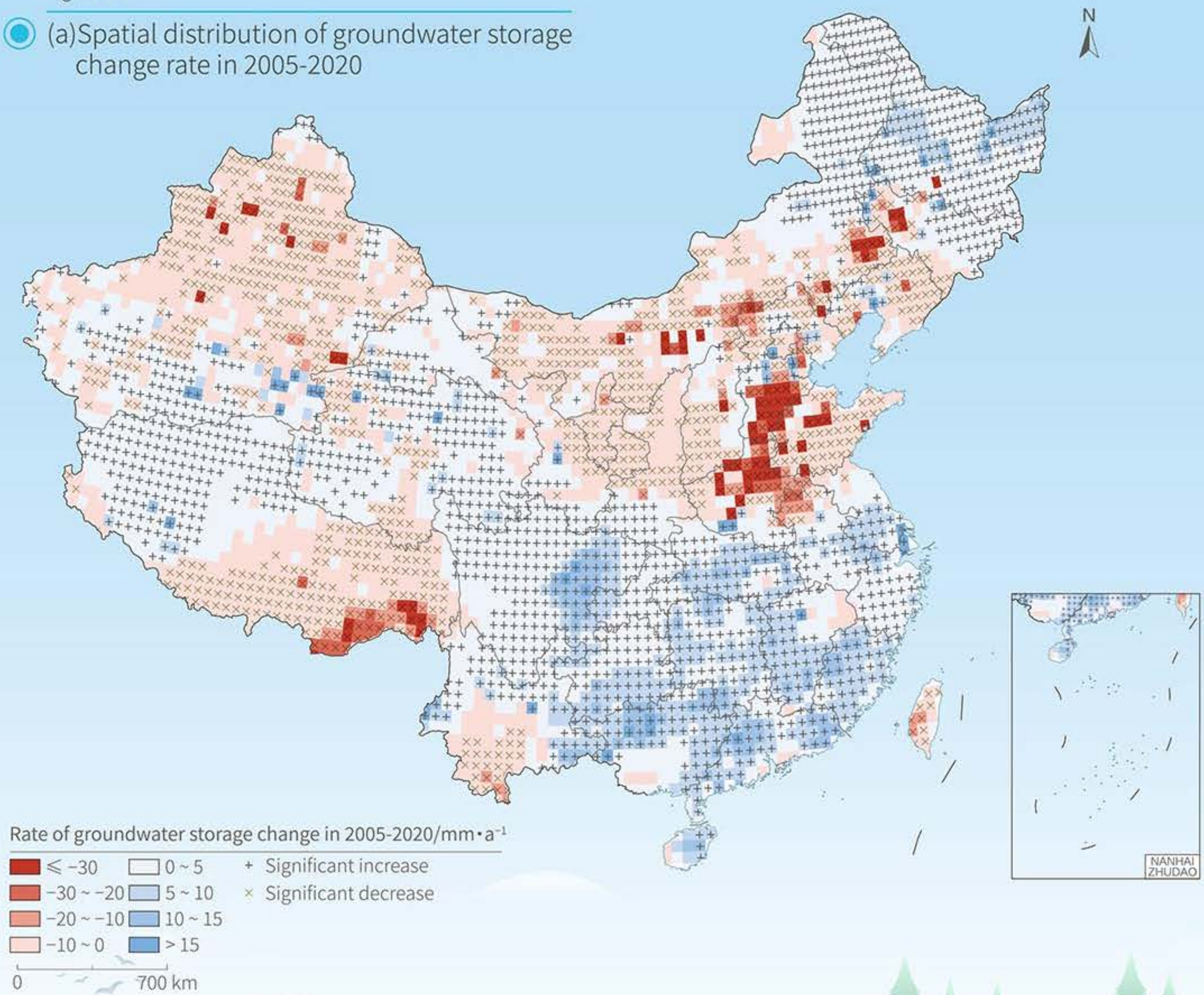
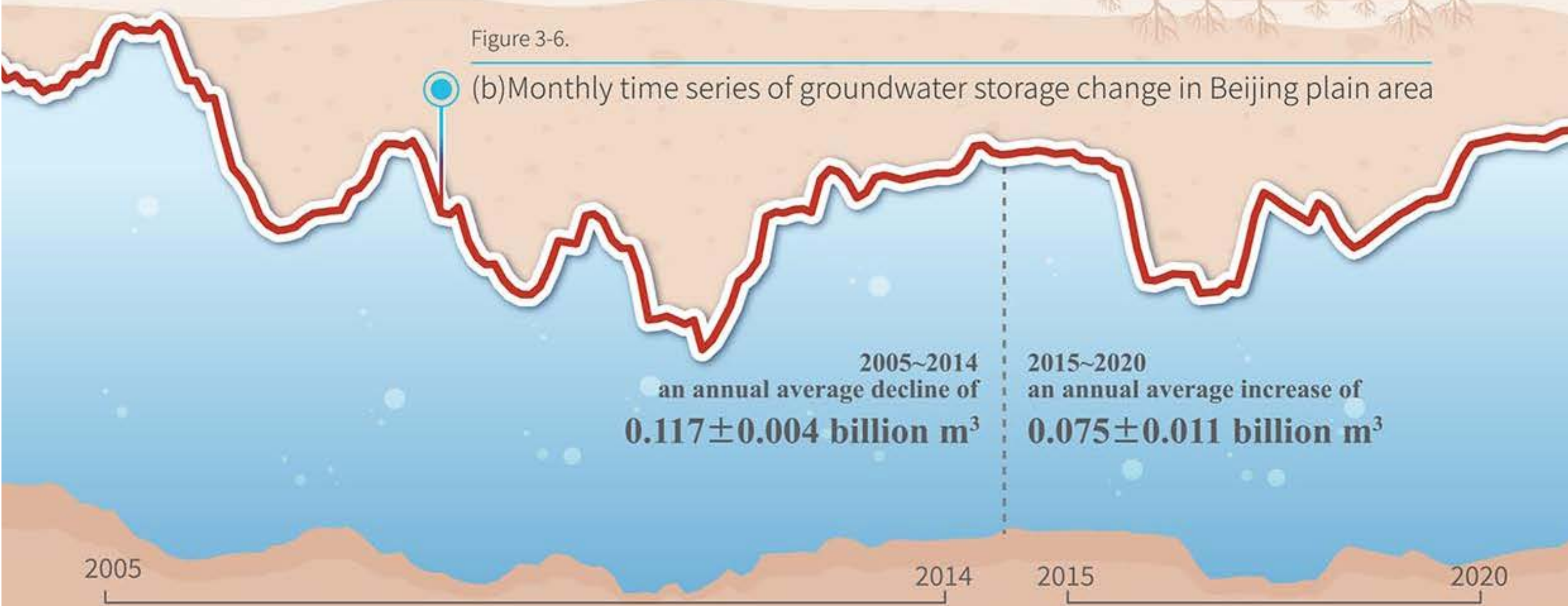


Figure 3-6.

(b)Monthly time series of groundwater storage change in Beijing plain area



SDG 6

Comprehensive Evaluation

Comprehensive evaluation of China's SDG 6 progress from 2015 to 2020

Pulling together the datasets from sections in this chapter on the proportion of water bodies with good ambient water quality (SDG 6.3.2), water stress level (SDG 6.4.2), and integrated water resources management (SDG 6.5.1); rate of safe drinking water obtained through analysis of monthly data from provincial centralized drinking water sources (SDG 6.1.1), the proportions of safely treated domestic and industrial wastewater flows (SDG 6.3.1) from China Urban Construction Statistical Yearbook; the calculated change in water-use efficiency (SDG 6.4.1) in China Statistical Yearbook and China Water Resources Bulletin; extracted change in the extent of water-related ecosystems over time in CNLUCC (Remote sensing monitoring data set of land use and land cover in China) and CAS (Chinese Academy of Sciences) Mangroves 2.0 (SDG 6.6.1); the sustainability index of water resources development and conservation (SDG 6 Composite Index) was constructed by the normalization and equal weighting method, and the change in provincial implementation of SDG 6 was evaluated.

From 2015 to 2020, significant progress was made in all SDG 6 indicators. The provincial administrative regions with higher SDG 6 Composite Index included Xizang and Guizhou province, which had sound natural environment, and Beijing, Shandong province, Chongqing, and Zhejiang province, which enjoyed fast growth rates; those with low SDG 6 Composite Index were mostly not economically advanced. Generally, regions scoring low on the Composite Index in 2015 included Inner Mongolia Autonomous Region, Ningxia, and Shanghai, and in 2020 included Ningxia, Inner Mongolia, Hebei and Qinghai provinces. The SDG 6 Composite Index was on an upward trend across all provincial regions, with the increase of over 50% in Xizang, Guizhou, and Shandong, in which the Xizang achieved the highest increase at 78.6% (Figure 3-7a).

Significant differences exist in the sustainable development level of water resources among China's provinces, autonomous regions, and municipalities. At the same time, the problems they face vary, with economically developed regions face challenges mostly in ambient water quality (SDG 6.3) and water-related ecosystems (SDG 6.6), while other regions facing generally low water-use efficiency (SDG 6.4) (Figure 3-7b).

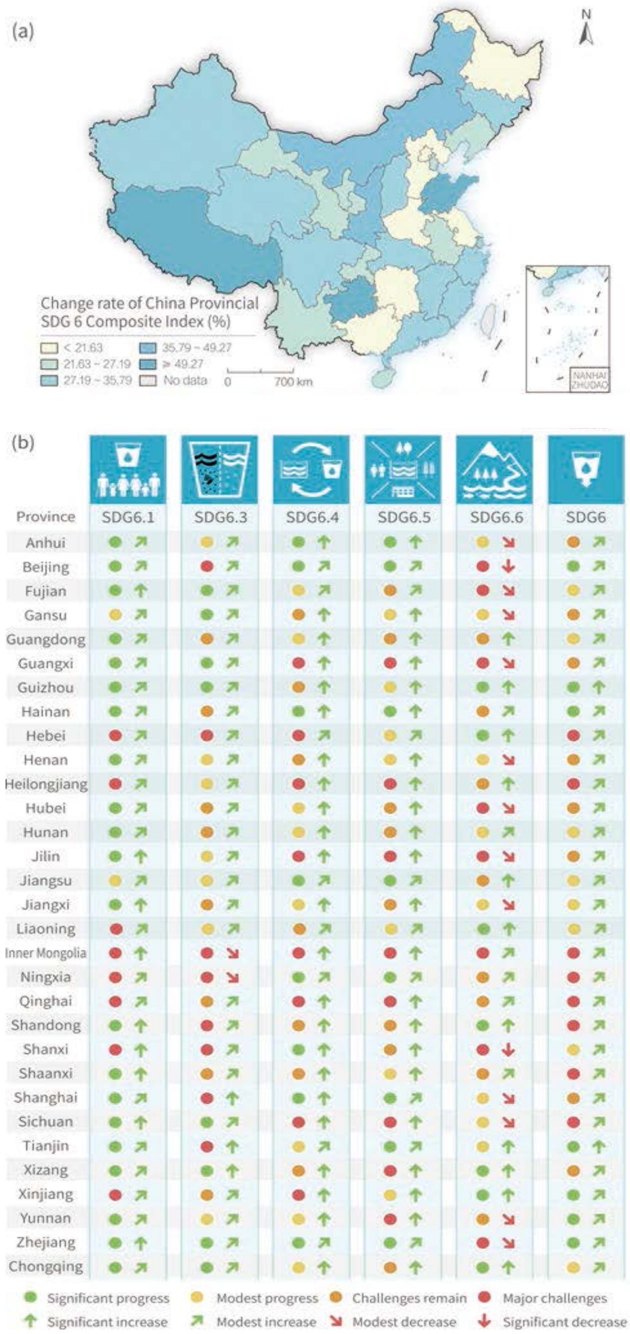


Figure 3-7. Progress variations in SDG 6 indicators and Composite Index in China between 2015 and 2020
(Note: no data for Hong Kong, Macao and Taiwan)

Recommendations and Outlook

Based on national statistics and satellite remote sensing data, this chapter analyzes the single indicators (SDG 6.3.2, SDG 6.4.1, SDG 6.4.2, SDG 6.5.1, and SDG 6.6.1) and comprehensive progress in different provincial administrative regions in China. The results show that China had made good progress in SDG 6 from 2015 to 2020. However, there were significant spatial changes at the provincial level due to differences in the natural and geographical conditions, resource endowment, and level of economic development in different regions.

Based on the above studies, we offer the following recommendations:

(1) Each provincial administrative region should formulate an optimal path to SDG 6 that suits its level of economic development, to improve its implementation of SDG 6 single indicators and Composite Index, in light of the current situation of regional water resources supply and water-related ecosystems management capacity. Such a path should also promote the synergized implementation of indicators across different regions.

(2) Due to the incomplete data on some indicators, there are some uncertainties in some evaluation results. In the future, it is advisable to include the local monitoring networks and statistical survey data in the evaluation to further improve the precision of the evaluation and inform provincial implementation policies.

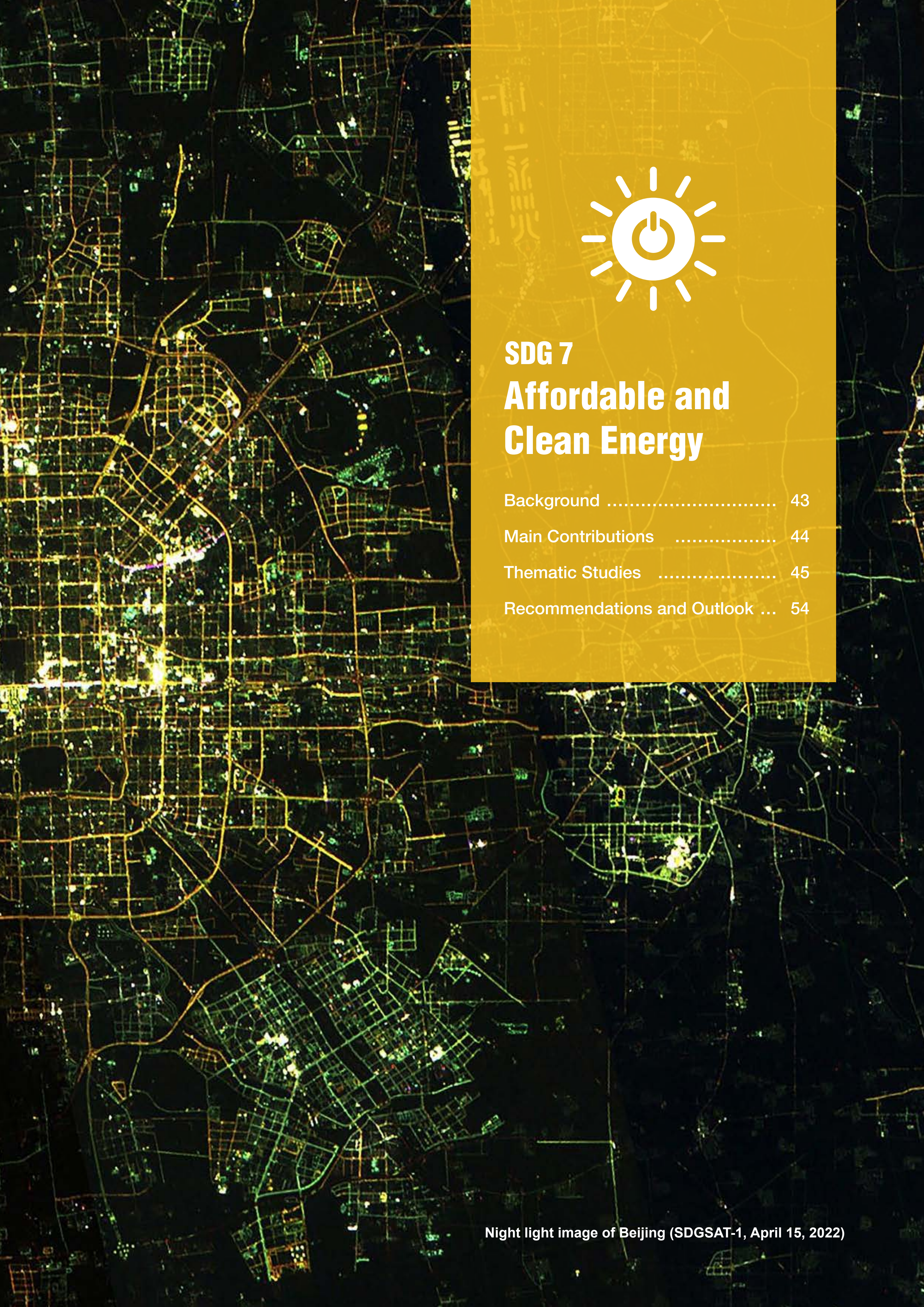
(3) The satellite remote sensing-based monitoring and evaluation methods developed in the above studies, such as crop water-use efficiency, reservoir surface water, and groundwater storages, should be further studied for their global application as a technical solution to the data gaps of these two indicators on a global scale.

Based on the improved monitoring methods and datasets at the national and provincial scales, future efforts will focus on further exploring the monitoring and evaluation at the watershed scale, to tap deep into the advantages of the Big Earth Data technology in data disaggregation and spatial correlation analysis, so as to provide decision making service at different spatial scales and concerning regional hydraulic connections.

SDG 7

SDG 7

Affordable and Clean Energy

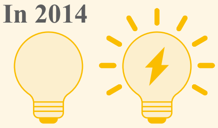


Night light image of Beijing (SDGSAT-1, April 15, 2022)

Highlights

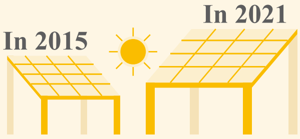
Access to Electricity

The electrified built-up areas increased significantly around the world. Nearly 30,000 km^2 of such areas were added globally in 2020 compared to 2014, raising its share by nearly two percentage points. 117 countries (regions) experienced substantial increase in electrified built-up areas; more than half of the countries (regions) experiencing decline were in fragile and conflict environments.



Renewable Energy

China has made remarkable progress in its transformation to green and low-carbon energy. In 2021, China's installed capacity and electricity generation of renewable energy were 2.12 times and 1.79 times that of 2015. Amid COVID-19, China still maintained a high average annual growth of 15.81% in installed renewable energy capacity. China has become the world's largest producer and exporter of wind turbines and photovoltaic modules, driving down the costs of wind power and photovoltaic power generation globally. China's photovoltaic industry has created a new path for rural poverty eradication and ecological restoration in the western region, contributing to eradication of absolute poverty and providing solutions and best practices for global poverty reduction.



SDG 7

International Energy Cooperation

China engages in international energy cooperation to help developing countries achieve SDG 7. China's international energy cooperation projects have increased per capita electricity consumption in 80 countries, raising the share of renewable energy power generation in 44 countries and the per capita installed capacity of renewable energy in 49 developing countries. China has invested more than USD 100 billion in renewable energy in developing countries. The international training programs on solar power, sponsored by China in spirit of openness and transparency and in partnership with relevant international organizations for the realization of SDG 7, had trained people from 133 countries and regions by 2021, with 49.70% of them from African countries.

Background

Anthropogenic carbon emissions from the use of fossil fuels are a major cause of global warming. The transformation from fossil to green, low-carbon energy has become a globally shared vision in response to climate change. SDG 7: Affordable and Clean Energy, one of the 17 goals on the 2030 Agenda for Sustainable Development adopted by the United Nations, aims at driving global energy transformation. Under it are six targets in four areas – energy access, renewable energy, energy efficiency and international energy cooperation – together to ensure access to affordable, reliable, sustainable and modern energy for all by 2030.

China attaches great importance to ecological conservation and renewable energy, and has taken a series of actions in response to climate change and made significant progress in clean energy. China's installed capacity of renewable energy has ranked first in the world for many years, and its wind power and photovoltaic (PV) power generation industries have driven large-scale power generation from renewable energy worldwide. In 2020, China went a step further and set the goals of "striving to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060" (the dual carbon goals). China has also been active in helping other countries, especially developing countries, through international energy collaboration under the Global Development Initiative and South-South cooperation, in such forms as investment, construction projects, equipment supply and training, making a major contribution to the global achievement of SDG 7.

Timely and accurate tracking and assessment of SDG 7 progress globally is important to policy-making and project implementation at the national level. The International Energy Agency and other international agencies have been jointly issuing the annual edition of *Tracking SDG 7: The Energy Progress Report* since 2017. Given the current challenges to SDG 7 progress assessment posed by missing data and untimely updates, the Big Earth Data technology has drawn international attention as an enabler for a new generation of SDG 7 tracking and assessment methods.

This report aims to use remote sensing, Geographic Information System and other Big Earth Data technologies to regularly acquire and comprehensively analyze global multi-source data, improve the Big Earth Data-based global monitoring and assessment methods for SDG 7, assess global progress in each SDG 7 indicator, and provide scientific data in support of SDG 7 achievement globally.

Main Contributions

This chapter evaluates progress of SDG 7.1, SDG 7.2, SDG 7.a and SDG 7.b in China and globally through five cases. The main contributions are as follows (Table 4-1).

Table 4-1 Cases and Their Main Contributions

Theme	Target	Case	Contributions
Access to Electricity	SDG 7.1	Global electrification of built-up areas	**Data product:** Global datasets on the state of electrification of built-up areas in 2014 and 2020 **Method and model:** Remote sensing monitoring of electrification of built-up areas worldwide **Decision support:** Inform global electrification policies and investment decisions
Renewable Energy	SDG 7.2	Electricity generation from renewable energy in China	**Decision support:** Offer China's best practice in renewable energy electricity development and inform Chinese policies on renewable energy electricity
		Construction of photovoltaic power stations in China	**Data product:** Chinese photovoltaic power stations distribution dataset for 2015 and 2020
International Energy Cooperation	SDG 7.1 SDG 7.2 SDG 7.a SDG 7.b	China's international energy cooperation projects	**Data product:** Dataset on the impact of China's international energy cooperation projects on SDG 7 in developing countries **Method and model:** Methodology for assessing the impact of China's international energy cooperation projects on SDG 7 in developing countries **Decision support:** Inform decisions on China's international energy cooperation
	SDG 7.a	China-sponsored international training programs on solar energy utilization	**Data product:** The statistical dataset of China-sponsored international training programs on solar energy utilization **Decision support:** Inform policies on China-sponsored training programs on solar energy utilization

SDG 7

Thematic Studies

Access to Electricity

Electricity shortage is the primary energy challenge faced by developing countries, with around 700 million people worldwide still lack access to electricity in 2020. Access to electricity is a SDG 7 indicator reflecting electricity penetration, timely and accurate data on which is of practical importance to its universal achievement. This study develops a 500 m resolution dataset of electrification conditions in built-up areas in the world in 2014 and 2020. It proposes a new method for remote sensing monitoring of electrification in built-up areas, analyses its global spatial distribution and change, and addresses the problems of missing data and untimely updates of existing electrification rates in some countries. It improves the global monitoring capacity of electrification conditions in built-up areas, and provides data to inform the formulation of targeted power supply strategies.

Global electrification of built-up areas

Target: 7.1 By 2030, ensure universal access to affordable, reliable and modern energy services.

Based on global 500 m resolution nighttime lights remote sensing data, a remote sensing monitoring method was proposed (Gao *et al.,* 2022), by which electrification of global build-up areas in 2014 and 2020 was monitored with an accuracy of 98.10%. Their spatial distribution and temporal variation patterns were analyzed for the purpose of assessing global progress in achieving SDG 7.1.1 access to electricity.

Africa and Asia, especially Sub-Saharan Africa have the largest unelectrified built-up areas in the world. The world's unelectrified built-up areas were mainly found in Africa and Asia in 2020 (Figure 4-1), with 76% of the 20 countries with the largest share of unelectrified built-up areas located in sub-Saharan Africa. Achieving the SDG 7 indicator of access to electricity for all globally will require additional and greater international support for developing countries.

Global electrified built-up areas increased notably in 2020 from 2014. Global electrified built-up areas increased from 96.95% to 98.68%, by 29,108.62 km^2, from 2014 to 2020 (Figure 4-2). According to the Global Power Plant Database of the World Resources Institute, in this period, the share of unelectrified built-up areas decreased in 117 countries (regions), thanks to the construction of 415 power stations. In contrast, only 17 power stations were constructed in the 18 countries with the largest increase in the share of unelectrified built-up areas.

More than half of the countries (regions) where unelectrified built-up areas increased notably are in fragile and conflict environments. 32 countries (regions) saw their unelectrified built-up areas increase, by more than 0.1% in 18 of them. Six of these 18 countries were in medium- to high-intensity conflict (World Bank, 2022), one had a fragile social environment, three experienced armed conflict (riots) and five were in economic recession due to the COVID-19. Thus, political unrest, armed conflict and economic recession are among the main reasons behind the increases in unelectrified built-up areas.

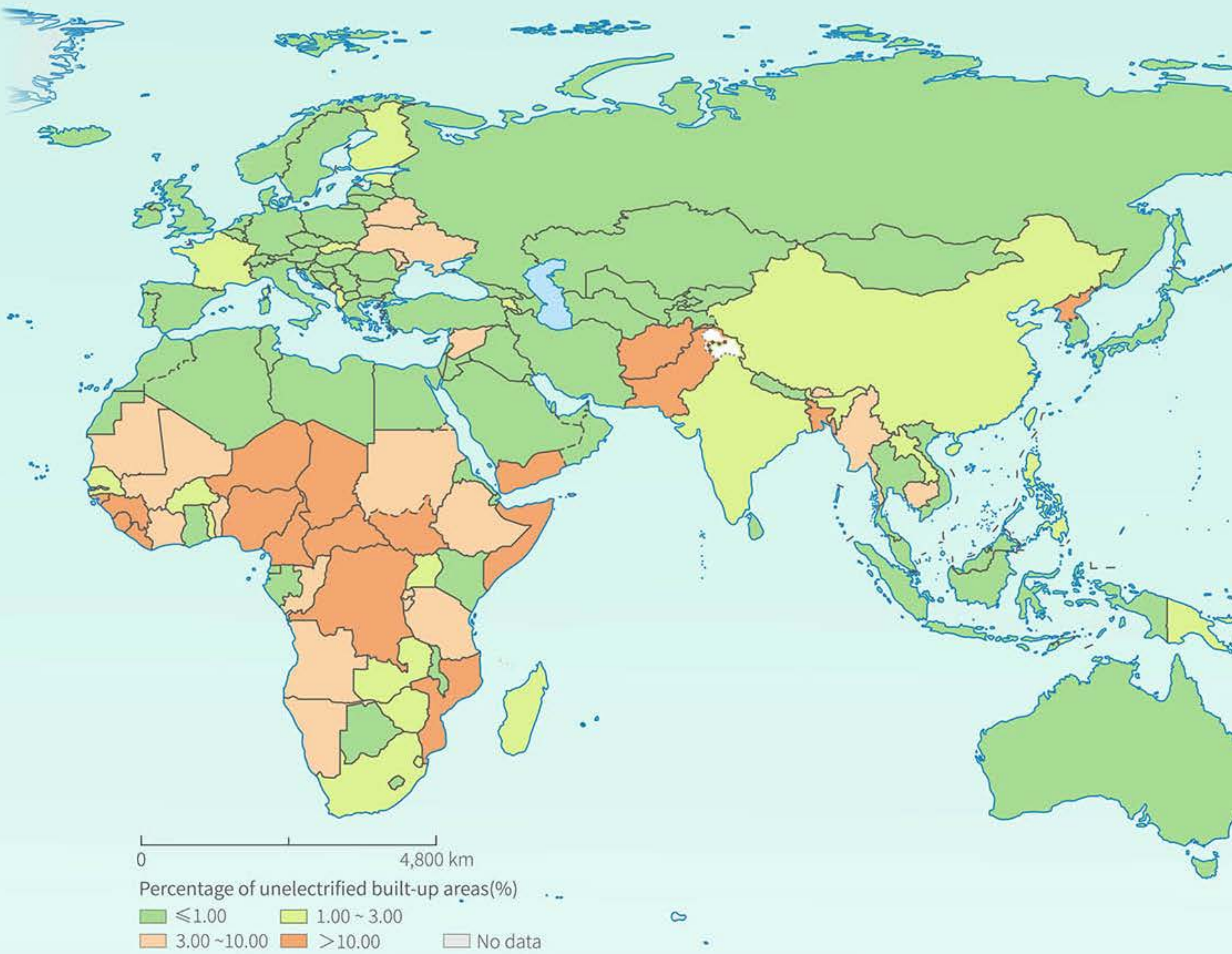


Figure 4-1.

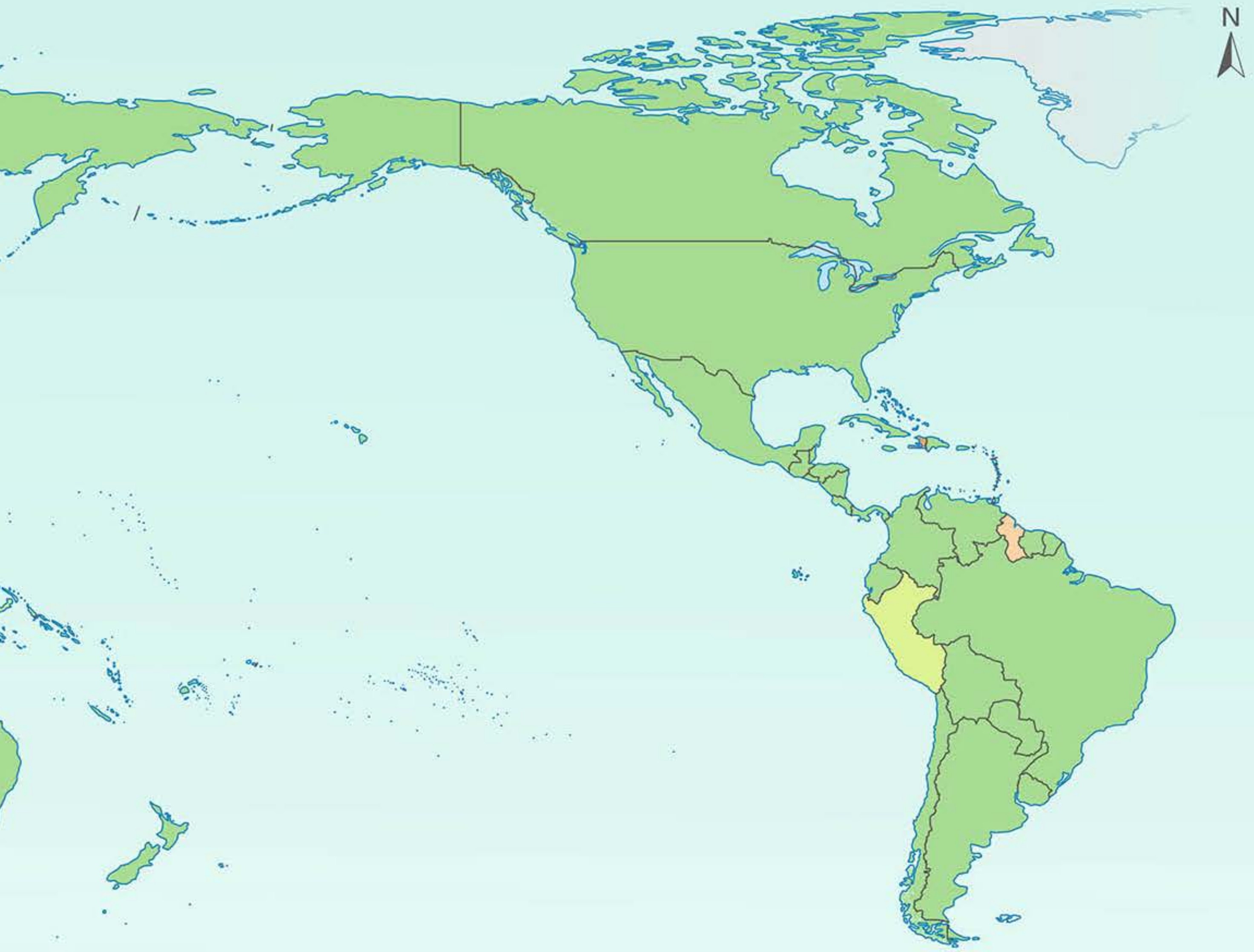
Percentage of global unelectrified built-up areas in 2020

415 power stations

117 countries (regions)
Increased share of electrified built-up area

In 2020,
Global electrified built-up areas increased

by **29,108.62 km²**, from 96.95% to 98.68%.



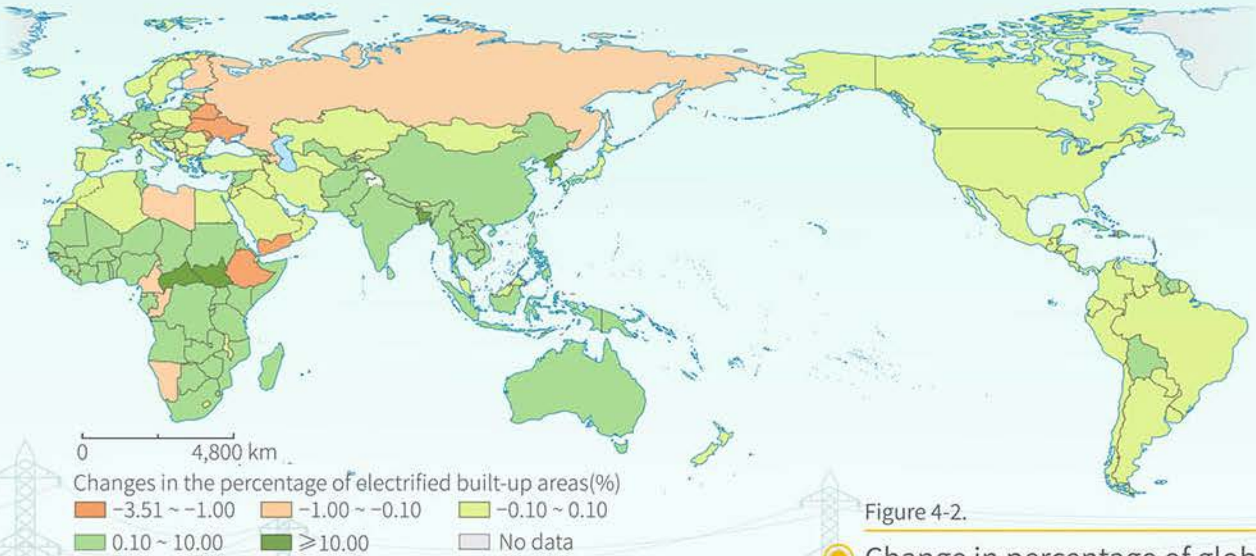


Figure 4-2.

Change in percentage of global electrified built-up areas in 2020 compared to 2014

Renewable Energy

Renewable energy is the key to the global energy transformation and climate change response. Since 2012, China has promoted its energy development in the new era with a strategy to revolutionize energy production and consumption. The dual carbon goals have clearly defined the direction of China's energy transformation. As a responsible major country, China is no longer building new coal-fired power projects abroad, and strongly supports the development of green and low-carbon energy in developing countries, setting an example for global energy transformation and green development. Based on Big Earth Data, this section establishes datasets on China's electricity generation from renewable energy between 2015 to 2021, PV power stations remote sensing monitoring and renewable energy policy between 2015 to 2020, which provides a comprehensive analysis of China's electricity generated from renewable energy and policy experience to inform other developing countries' efforts to develop renewable energy.

Electricity generation from renewable energy in China

Target: 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix.

Based on China's renewable energy power installation and production data from 2015 to 2021 (National Energy Administration of China, 2016-2022a, 2016-2022b; China Electric Power Yearbook, 2016), this case analyzes the change in the share of installed capacity and electricity generation of renewable energy, summarizes the Chinese experience of policy-making on renewable energy development, and assesses progress in the promotion and utilization of electricity generated from renewable energy.

China's installed renewable energy capacity in 2021 was 2.12 times that of 2015, accounting for one third of the global total and contributing to the global energy transformation. China's renewable energy installation reached 1,063 gigawatts (GW) in 2021, 2.12 times that of 2015, accounting for 44.72% of China's total installed power capacity (Figure 4-3) and 34.69% of global renewable energy installation; electricity generation reached 2,485.3 terawatt-hours, 1.79 times that of 2015, constituting 29.90% of total electricity consumption. The growth of non-water renewable energy was even stronger, with the 2021 cumulative installed capacity and electricity generation 3.69 times and 4.12 times that of 2015. China's renewable power installation, in particular, maintained a high growth rate despite COVID-19, hitting an average annual growth of 15.81%. The large-scale development of renewable energy in China has laid a good foundation for achieving the dual carbon goals and also given a boost to the achievement of global access to reliable and clean energy.

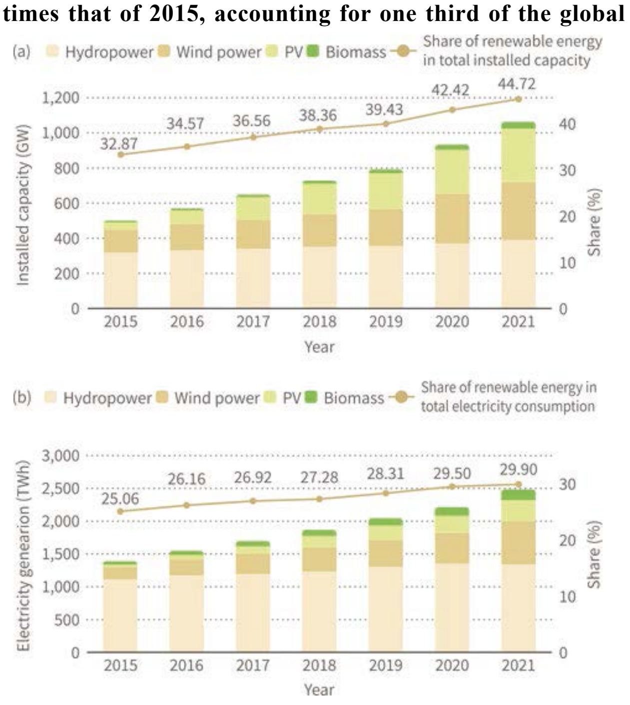
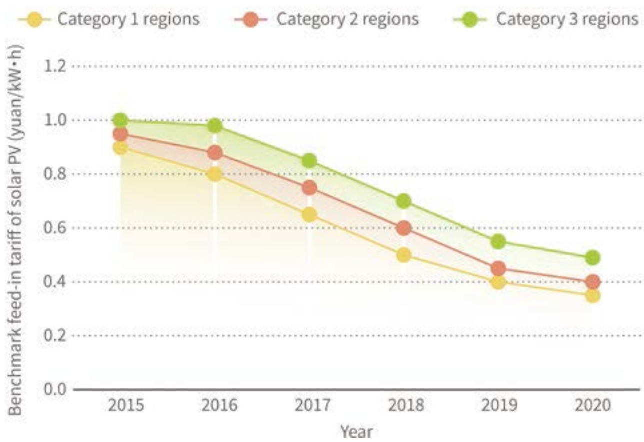


Figure 4-3. China's installed renewable electricity capacity and share (a) China's renewable electricity generation and its share in the total electricity consumption (b)

In the last 10 years, costs of onshore wind power and PV power fell 30% and 75% respectively in China, driving global clean energy transformation. The recent decade has seen steady growth, technological upgrading and fast cost reduction in China's wind power and photovoltaic industries. The average cost per kilowatt has dropped by about 30% for onshore wind power and 75% for PV. Consequently, the national PV feed-in tariff has dropped continuously since 2015 (National Development and Reform Commission of China, 2019, Figure 4-4), and grid parity (PV feed-in tariffs being the same as thermal power) was realized in 2021. China has become the world's largest producer and exporter of wind turbines and PV modules. 181.8 GW of PV modules were produced in 2021 in China (No data is available for Hong Kong, Macao and Taiwan), making up about 82.34% of total global output (China Photovoltaic Industry Association, 2021). The fast growth of renewable energy in China has given strong impetus for global access to affordable clean energy.

China continuously fine-tunes and improves its renewable energy policy system, which can inform global efforts to develop renewable electricity. The rapid development of power from renewable energy in China is attributable to the sound laws and policies made at the top level. The *Renewable Energy Law of the People's Republic of China* was adopted in 2016, laying the legal foundation. The subsequent suite of policies and regulations have made this sector's large-scale development possible and the promotion and application of relevant technologies. Since 2016, central government departments concerned have issued more than 200 policies and circulars and over 660 standards, and regions across the country have also formulated their own renewable energy development plans.



↑ Figure 4-4. Change in China's solar feed-in tariff benchmark

Policy measures have been continuously adjusted to suit the different stages of renewable energy development. Initial investment subsidies and concession bidding policies gradually gave way to fixed tariffs, guaranteed purchases, preferential taxation policies, financial incentive policies and other policies.

At present, a stage of grid parity has been achieved for wind and PV. China will continue to improve the policy supports based on the environmental value of renewable energy, and better connect the renewable energy green power certificate with carbon trading.

Construction of photovoltaic power stations in China

Target: 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix.

Based on the Big Earth Data platform and deep learning network of Deeplab V3+, this case creates the identification samples database and extraction model of China's PV power stations, using the Sentinel-2 satellite images in 2015 and 2020. The spatial distribution and development trend of photovoltaic (PV) power stations was analyzed. The impact of photovoltaic poverty alleviation projects on the rural economy was revealed, based on the statistical data from China's Finance Ministry's subsidy catalogue for such projects.

China's centralized PV power stations are mainly located in the northwest region, creating a new approach to restoration of fragile ecosystems. 56.75% of China's PV power stations are located to the west of the Aihui-Tengchong Line and 43.25% to its east. Most of the centralized PV power stations are in the northwest, rich in desert, Gobi, and wilderness. These stations help reduce surface water evaporation by 20-30% in the way of slowing down wind and blocking direct sunlight, and they can also improve the environment for vegetation by collecting rain. The Photovoltaic for Desertification Control Project in western China has helped improve the fragile ecological environment there. The new PV power stations built between 2015 and 2020 are mainly located in the northwest (37.54%) and north (17.25%) of China (Figure 4-5).

China's PV for Poverty Alleviation Program provides new impetus for rural economic development. China has pioneered a program of using PV for poverty alleviation. According to the catalogue data of photovoltaic poverty alleviation subsidies of the Ministry of Finance of China and the photovoltaic poverty alleviation benefit data of the National Energy Administration, by the end of 2020, there were 83,000 village-level solar power stations (Figure 4-6), serving 92,300 villages. They generated about CNY 18 billion annually from power generation, or about CNY 4,337 per household, and have created 1.25 million jobs. This successful program has provided rural households with clean energy, raised rural governance capacity, and improved rural living conditions. Building on this success, China will promote rural distributed photovoltaics, with a view to revitalizing the countryside and also offering other developing countries a demonstration of rural energy transformation and economic development.

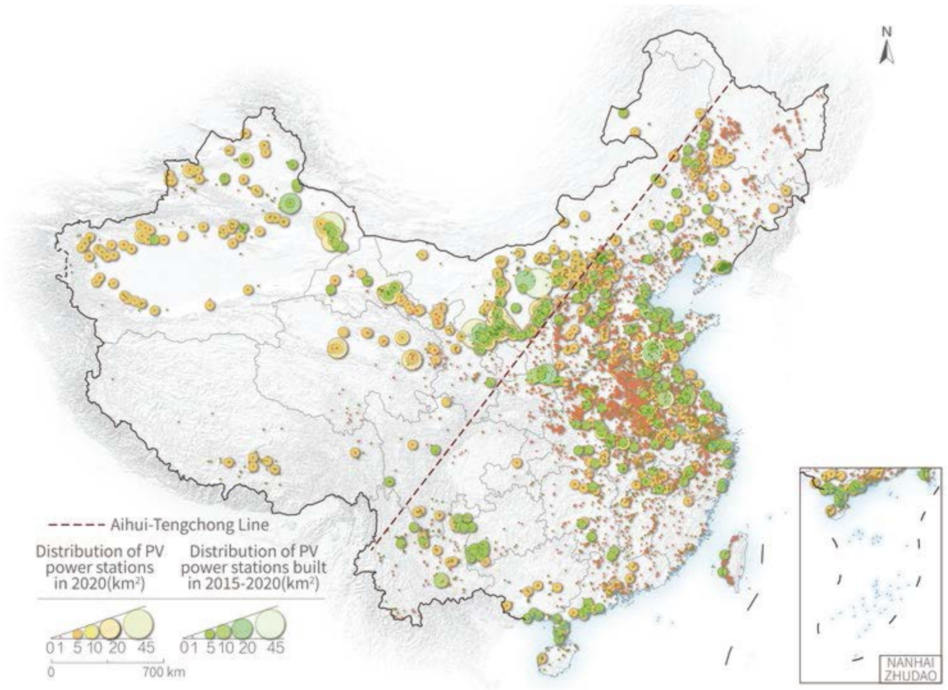


Figure 4-5. Spatial distribution of PV power stations in China in 2020

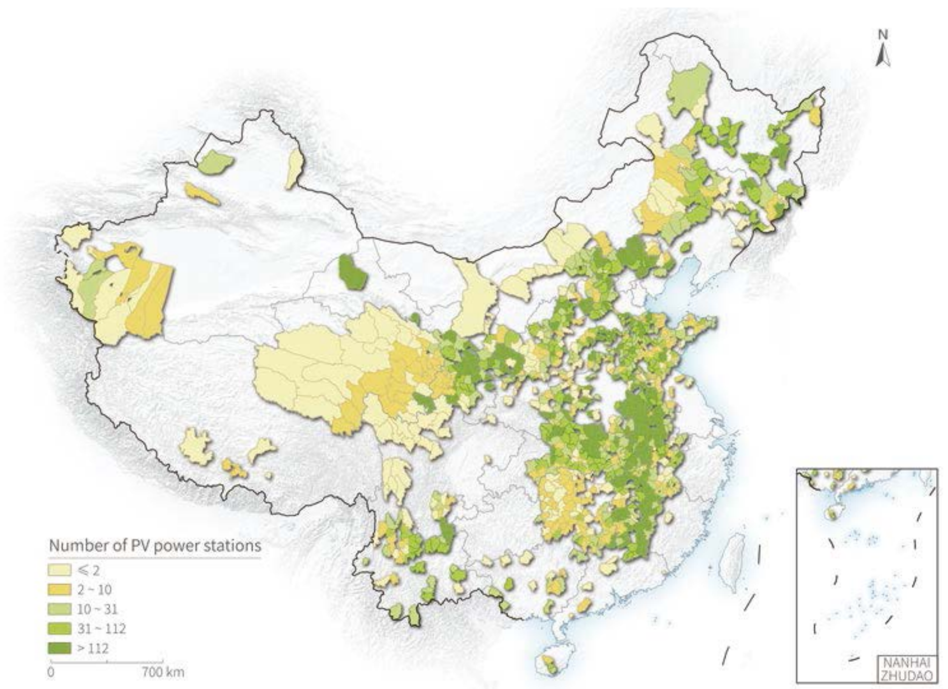


Figure 4-6. Spatial distribution of PV power stations for poverty alleviation in China

International Energy Cooperation

Developing countries face widespread energy shortages, and shortages in finance and technology on their paths to energy self-sufficiency and transformation. To achieve SDG 7 of ensuring universal access to affordable, reliable and modern energy services, the key lies in helping developing countries address energy shortages and energy transformation. To this end, under SDG 7 are two targets – SDG 7.a and SDG 7.b – to promote developing countries' green and low-carbon energy transformation through international cooperation.

China has actively implemented the international cooperation targets under SDG 7 in the 2030 Agenda by helping developing countries develop clean energy and promoting a green and low-carbon energy transformation globally under the framework of Global Development Initiative and South-South cooperation. Clean energy has always been a focus of China's international cooperation projects. China has provided funding and technologies to energy projects in developing countries through investment, construction projects and equipment supply to help them achieve the SDG 7. China has also provided developing countries with intergovernmental training programs on policy-making, industrial planning, project implementation, and talent cultivation in the field of clean energy development.

This section produces the dataset of impact on SDG 7 of China's international energy cooperation projects (CIECPs) and the dataset on China-sponsored international training programs on solar energy utilization (CITPSEU), proposes a methodology for assessing the impact on SDG 7 of CIECPs, and evaluates the impact of those projects and programs on the achievement of SDG 7 in developing countries. .

China's international energy cooperation projects

Target: 7.1 By 2030, ensure universal access to affordable, reliable and modern energy services.

7.2 By 2030, increase substantially the share of renewable energy in the global energy mix.

7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.

7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programs of support.

This study assesses the impact of CIECPs on the achievement of SDG 7 in developing countries, using spatial statistical analysis of Big Earth Data based on the World Bank's global population and per capita electricity consumption, World Resources Institute's Global Power Plant Database and independently developed CIECP dataset. China has been involved in 437 energy projects in 80 countries through investment, construction or equipment supply (Gao *et al.*, 2022b), making a notable contribution to their SDG 7 implementation (Figure 4-7). Specifically, CIECPs have increased the electricity installation and per capita consumption and the ratios of those from renewal sources in the host developing countries. China's investment in renewable energy in developing countries from 2000 to 2020 exceeded USD100 billion.

Assistance to developing countries in addressing electricity shortages has improved global access to electricity. CIECPs account for more than 50% of the total installed capacity in 13 countries, including Angola and Guinea, and more than 20% in 20 countries, including Myanmar and Zambia (Figure 4-8). These projects can meet the demand for additional electricity in 32 countries, including Ethiopia and Pakistan, and help solve their electricity shortage problems. They have increased the per capita electricity consumption in 80 countries, in 10 of which the increase is more than 400 kilowatt-hours.

Renewable energy as a share of total electricity increases in 44 host countries, promoting a global transformation towards green and low-carbon energy. 51.26% of CIECPs are renewable energy power plants, with installed capacity making up 41.35% of the total. They have raised the share of renewable energy electricity generation in 44 countries by an average rate of 3.70%, and filled the gap of renewable energy power plants in five countries, including Saudi Arabia. In 2020, the installed capacity of CIECP renewable energy power plants was 1.37 times that of 2015.

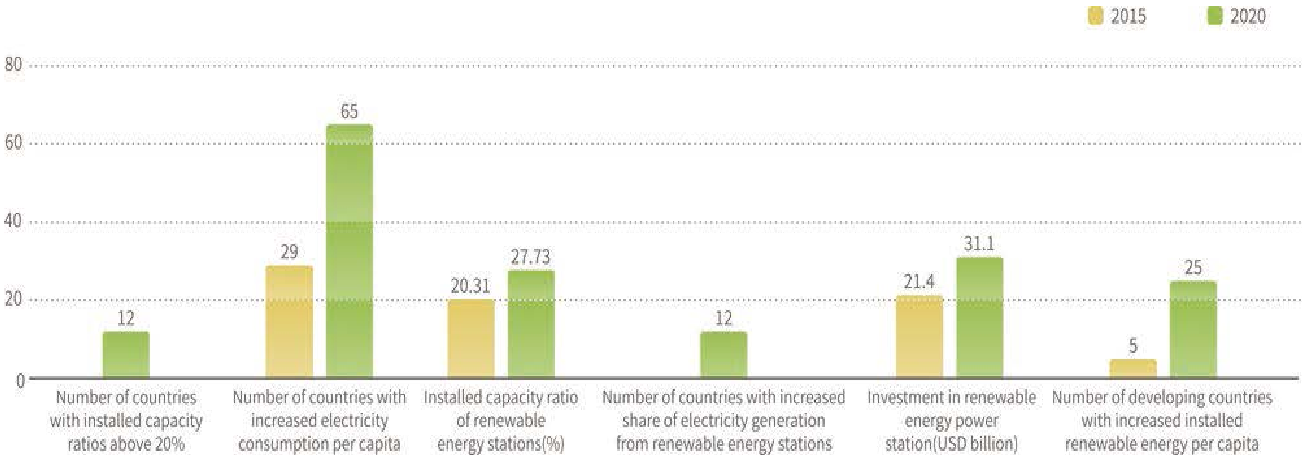


Figure 4-7. Contribution of CIECPs to 80 countries' SDG 7 indicators in 2015 and 2020

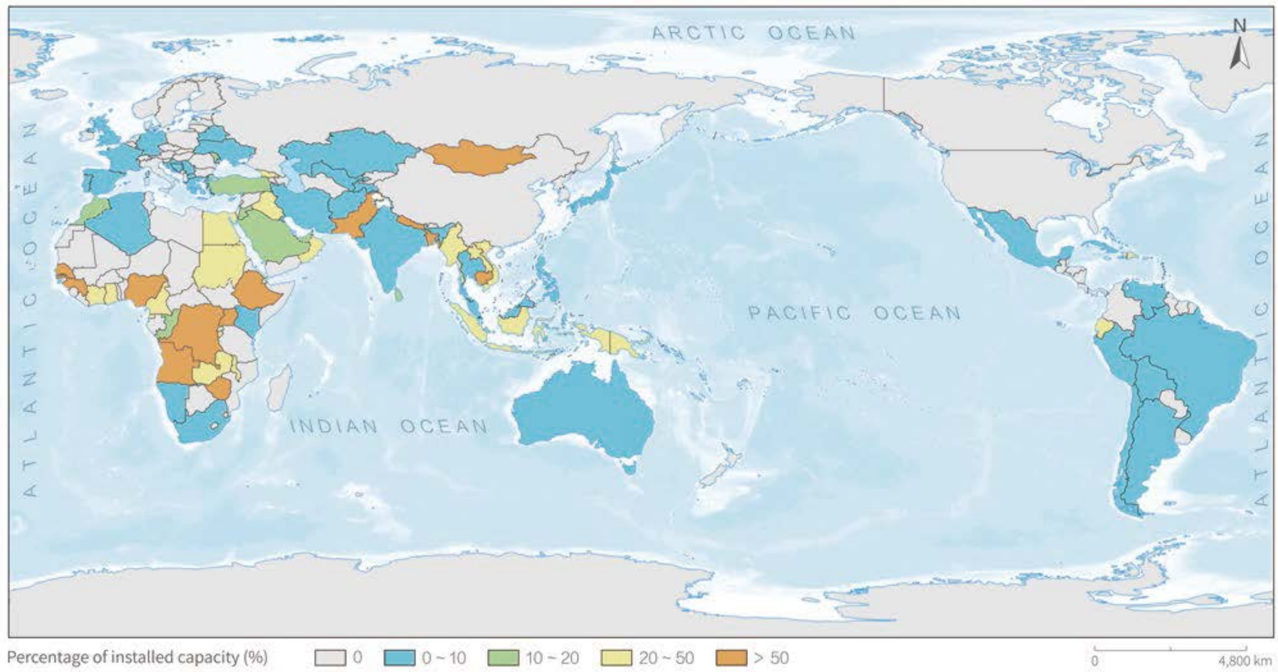


Figure 4-8. Percentage of installed capacity of CIECPs to total installed capacity in host countries 2000-2019

Chinese energy funding for developing countries mainly goes into renewable energy to support their development and use of clean energy. According to the China's Global Energy Finance Database of the Global Development Policy Center, from 2000 to 2020, the China Development Bank and the Export-Import Bank of China provided USD 234.6 billion in overseas energy investment, of which 42.75% went into renewable energy as direct investment. Power stations received USD 80.3 billion in direct investment, including 38.73% in renewable energy. In 2021, President Xi Jinping announced that China would no longer build new coal-fired power projects abroad and that renewable energy will become the main destination of Chinese overseas energy investment.

CIECPs have substantially increased per capita installed renewable capacity in 49 developing countries, in support of their energy transformation. The total installed renewable capacity of CIECPs amounts to 85.42 million kilowatts, or 26.90 watts per capita. They are located in 55 countries, 49 of which are developing countries. Thanks to them, 12 host countries have seen an increase of more than 50 watts in their per capita installed renewable capacity, with the maximum increase being 189.78 watts.

China-sponsored international training programs on solar energy utilization

Target: 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.

Drawing references from the work of the Chinese Ministry of Commerce, Ministry of Science and Technology and other foreign-aid training sponsors, and using the statistical data (1991-2021) from the Gansu Natural Energy Research Institute, an organizer of the China-sponsored training programs on solar energy utilization, this study produces the dataset of CITPSEU, analyzes the global distribution of participants in the training and their countries, and evaluates the effect of the programs on the international cooperation in solar energy utilization.

CITPSEU have benefited countries from all over the world and promoted cooperation between China and other developing countries. By 2021, about 2,000 people had participated in the training programs, 49.70% of whom were from Africa. They came from 133 countries and regions, 93.23% of which were developing countries (Figure 4-9). The training programs brought more than 3,200 leaders, envoys and experts from 120 countries to Chinese institutions on training visits, led to the signing of cooperation agreements between China and more than 50 of those countries, and assisted developing countries in achieving their sustainable development goals.

The training programs follow the principles of openness and transparency and are part of China's cooperation with the United Nations and other relevant international institutions and organizations in the realization of SDG 7. The training programs are the results of open and transparent cooperation China has engaged in with the United Nations Development Program and other more than ten institutions and organizations. The International Solar Energy Center for Technology Promotion and Transfer, was recognized as one of the six biggest collaboration achievements between the United Nations Industrial Development Organization (UNIDO) and the Chinese government at UNIDO's 50th anniversary. So far, the training programs have brought more than 240 officials and experts from international organizations to China to give lectures or have technical exchanges (figure 4-10), promoted the application of practical products and broadened the international cooperation.

Figure 4-10. Trainees' visit to a solar power station in China

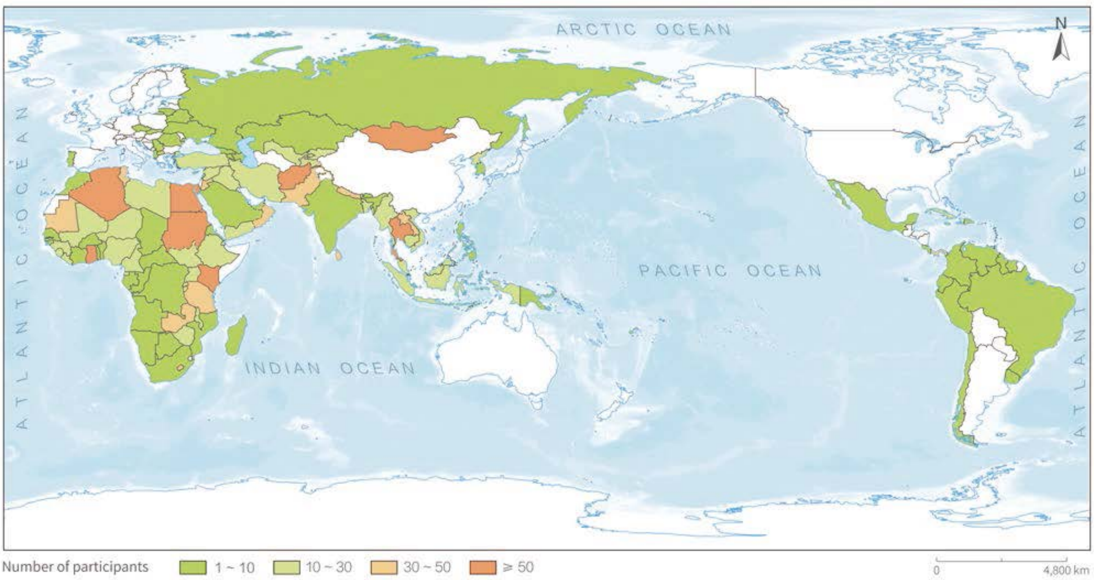


Figure 4-9. Distribution of participants in China-sponsored training programs on solar energy utilization (1991–2021)

7 AFFORDABLE AND CLEAN ENERGY

Recommendations and Outlook

This chapter examines methodologies for monitoring and analyzing SDG 7 progress based on Big Earth Data, centering on three themes under SDG 7: access to electricity, renewable energy and international energy cooperation, and assesses the progress globally and in China. The results show that notable progress in SDG 7 has been made globally and in China in recent years.

To facilitate the global realization of SDG 7, we offer the following recommendations:

(1) Further improvement in the capacity of Big Earth Data to support SDG 7 progress is needed and more big data infrastructure for SDGs should be constructed. The Big Earth Data technology has the potential of global application for SDG 7.1 and SDG 7.2 monitoring, in support of global SDG 7 monitoring. However, due to the limited spatial resolution of satellite remote sensing data, there is still room for improvement in some of the assessment results. In the future, a constellation of satellites for sustainable development should be developed to further enhance the supporting capacity of Big Earth Data for sustainable development goals.

(2) Renewable energy is key to addressing climate change and achieving a global energy transformation. China's energy transformation experience shows that national policies give strong support to renewable energy development. To achieve SDG 7 and energy transformation globally, countries need to formulate industrial policies that promote renewable energy development, work together to maintain an international environment conducive to this purpose and promote global green and low-carbon development.

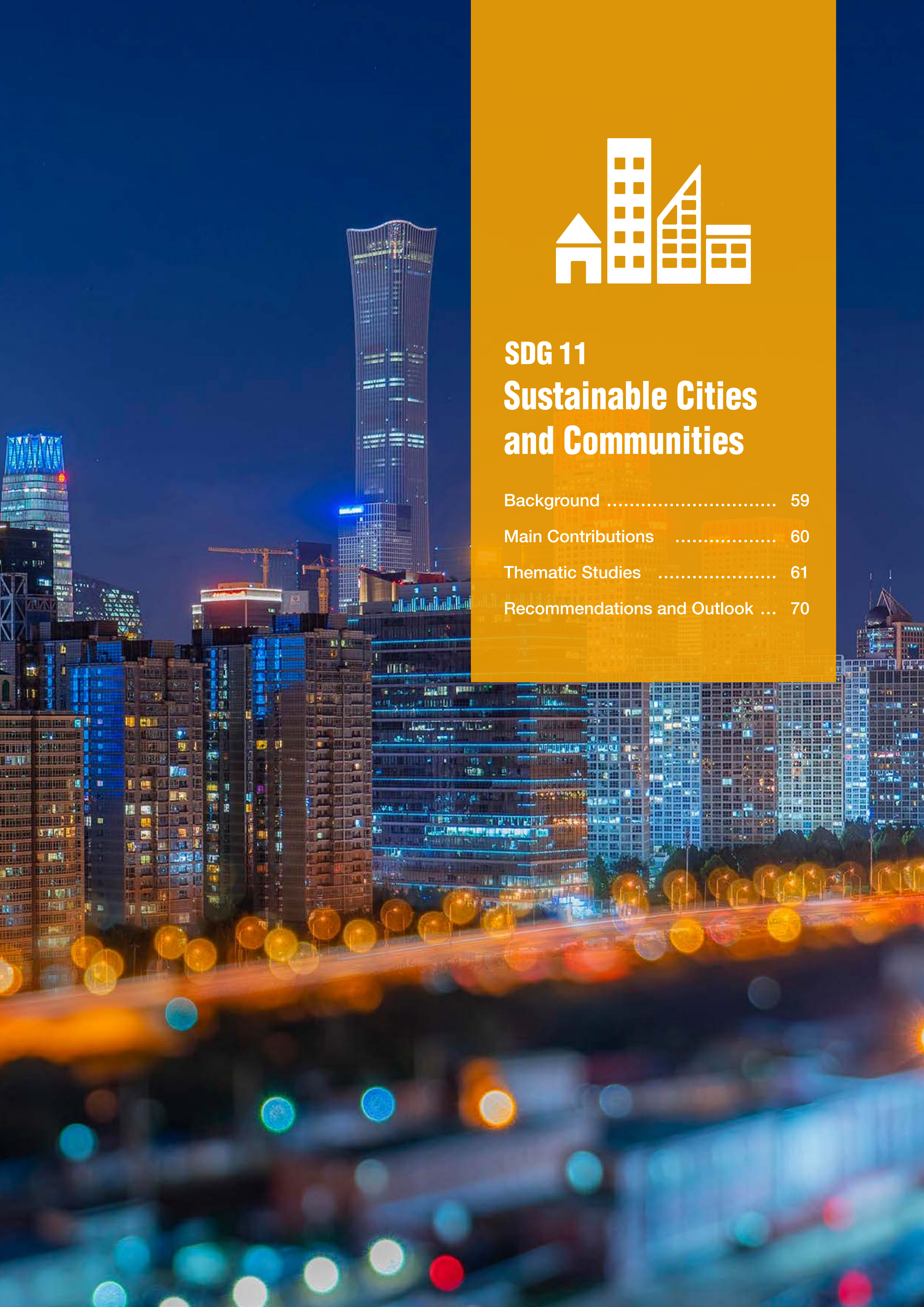
(3) Developing countries may address their energy shortages by building new power plants and renewable energy should be the focus in this endeavor. Most of the unelectrified built-up areas in the world are found in developing countries. 117 countries have seen a reduction in unelectrified buildings due to the construction of power plants. Developing countries are suggested to vigorously develop renewable energy, such as wind and solar energy, because those renewable energies are widely available and easy to develop and use.

(4) A global partnership for development is crucial for developing countries to achieve SDG 7. The international community should give even more support to developing countries, which generally lack the financial resources and technology to develop renewable energy. CIECPs play an important role in helping developing countries achieve SDG 7 targets. To achieve SDG 7 globally requires greater attention and support from the international community to developing countries.

The costs of new energy sources such as wind power and PV power generation are already comparable to those of traditional fossil energy sources. In the future, new energy sources will gradually become the mainstay of the energy systems of countries around the world, significantly reducing the carbon emissions of the global energy system and enhancing the energy autonomy of countries.

Multispectral remote sensing image of Kubuqi Desert Photovoltaic Power Station (Gaofen-2, March 31, 2022)

SDG 11

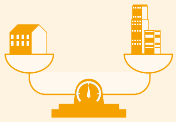


SDG 11
Sustainable Cities and Communities

Highlights

Urbanization Process Monitoring and Evaluation

Global urbanization is generally developing in a more balanced way. The indicator of global land use efficiency decreased from 1.65 in 2000-2005 to 1.31 in 2015-2020, but the speed of land urbanization still exceeds that of population urbanization.



World Heritage Protection

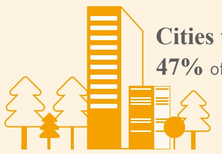
From 2015 to 2020, land cover changes in 564 World Cultural Heritage sites were generally smaller than 1%, indicating overall good protection. The analysis of the positive/negative impacts of land cover changes on World Cultural Heritage protection reveals a close correlation with GDP per capita.

Urban Disasters and Response

With the implementation of the *Sendai Framework for Disaster Risk Reduction* 2015-2030, the global average annual number of deaths and affected persons attributed to extreme disasters has decreased notably, but direct economic losses have increased substantially. The two indicators, SDG 11.5.1 (number of deaths and affected persons) and SDG 11.5.2 (direct economic losses), have both shown a clear downward trend in China.

Urban Green Space

With only 19% of the world's total built-up areas (BUAs), China accounted for 28% of the significant greening BUAs. Globally, 310 million people directly benefit from such BUAs, and about 47% of them live in China.



Multiple Targets Monitoring for SDG 11 at Community Scale

Overall progress has been made in the implementation of SDG 11.1, SDG 11.2 and SDG 11.3 in Chinese communities. The proportion of residents living in original shanty towns in major Chinese cities dropped by 30.8% from 2015 to 2020, as a result of successful renovations and improved living conditions. Transportation accessibility across all communities increased by 2.9% on average, benefiting additional 19 million people. The community volume ratio increased by 8%, indicating higher land use efficiency.

Background

Cities are the engine of economic growth, contributing about 60% of global GDP. At the same time, they are the main battleground in our fight against climate change. Cities generate about 70% of the global carbon emissions and use more than 60% of all resources. SDG 11 aims at making cities and human settlements "inclusive, safe, resilient and sustainable" and overcoming the challenges of congestion, lack of funds and infrastructure damage in ways that allow them to continue to thrive and grow, and improve resource use and reduce pollution and poverty as well. However, the average urban solid waste collection rate worldwide is 82% by 2022, and the rate under management in controlled urban facilities is 55%. Only 3% of the 6,475 cities in 117 countries and territories around the world do not exceed the threshold of air quality guidelines of the World Health Organization (WHO).

With the development and progress of Earth observation and big data technology, the Big Earth Data method that pulls together remote sensing, statistics and geographic information plays an important role in the monitoring and evaluation of SDG 11 indicators, as it is becoming widely used in the sustainability evaluation, e.g., evaluation of urban atmospheric environment, sustainable land use, and social and economic development. In the process of advancing SDGs, the focus of research work has been shifting from the construction of SDG indicator systems to the monitoring and evaluation of SDG progress.

Centering on 5 themes under SDG 11 – urbanization process monitoring and evaluation, world heritage protection, urban disasters and response, urban green space and multiple targets monitoring for SDG 11 at community scale, this chapter draws on the research from the previous three editions of the report and uses the Big Earth Data method to monitor and evaluate individual and multiple SDG 11 targets, including in Chinese cities at the community scale.

11 SUSTAINABLE CITIES AND COMMUNITIES

Main Contributions

This chapter evaluates progress of SDG 11.3, SDG 11.4, SDG 11.5 and SDG 11.7 in China and globally, and the community sustainability indexes integrating SDG 11.1, SDG 11.2 and SDG 11.3 in major Chinese cities through six cases. The main contributions are as follows (Table 5-1).

Table 5-1 Cases and Their Main Contributions

Theme	Target	Case	Contributions
Urbanization Process Monitoring and Evaluation	SDG 11.3	Comprehensive assessment of global urban land use efficiency from 2000 to 2020	**Data product:** A dataset of 1,702 urban built-up areas (population > 300,000) from 2000 to 2020 **Decision support:** Inform policies and offer recommendations on sustainable development of cities globally
World Heritage Protection	SDG 11.4	Land cover change monitoring for the protection assessment of World Heritage sites	**Data product:** Boundary data (vector format) of World Heritage sites up to 2020 **Method and model:** Monitoring and evaluation methods of land cover changes and sustainable development of world heritage **Decision support:** Improve the indicator system under SDG 11.4
Urban Disasters and Response	SDG 11.5	Global assessment of extreme weather and climate events 2000-2021	**Data product:** Dataset of extreme weather and climate disaster losses worldwide 2000-2021 **Decision support:** Provide data and information for the mid-term review of the implementation of the Sendai Framework, and inform national strategies on climate security and extreme event response
		SDG 11.5 monitoring for natural disasters at the prefectural level in China (2010-2021)	**Data product:** SDG 11.5 monitoring indicators dataset for 337 prefectural-level cities in China 2010-2021 **Decision support:** Inform municipal decision-making on enhancing disaster prevention capabilities and resilience
Urban Green Space	SDG 11.7	Change in urban greenness and beneficiary population in large cities in the world	**Data product:** Dataset on global trends of greenness with 250 m spatial resolution from 2001 to 2021 **Method and model:** The study applied non-parametric Mann-Kendall test to calculate the trend and significance level of each urban pixel, and calculated the ratio of the BUAs pixels with significant greening trend to the total BUAs for each city. **Decision support:** Provide a low-cost solution for urban sustainability monitoring in developing countries
Multiple Targets Monitoring for SDG 11 at Community Scale	SDG 11.1 SDG 11.2 SDG 11.3	Fine-scale monitoring of community sustainability in major Chinese cities	**Data product:** Dataset on China's community functional classification in 2015 and 2020 and dataset on China's community sustainability indexes **Decision support:** Inform the science-based and fine-scale governance of urban communities

SDG 11

Thematic Studies

Urbanization Process Monitoring and Evaluation

Sustainable urban development requires quantifying the relationship between urban land expansion and population growth. SDG 11.3.1 – ratio of land consumption rate to population growth rate (LCRPGR) – is an important indicator to evaluate the efficiency of urban land use. To address the issue of missing data for this indicator, this section discusses the monitoring and assessment of urban land use efficiency at a global scale, the results of which can inform decisions on sustainable development of cities around the world.

Comprehensive assessment of global urban land use efficiency from 2000 to 2020

Target: 11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated, and sustainable human settlement planning and management in all countries.

This case independently generated data products of global 30-m urban impervious surface in 5 periods from 2000 to 2020. Using the definition of built-up area recommended by the United Nations Human Settlements Programme (UN-Habitat), impervious surfaces were converted into standardized built-up area products (Jiang *et al.,* 2021, 2022); combining them with the population data in the corresponding period of 1,702 cities with a population above 300,000 provided by the 2018 Revision of *World Urbanization Prospects*, the SDG 11.3.1 was calculated to comprehensively compare, analyze, and evaluate global urban land use efficiency (Figure 5-1).

While global urbanization develops in a more balanced way, land urbanization still outpaces population urbanization. The proportions of cities in different LCRPGR categories among typical cities worldwide from 2000 to 2020 reveal that the land consumption rate was still faster than population growth rate between 2015 and 2020, but compared with the period between 2000 and 2005, the global urban land expansion and population growth were moving in a more balanced way. The proportion of cities with LCRPGR larger than 1 decreased from 65.10% to 63.57%; those with LCRPGR between 0 and 1 increased from 28.91% to 30.91%; those with negative population growth (with LCRPGR below 0) fell from 6.00% to 5.52%.

The change in LCRPGR in the world's typical cities from 2000 to 2020 shows a drop from 1.65 in the 2000-2005 period to 1.31 in the 2015-2020 period in the indicator of global urban land use efficiency, demonstrating a positive trend of balanced development of global urbanization, but the speed of land urbanization still exceeds that of population urbanization.

There are obvious regional differences in global urbanization. In Europe, the speed of land urbanization is much faster than that of population urbanization. The trend of LCRPGR indicator in typical cities on all continents from 2000 to 2020 shows that the values in Europe, South America, North America, Africa, and Oceania, except Asia, displayed a downward trend throughout different periods. For example, the results show a pattern of Europe (2.76) > Asia (1.59) > North America (1.41) > Africa (1.13) = South America (1.13) > Oceania (1.01) from 2015 to 2020, indicating much faster land consumption rate than population growth rate in Europe.

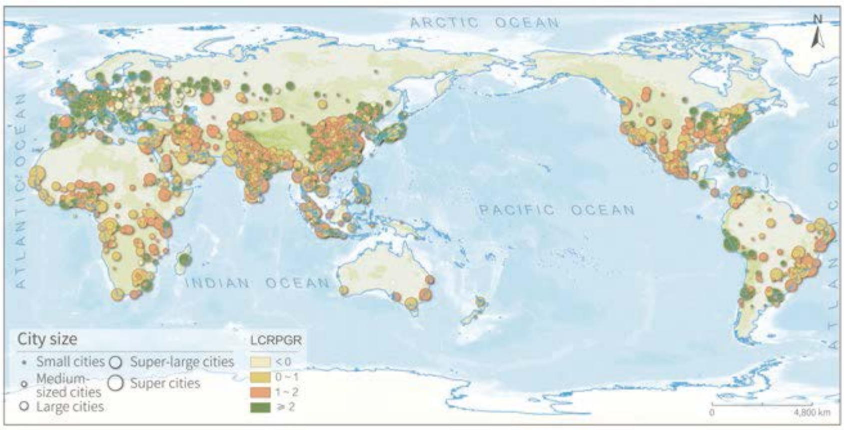


Figure 5-1. Change in LCRPGR indicator of global cities from 2000 to 2020

World Heritage Protection

"Strengthen efforts to protect and safeguard the world's cultural and natural heritage" is a specific target under SDG 11 Sustainable Cities and Communities. Currently, problems hindering the monitoring and evaluation of this target include the lack of data and enough indicators. This section discusses a case on the monitoring of land cover changes in selected World Natural and Cultural Heritage sites for the assessment of heritage protection based on the availability of boundary and remote sensing data. It represents effort to explore new monitoring and assessment methods for the better protection and management of world heritage.

Land cover change monitoring for the protection assessment of World Heritage sites

Target: 11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage.

Based on the global land cover datasets and high-resolution remote sensing images, the land cover changes were extracted at the World Natural and Cultural Heritage sites from 2010 to 2020, using the object-based image analysis (OBIA) (Tang *et al.,* 2022). The percentage of anthropogenic land cover change areas to the total protected area was calculated to quantitatively characterize change in heritage protection. The results reveal an internal relationship between the positive-negative change trend of the land cover in cultural heritage sites and the level of socioeconomic development, which in turn provide scientific data and technical approaches for the assessment of World Heritage protection and sustainable development.

The change in land cover related to human activities is generally smaller than 5% at the boundary areas of World Natural Heritage sites, and attention should be paid to the interference caused by artificial facilities. Each monitored zone was one that covers 2 kilometers on each side of the boundaries of the 173 selected World Natural or Mixed Heritage sites. The land cover changes related to human activities were less than 5% from 2010 to 2020 in the heritage area and boundary areas of 90% of sites. Further analysis of the 20 heritage sites with the maximum change disturbance revealed a notable increase in man-made constructions in their boundary areas.

The environments where World Cultural Heritage sites are located are generally well protected and the level of protection is highly correlated to the national socioeconomic development level. Analysis of 564 World Cultural Heritage sites shows that the change in land cover was less than 1% from 2015 to 2020 at the protected areas (heritage and buffer zones) of 90% of those sites. The change at the buffer zone was notably greater than that at the heritage area (Figure 5-2).

Through the identification of the positive (e.g., environmental remediation and museum construction) and negative (e.g., construction occupation and disorderly development) land cover changes in World Cultural Heritage sites between 2015 and 2020, and through analysis of national statistics, it is found that there is an internal relationship between the level of site protection and national GDP per capita . The pressure for cultural heritage protection is particularly high on underdeveloped countries, implying the role of social and economic development in promoting the sustainable development of World Cultural Heritage sites, i.e., the growth in national GDP per capita leading to a positive trend of heritage protection.

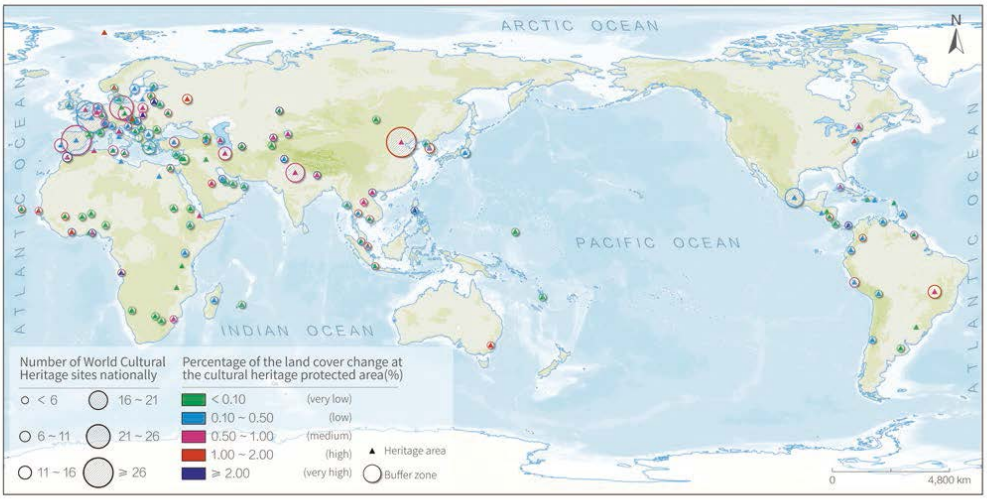


Figure 5-2. Land cover change ratio in the protected areas (heritage area and buffer zone) of World Cultural Heritage sites from 2015 to 2020

Urban Disasters and Response

The number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population, as well as direct disaster economic losses, are key indicators of SDG 11.5 and core indicators in the UN *Sendai Framework for Disaster Risk Reduction 2015-2030* (Sendai Framework). The recent three decades have seen some progress in reducing disaster losses, but extreme weather and climate events brought by climate change and rapid urbanization pose new challenges to disaster response. Useful experience can be drawn for the achievement of relevant SDG indicators through a comparison of the changes in monitoring indicators before and after the implementation of the Sendai Framework.

Global assessment of extreme weather and climate events 2000-2021

Target: 11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

This case studies the spatiotemporal distribution and variation characteristics of global extreme weather and climate events from 2000 to 2021, through consideration of both severity of disasters and intensity of contributing factors and synthesization of multi-source global disaster data based on the criteria for determining extreme weather and climate events.

Global extreme weather and climate events from 2000 to 2021 were dominated by extreme floods, tropical cyclones, extreme heat and cold waves and winter storms. From 2000 to 2021, extreme floods, tropical cyclones, extreme heat, cold waves and winter storms accounted for 51%, 20%, 14% and 9% of total global extreme weather and climate events respectively, and were the main types of extreme weather and climate events affecting the world (Figure 5-3).

There has been a notable reduction in the average annual number of affected people and deaths attributed to extreme weather and climate events globally since the Sendai Framework began to be implemented. Compared with the pre-Sendai Framework period (2000-2015), the average annual number of affected people and deaths attributed to extreme weather and climate events decreased globally by 42.2% and 78% respectively, and the average annual number of affected people and deaths per 100,000 population were both substantially lower, thanks to the implementation of the Sendai Framework that started in 2016.

Both global average annual direct economic losses from extreme weather and climate events and their share of GDP were notably higher than the pre-Sendai Framework levels. From 2000 to 2021, due to the rapid increase in economic exposure, extreme weather and climate events resulted in direct economic losses that were four times and their share of GDP 2.5 times that of the pre-Sendai Framework level. Considerable increases were observed in the indexes associated with such losses.

SDG 11

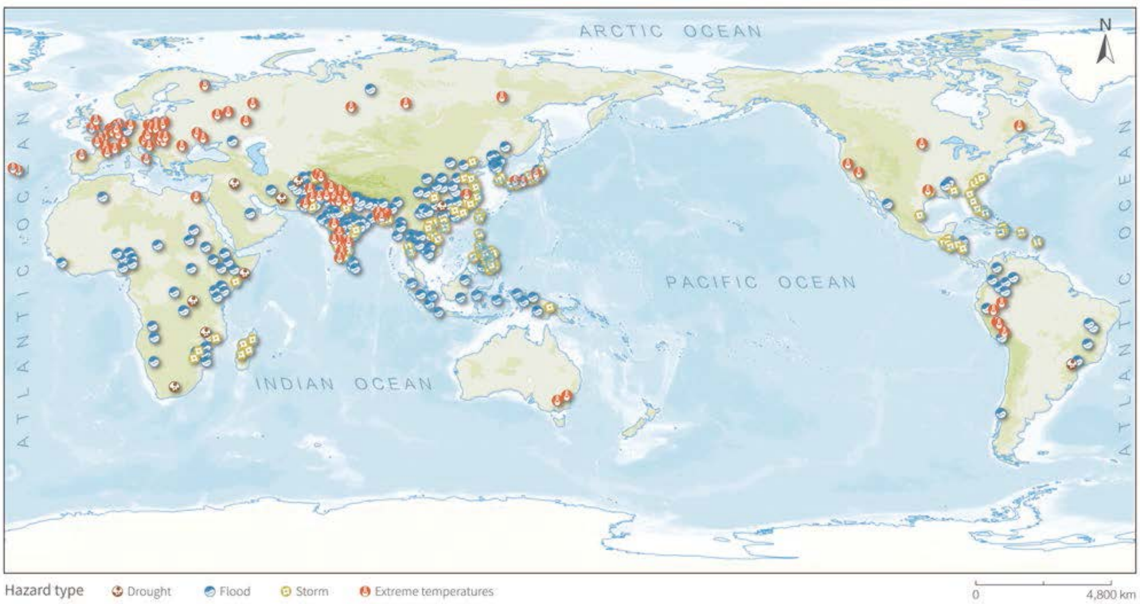


Figure 5-3. Global spatial distribution of extreme weather and climate events by hazard type (2000-2021)

SDG 11.5 monitoring for natural disasters at the prefectural level in China (2010-2021)

Target: 11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

This study uses data including annual statistics on the disaster affected population, deaths and missing persons, direct economic losses, year-end total population, and Gross Domestic Products (GDP) at the prefectural level in China since 2010, as well as year-end total population, Gross Regional Products (GRP) and typhoon disaster datasets at the county level between 2016 and 2020. This case details the multi-dimensional monitoring of variations in disaster risks and assessment of SDG 11.5 progress with a synergistic approach using both statistical and spatial data.

The two SDG11.5 indicators have both shown an obvious downward trend in China since 2010. The number of affected persons per 100,000 population, the number of deaths and missing persons per 100,000 population, and direct economic losses in relation to GDP in China decreased by 58.2%, 54.7% and 50.8% respectively in 2021, compared with annual average values from 2010 to 2020, which demonstrated a clear decreasing trend. However, extreme disaster events still have a heavy impact locally. Specifically, severe disasters such as the extreme rainstorm in Henan Province and the earthquake in Maduo County, Qinghai Province, took a toll on local economic and social development.

Compared to pre-Sendai Framework levels, China's average annual number of affected persons per 100,000 population, average annual number of deaths and missing persons per 100,000 population, and average annual direct disaster economic losses in relation to GDP all decreased substantially from 2016 to 2021. Between 2016 and 2021, after the implementation of the Sendai Framework, China's average annual number of affected persons per 100,000 population, average annual number of deaths and missing persons per 100,000 population, and direct economic losses in relation to GDP decreased substantially by 57.7%, 64.8% and 48.3% respectively, compared with pre-implementation levels (2010-2015). Such significant decrease shows China's active contribution to the achievement of the Sendai

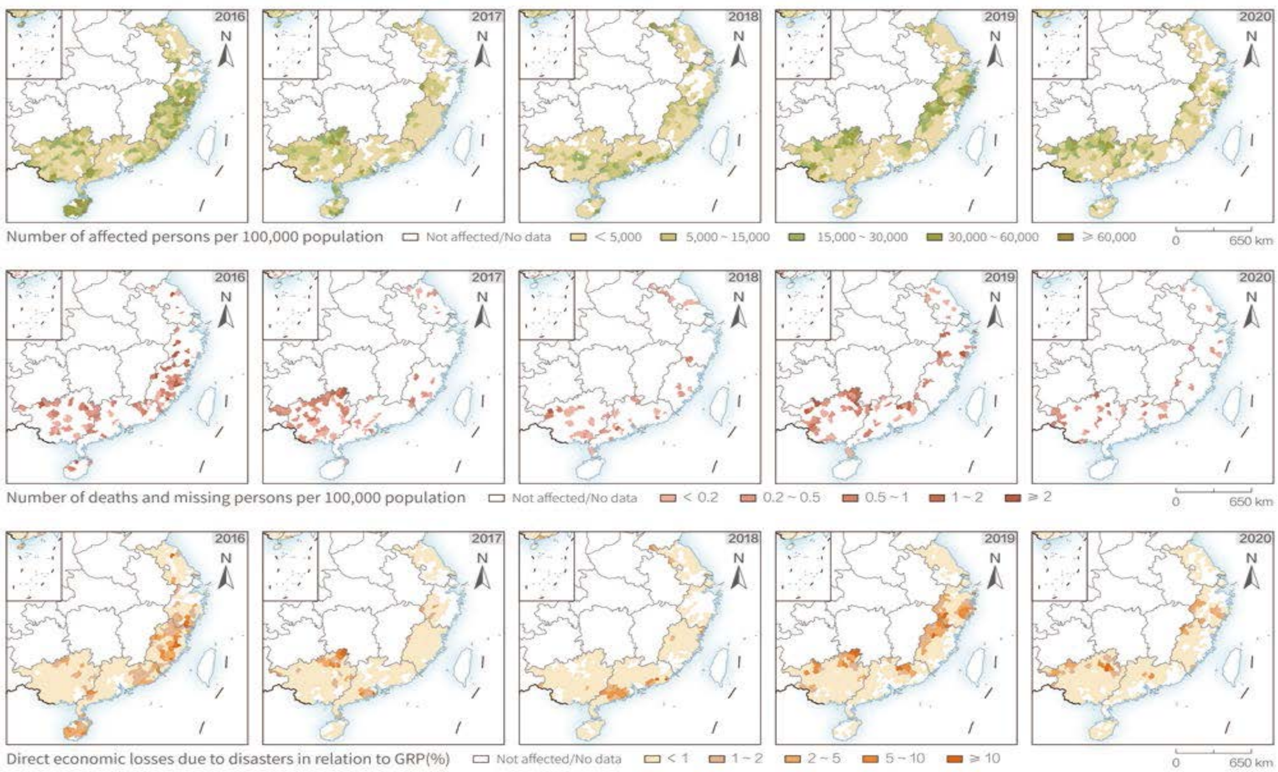


Figure 5-4. Overall trend of SDG 11.5 indicators for the typhoon disaster at county level along southeast coast of China, 2016-2020

Framework targets.

The impact of typhoon disasters on coastal urbanized areas has been generally mitigated. Since 2016, the relative impact of typhoon disasters on the southeastern coastal areas in China has generally been mitigated, thanks to the continuous improvement in China's comprehensive capacity for disaster prevention and mitigation and urban resilience against natural disasters. However, risk management for extreme typhoon events should be strengthened in the more urbanized regions along China's eastern and southern coasts, where typhoon hazards can produce a clustering effect, given the high population and economic density (Figure 5-4).

Urban Green Space

Urban green space is an important part of urban ecosystems and a key indicator in SDG 11.7. This study evaluates the greenness changes and beneficiary population from a global perspective, highlights improved urban ecosystems in China and also provides a low-cost solution for monitoring urban sustainability around the world.

Change in urban greenness and beneficiary population in large cities in the world

Target: 11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.

This study investigates the uneven change in urban environment amid global urbanization in terms of urban greening and beneficiary population between 2001 and 2021. The results provide a low-cost solution for monitoring urban sustainability globally and supply data in support of urban ecosystem improvement in China.

Using the 2020 land-cover change data of Moderate Resolution Imaging Spectroradiometer (MODIS) from US Terra and Aqua satellites, this case selects 1,783 cities (including urban agglomerations) worldwide, then uses the Enhanced Vegetation Index (EVI) data of MOD13Q1 between 2001 and 2021 to calculate the trend of the annual maximum EVI and significant level for each urban pixel (Sun *et al.,* 2020). Then the ratio of the significant greening areas to BUAs (Rg) is overlaid with population data to estimate the direct beneficiary population of a city (Giles-Corti *et al.,* 2016).

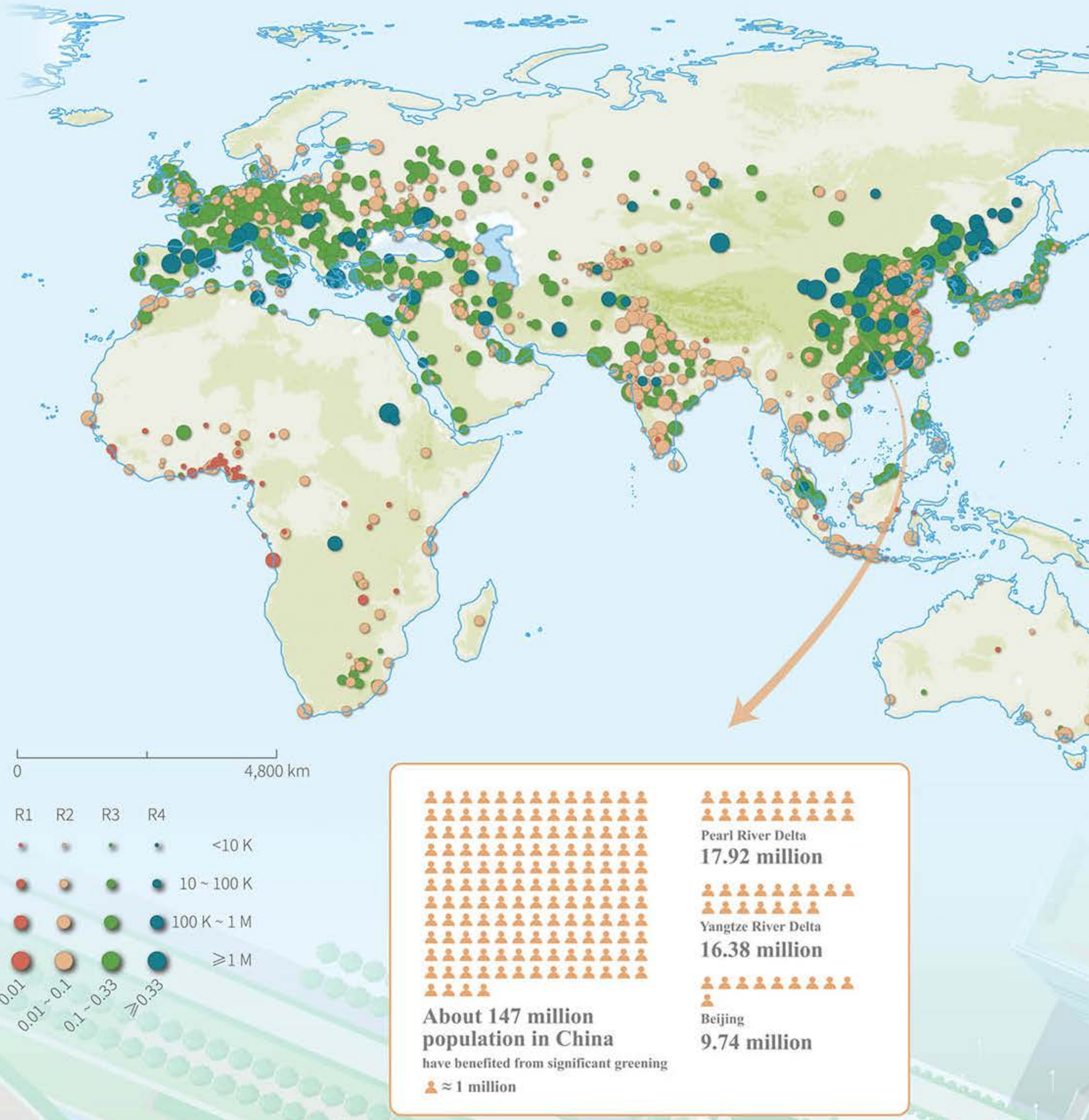
China has the largest urban area of significant greening in the world. Figure 5-5 shows the spatial distribution of Rg and the beneficiary population in 1,783 cities around the world from 2001 to 2021. Globally, the cities with large values of Rg (indicated by blue and green points on map) are located mainly in East Asia, Europe and Eastern United States in North America, and sparsely in Africa, Australia-Oceania and South America. The 316 Chinese cities accounted for only 19% of the global BUAs, but contributed 28% of significant greening BUAs among the 1,783 cities in the world.

Nearly half of the world's population benefiting from significant greening urban area are in China. Globally, about 310 million urban population live in significant greening BUAs. The proportions of beneficiary population by continent are: Asia (71%), Europe (12%), North America (8%), South America (6%), Africa (3%) and Australia-Oceania (0.4%) (Figure 5-6a). Approximately 147 million of them, or 47% of the global beneficiary population are in China. The top three cities with the largest beneficiary population in the world are the Pearl River Delta (17.92 million), the Yangtze River Delta (16.38 million) and Beijing (9.74 million).

The improvement in urban ecosystems is closely related to income level, with the most notable improvement seen in upper-middle-income countries. The average values of Rg ranging from high to low for the income groups defined by the World Bank are 15.40% for upper-middle-income countries, 13.90% for high-income countries, 11.78% for low-income countries and 9.70% for lower-middle-income countries (Figure 5-6b, bar graph). Using the average value of annual maximum greenness from 2019 to 2021 to represent the current environmental status of cities (EVIcity) (Figure 5-6b, broken line graph), it is found that the EVIcity is the highest (0.40) in high-income countries, while it is 0.35, 0.35, and 0.30 in upper-middle-income, lower-middle-income and low-income countries respectively, suggesting the need for major improvement in their urban environments.

Figure 5-5.

Spatial distribution of Rg and the beneficiary population in cities around the world



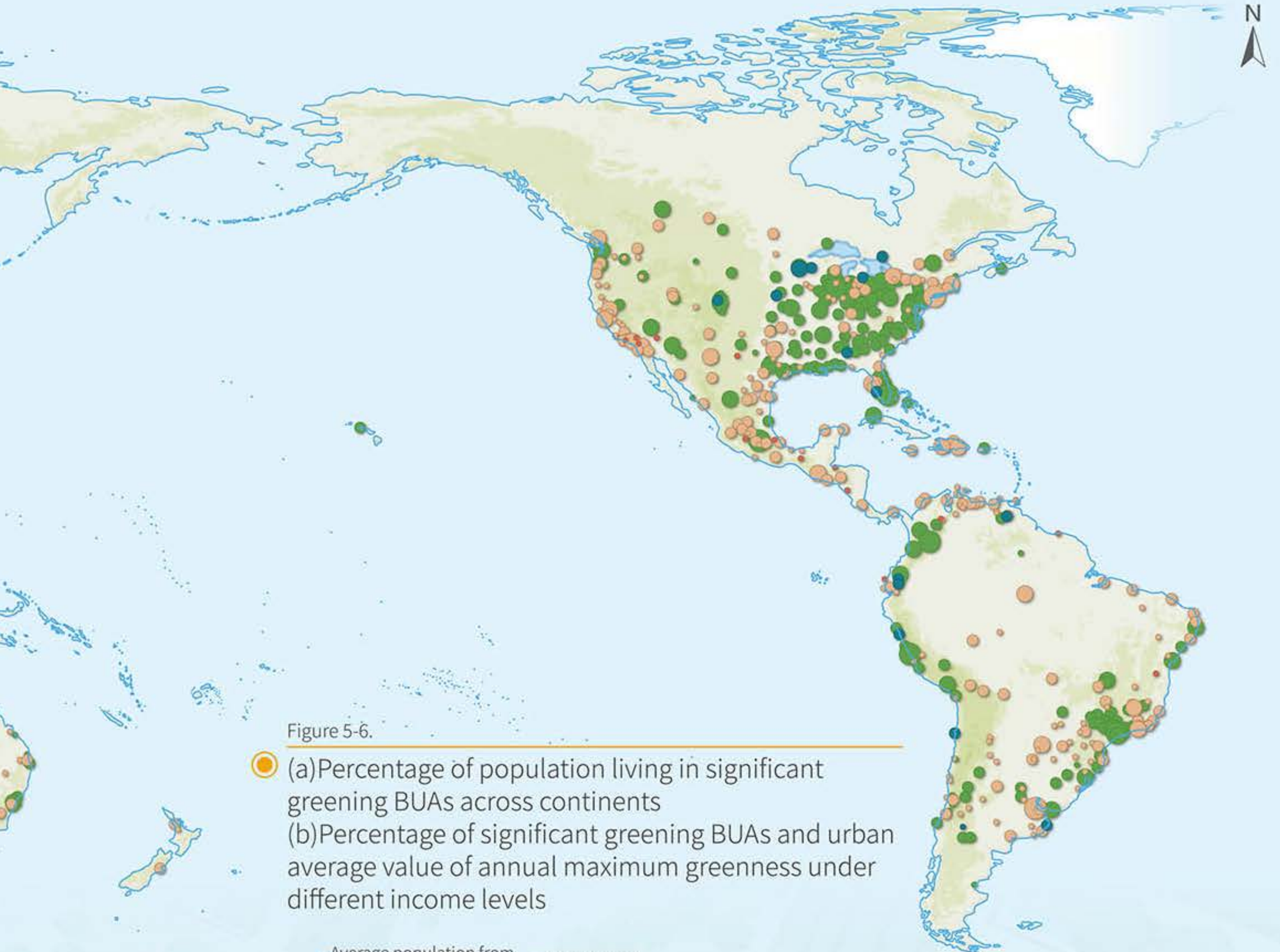
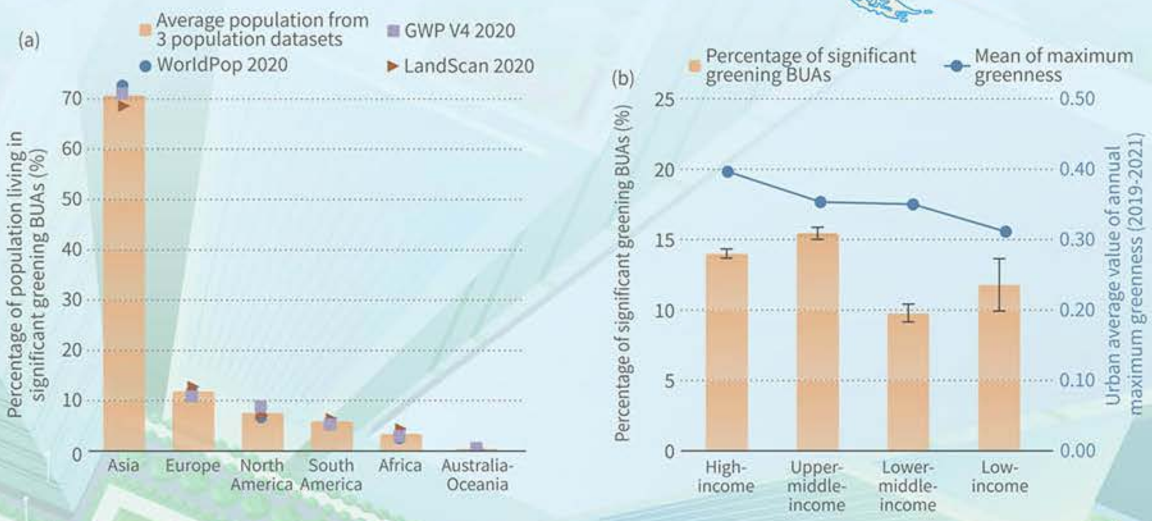


Figure 5-6.

(a)Percentage of population living in significant greening BUAs across continents
(b)Percentage of significant greening BUAs and urban average value of annual maximum greenness under different income levels



Multiple Targets Monitoring for SDG 11 at Community Scale

Urban sustainability is the top priority in achieving SDGs, and its evaluation is the yardstick for measuring the level of urban sustainable development and the foundation to support it. The current urban sustainability (SDG 11) targets, which focus on the cities without recognizing the heterogeneity within cities, are not conducive to fine-grained evaluation or localized decision-making. Therefore, this study proposes a fine-scale , monitoring and comprehensive evaluation method for multiple SDG 11 targets at the community level, and generates full-coverage, multiple-category, and fine-grained data products for community sustainability indexes in major Chinese cities, which can infrom fine-scale community planning and governance.

Fine-scale monitoring of community sustainability in major Chinese cities

Target: 11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.

11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.

This case considers functionally defined communities in cities as the basic units and establishes a community-scale SDG 11 targets monitoring system. Specifically, by coupling community landscape and global urban boundary data, communities with similar physical structure and socio-economic functions are extracted and put into functional categories to produce community functional classification data. For each community, multiple urban features and their spatial distributions are extracted based on muti-source data. Then indexes on community sustainability and their calculation methods are established for communities of three functional categories. First, population index of residential communities. Using community functional classification data, coupled with population data from WorldPop, the proportions of populations living in different residential communities are calculated; using urban population data from the *China Urban Construction Statistical Yearbook*, resident populations in different residential communities are calculated, giving special attention to the resident populations of shanty towns (a shanty town in this case is defined as a continuous area of old, low-rise buildings of high density, having a lot of ramps or dead ends and inadequate infrastructure, situated within the planned urban area). Second, community transportation accessibility index. Based on transportation points of interest, a 500 m buffer for short-distance commuting sites (bus stations, subway stations and parking lots) and a 1,000 m buffer for long-distance travel sites (airports and train stations) are constructed to form transportation accessible areas, which are then overlaid with the community functional classification data to calculate the transportation accessibility of each community. Third, community volume ratio index. Using community functional classification data coupled with building data, the community volume ratio index is calculated by the formula of buildings' footprint areas in a community × number of floors / the total area of the community. The study generates community sustainability index data on 31 major Chinese cities (provincial capitals and municipalities directly under the central government), covering the full breadth (13.41 million communities, 0.51 million km^2), multiple targets (3 SDG 11 targets) and multiple years (2015-2020), with fine granularity (2 m resolution, 13 categories of communities) (Figure 5-7). Such data can inform fine-scaled community planning and governance.

The findings are as follows:

The resident population of shanty towns in major Chinese cities declined notably from 2015 to 2020. The shanty town is the focus of SDG 11.1. From 2015 to 2020, the resident population of original shanty towns in major Chinese cities decreased from 22.03 million to 15.24 million by 30.8%, reflecting the remarkable improvement in living conditions thanks to the effective renovation efforts.

Community transportation accessibility and the benefitiary population increased in these major Chinese cities from 2015 to 2020. The transportation accessibility at almost all communities in these cities increased (except water areas), with an average increase of 2.9%. The largest increases, above 20%, are seen in the undeveloped areas and open spaces. In the context of SDG 11.2, the population benefiting from community transportation accessibility in major Chinese cities increased by 19 million.

Land use efficiency improved in these cities from 2015 to 2020. The community volume ratio measures the building densities and heights in a community, which reflects the land use conditions at the community scale. Regarding SDG 11.3, it is found that the community volume ratio in major Chinese cities increased by 8% on average from 2015 to 2020, indicating a significant increase in land use efficiency at the community scale.

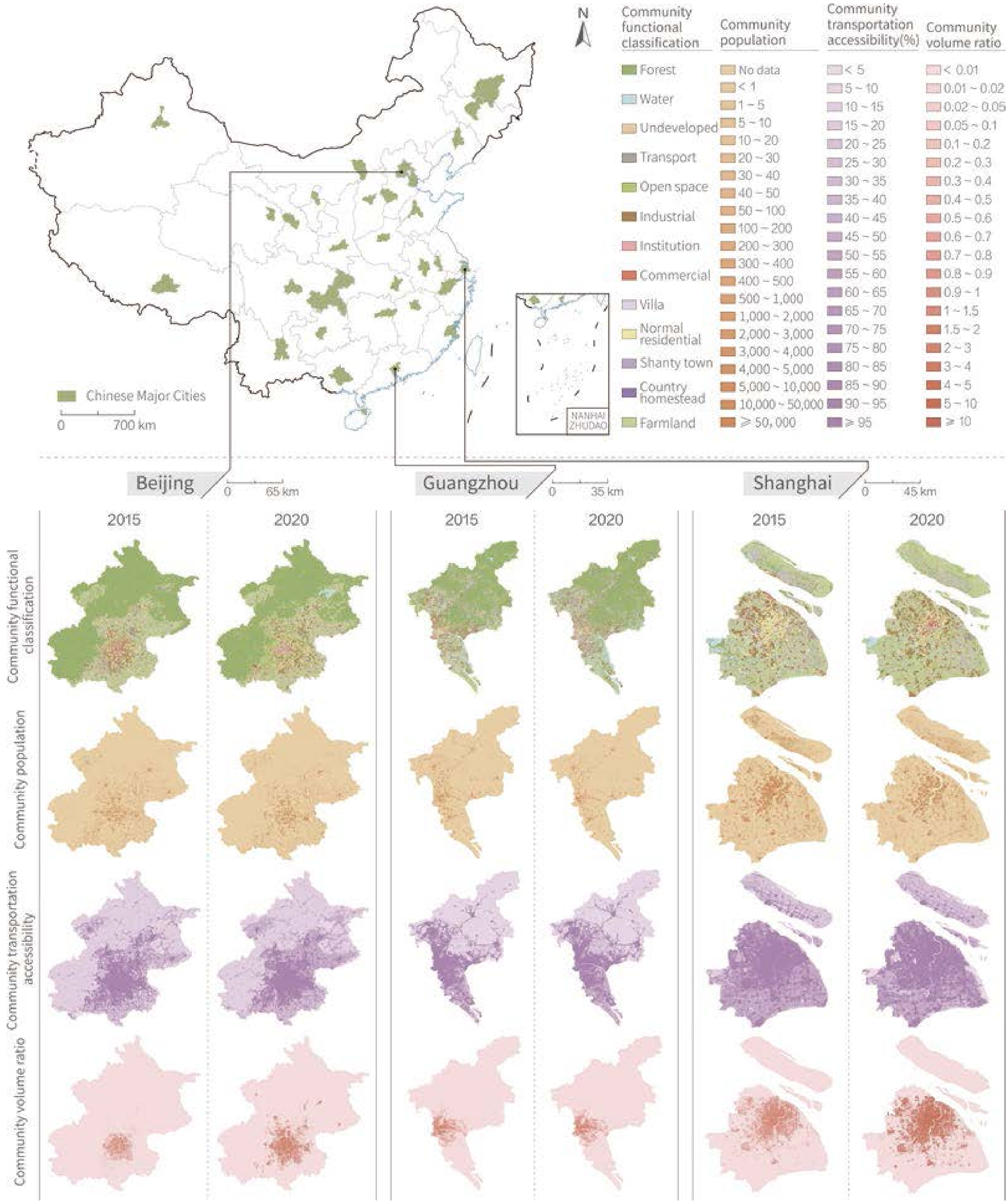


Figure 5-7. Community functional classification and sustainability indexes for major Chinese cities from 2015 to 2020

Recommendations and Outlook

This chapter discusses progress in 4 themes: the urbanization process monitoring and evaluation, world heritage protection, urban disasters and response and urban green space at the global and Chinese scales, and details the dynamic monitoring and analysis of the three indexes reflecting shanty towns' population, transportation accessibility and volume ratio at urban communities in China.

Based on the study, we offer the following recommendations:

(1) Regarding SDG 11.3.1 – urban land use efficiency, the study found that urbanization developed in a more balanced way globally from 2000 to 2020. It is recommended that urban land expansion should be rationally planned to achieve optimized allocation of land resource and avoid low-level development and poor land use efficiency.

(2) Regarding SDG 11.4.1 – World Heritage protection, the study found that the positive/negative trend of land cover at cultural World Heritage sites is highly correlated with GDP per capita. It is recommended that the monitoring and evaluation of heritage-related indicators should be strengthened in accordance with the World Heritage Convention and its Operational Guidelines, with special attention to addressing the issue of how to balance world heritage protection and community development in middle-income countries and regions.

(3) Regarding urban disaster-related SDG 11.5.1 and SDG 11.5.2, this study found that some progress has been made in the implementation of the Sendai Framework both in China and around the world, but joint global response to extreme disasters remains urgent. Disaster risk reduction should remain a high priority in municipal and community development, as well as in economic, social and environmental policy-making.

(4) Regarding SDG 11.7.1 – urban open space, the study found that while its total BUAs are only 19% of the world's total, China accounted for 28% of significant greening BUAs and 47% of global population benefitting from such BUAs. Countries, especially developing ones, are recommended to strengthen urban planning and invest more in green infrastructure amid rapid urbanization.

(5) Regarding the comprehensive monitoring of multiple SDG 11 targets at community scale, the study found that the implementation of SDG 11.1, SDG 11.2 and SDG 11.3 in Chinese communities is generally making progress, but with differences among communities. It is recommended that attention should be paid to the community-scale monitoring and evaluation of SDG 11 so as to promote balanced and sustainable development of different communities. Regarding SDG 11.1, the study found notable progress in shanty town renovations in China, evidenced by smaller area of and steadily lower ratio of population living in shanty towns in major Chinese cities. But due to the expansion of BUAs, shanty town population still accounted for 5.2% of the resident urban population, suggesting that shanty town renovations should continue to improve urban living conditions.

Future studies should help understand the transformation toward sustainable urbanization and continue to explore the capacity of digital technology represented by Big Earth Data in monitoring and evaluating sustainable cities and communities, so as to provide scientific solutions to the realization of SDG 11 by filling the data gap, expanding the indicator system and informing government decision-making.

Nuorilang Waterfall, Jiuzhaigou Valley


SDG13

SDG 13

Climate Action

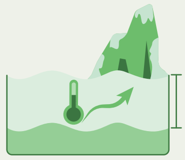
Highlights

Disaster Monitoring and Reduction Actions

As climate-related disasters become more and more destructive, disaster reduction policies in China have gradually improved. From 2011 to 2020, the global area affected by heat waves increased by about 5%. In 2021, the cultivated land affected by water-logging in China was 2.6 times that of previous average years. The loss of crop yield due to water-logging was effectively compensated through scientific field management and other measures. China has developed a comprehensive national disaster reduction system on the basis of the Sendai Framework, and all sub-national governments have adopted and implemented their own disaster risk reduction systems.

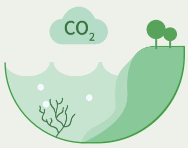
Long-term Early Warning for Climate Change

Changes in the physical environment of oceans are intensifying. As the upper 2,000 m of the global ocean gets warmer at a faster rate, the existing salinity pattern has amplified, with the fresh getting fresher and the salty getting saltier in much of the ocean, which poses a long-term threat to the marine ecological environment and sustainable development.



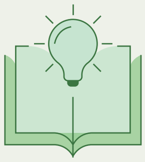
Global Terrestrial/oceanic Carbon Sink Estimation

The carbon sink capacity of global terrestrial and oceanic ecosystems has strengthened. In the past 20 years, the net ecosystem productivity of global terrestrial ecosystem has increased significantly. The carbon sink intensity of global oceans fluctuates greatly under the influence of El Niño and La Niña, but overall has been continuously strengthening since 2008.



Climate Change Education

China has relatively sound policies and systems for climate change education. Teachers and students approve of the relevant topics and conscientiously participate in climate actions. However, there is still room for improvement in terms of teaching design and related practical activities.



SDG 13

Background

Climate change is triggering unpredictable responses on the global land and in the oceans and atmosphere, and has a lasting and far-reaching impact on sustainable development and the ecological environment (WMO, 2022). According to data released by the EM-DAT international disaster statistics database, disasters and economic losses caused by extreme weather events across the world have increased significantly in the past 20 years. Mitigation of climate change requires all countries to take the most urgent actions to reduce greenhouse gas emissions and increase carbon sinks through forest protection, soil management and carbon capture (IPCC, 2022).

In order to cope with the threat of climate change to the sustainable development of humankind, SDG 13 was established to "take urgent action to combat climate change and its impacts" (hereinafter referred to as "climate action"). Targets under this Goal include, among others, strengthening resilience to natural disasters, reducing greenhouse gas emissions, and improving education and early warning. China has actively responded to the call for climate action by setting its carbon peaking and neutrality targets and implementing disaster prevention and reduction strategies. Furthermore, in 2022, the Chinese government released the *National Climate Change Adaptation Strategy 2035*, which proposes to build a climate-resilient society by 2035 by improving climate change monitoring, early warning, and response capabilities.

Currently, among all 17 SDGs, climate action suffers the most severe shortage of data (UN, 2021). Therefore, this chapter focuses on the four themes of disaster monitoring and reduction, early warning, global terrestrial/oceanic carbon sink estimation, and climate education, and describes the use of the Big Earth Data method system to generate data products to monitor climate action progress and conduct spatiotemporal analysis to support decision-making.

Compared with the reports of the previous three years, the big data in this report are of broader scope and spatial scale and with greater relevance to SDG indicators. The progress in China of four indicators of SDG 13 was assessed, and global-scale disaster and carbon sink data products were generated to make a greater contribution to climate change response and adaptation.

13 CLIMATE ACTION

Main Contributions

This chapter evaluates the progress of SDG 13.1, SDG 13.2 and SDG 13.3 in China and globally through seven cases. The main contributions are as follows (Table 6-1).

Table 6-1 Cases and their main contributions

Theme	Target	Case	Contributions
Disaster Monitoring and Reduction Actions	SDG 13.1	Spatial-temporal distribution of water-logging and its impact on crops in China	**Data product:** Daily soil moisture products that combine observation data from 2,075 automatic soil moisture stations in China and passive microwave remote sensing from 2016 to 2021 **Decision support:** The area of water-logged cultivated land in China in 2021 was about 2.6 times that of average previous years. The yield loss can be effectively compensated through fine field management.
		Global heat waves: trends and impacts	**Method and model:** Identification of the intensity and frequency of heat waves and the size of affected population on global scale by combining the relative and absolute thresholds
		Quantitative evaluation of China's disaster prevention and reduction policies under the climate action goal	**Data product:** China's disaster prevention and reduction policy data set **Decision support:** China has developed a fairly full-fledged disaster reduction system using the Sendai Framework for Disaster Risk Reduction 2015-2030
Long-term Early Warning for Climate Change		Ocean physical environment changes in the context of global warming	**Data product:** Gridded data sets of global ocean heat content, salinity, and stratification for the past 60 years **Decision support:** The changes of marine physical environment caused by global warming seriously threaten marine ecosystems and their sustainable development
Global Terrestrial/ oceanic Carbon Sink Estimation	SDG 13.2	Variability of global ocean carbon budget in the recent three decades	**Data product:** Partial pressure of carbon dioxide in global surface ocean from 1992 to 2020 **Method and model:** Estimation of carbon dioxide flux absorbed by global oceans from the atmosphere
		Analysis of spatiotemporal changes of global terrestrial net ecosystem productivity from 2000 to 2020	**Data product:** Global terrestrial net ecosystem productivity products from 2000 to 2020
Climate Change Education	SDG 13.3	A survey on climate change education in China	**Decision Support:** Teachers and students need to improve their knowledge and understanding of the climate action

Thematic Studies

Disaster Monitoring and Reduction Actions

Climate change increases the intensity and frequency of natural disasters such as floods and heat waves. Water-logging is a general term for both floodwater on low-lying land and sludge, the former being ponding caused by inefficient drainage after heavy rainfalls and the latter being a protracted state of excessive moisture or water saturation of the soil. It is an agro-meteorological disaster that causes poor crop growth and serious yield reduction. Heat wave is an extreme weather and climate event caused by continuous high temperatures far beyond the current climate state. Under this topic, satellite remote sensing and ground station data were used to evaluate the impact of water-logging in China and global heat waves in recent years and analyze the risks to human life.

China is committed to comprehensively improving integrated preparedness and resilience of the whole society against natural disasters. Therefore, understanding the characteristics of the relevant disaster prevention and reduction policies and conducting timely evaluation and monitoring of the progress in developing a disaster prevention and reduction system are of great significance to building national capacity in disaster prevention, reduction, and relief.

Spatial-temporal distribution of water-logging and its impact on crops in China

Target: 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

In this case study, the observation data of 2,075 automatic soil moisture stations in China and L3 9-km daily soil moisture products from the Soil Moisture Active and Passive satellite (SMAP) were combined to generate a high-precision data set of daily volumetric surface soil (0-10 cm) moisture in China from 2016 to 2021. The precision is 79%. Field water capacity data (Wu *et al.,* 2021) were used to calculate the relative water content of surface soil. The area of water-logging was obtained by mapping the data with a soil relative water content greater than or equal to 90% for 10 consecutive days to the distribution of cultivated land (rice farms excluded). The impact of the most severe water-logging on cultivated land in 2021 was analyzed based on the soil moisture data.

The area of water-logged cultivated land in China from July to September 2021 was about 2.6 times that of the same period in an average year from 2016 to 2020. From July to September, 2021, the area of water-logging accounted for about 90% of total cultivated land, significantly higher than that in other years. More specifically, it was about 2.6 times the annual average from 2016 to 2020. The water-logging disasters in Northeast and North China were relatively severe (Figure 6-1a), which had a negative impact on the growth of crops such as summer corn.

The area of water-logging in China's cultivated land from October to December 2021 was larger than that in the same period of previous years and affected wheat sowing. The areas of water-logged cultivated land in Hebei, Henan, Shandong,

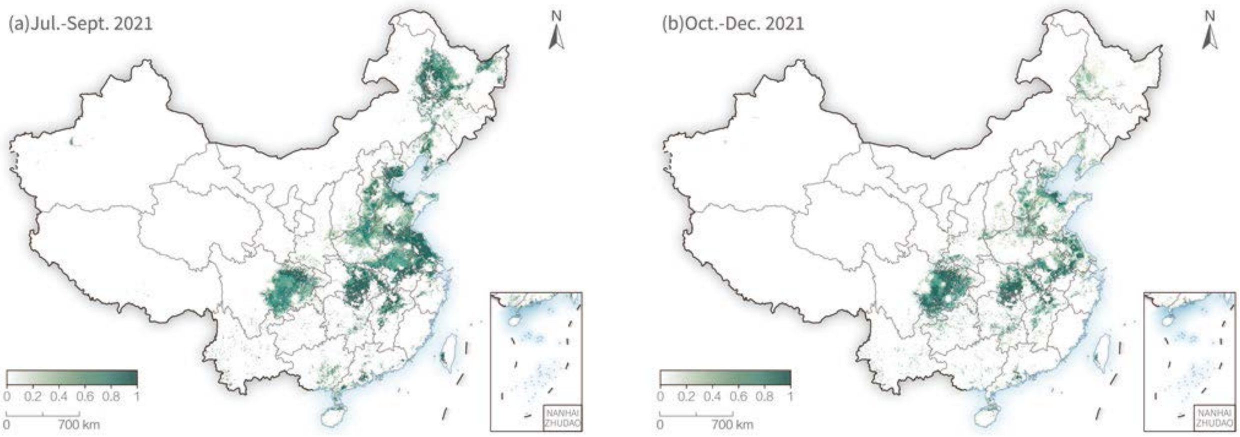


Figure 6-1. Ratio distribution of days affected by water-logging in cultivated land from July to September and October to December, 2021

SDG 13

and Anhui provinces increased significantly from October to December 2021 compared with the same periods from 2016 to 2020. The total area affected by water-logging accounted for about 66.7% of the total cultivated land (Figure 6-1b). October to December is the period of winter wheat sowing and emergence. Water-logging makes it impossible to sow since the land is flooded.

In order to reduce the impact of water-logging, in the spring of 2022, provinces in North China campaigned to "strengthen seedlings with science and technology" and practised in-depth field management, which effectively improved per unit wheat yield. Ultimately water-logging did not affect summer grain output in North China.

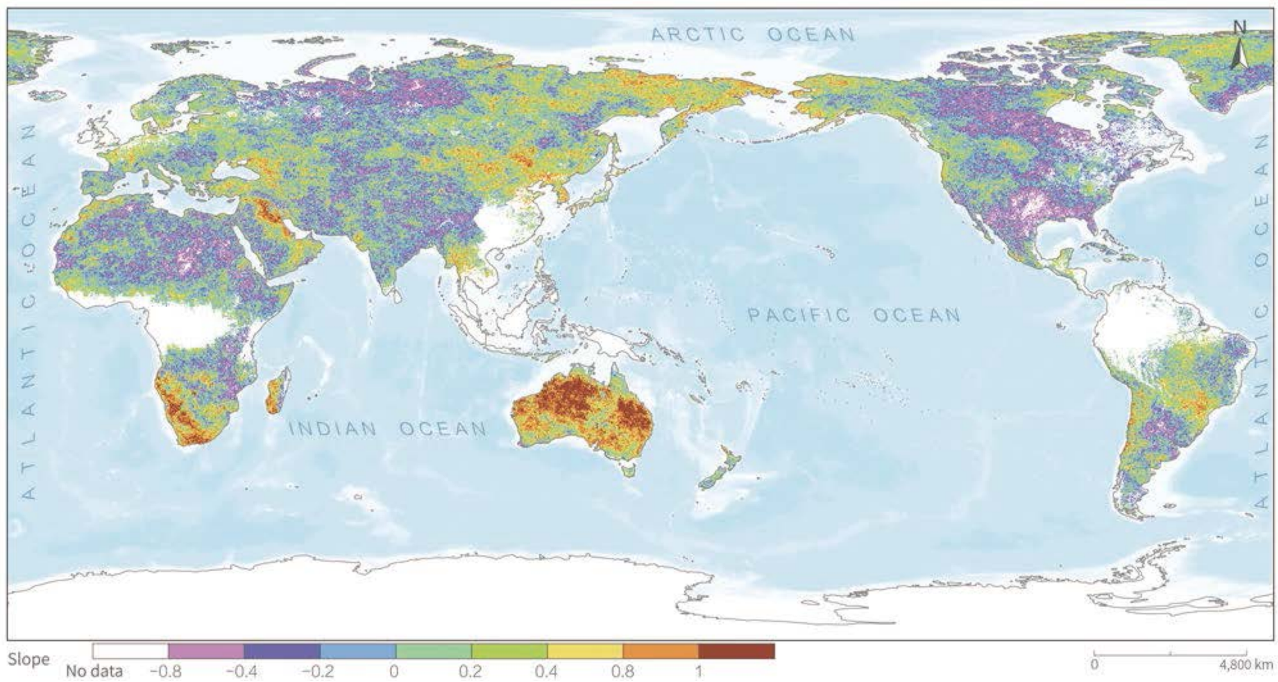
Global heat waves: trends and impacts

Target: 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

In this case study, data from satellite remote sensing and meteorological stations were used to conduct spatial statistics of global high-temperature and heat wave events using both absolute and relative thresholds. The intensity and scope of heat waves across the world in 2011-2020 were examined to identify spatial distribution of population affected (SDG 13.1.1). For the purpose of the research, a heat wave event was defined as at least 3 consecutive hot days and three levels of harm (moderate, severe and ultra) were defined on the basis of the number of episodes within a year (10, 15 and 20 respectively).

The total land area affected by heat waves occurring for 30 days expanded by about 5% from 2011 to 2020, with the largest area recorded in 2019. Global meteorological station and satellite data were used to analyze the global spatial distribution of heat waves from 2011 to 2020. The results showed an increasing area hit by heat waves during the decade. In 2011, 25.5% of global land was exposed to 30 hot days. The ratio was 29.7% in 2020 and hit the highest in the decade at 31% in 2019. The Oceania, Southwest of Asia and northern and southern Africa were more frequently hit then other regions, with the most frequent episodes at 20° N latitude in the northern hemisphere and 18° S and 23° S latitudes in the southern hemisphere.

About 6,300 and 1,200 out of every 100,000 people were directly affected by heat waves with moderate and severe harms respectively. Thirty-three percent of the world's land area experienced increased heat wave events from 2011 to 2020, with the most obvious increases in Oceania and southern Africa (Figure 6-2). Spatial statistics showed that on average about 470 million, 90 million and 1.7 million people were directly affected every year by heat waves with moderate, severe and ultra harms respectively. In other words, moderate heat waves directly affect 6,300 out of every 100,000 people.



↑ Figure 6-2. Trend of global heat wave frequency from 2011 to 2020

SDG 13

Quantitative evaluation of China's disaster prevention and reduction policies under the climate action goal

Target: 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

In this study, the implementation progress of national disaster risk reduction strategies (SDG 13.1.2) and local disaster risk reduction strategies (SDG 13.1.3) in China was assessed by establishing the data set of national and provincial disaster prevention and reduction policies from 2010 to 2022 and statistically analyzing the patterns of changes in the characteristics of those policies mapped to the four priority action areas of the Sendai Framework. The results were as follows:

China has been actively implementing disaster risk reduction strategies since the adoption of the Sendai Framework. From 2010 to 2022, 185 national-level and 909 provincial-level disaster prevention and reduction policies were promulgated in China. In response to the Sendai Framework, the country produced the largest number of national strategies and plans for disaster risk reduction in 2016. By far, 31 provincial-level governments and Xinjiang Production and Construction Corps (no data for Hong Kong, Macao and Taiwan) have adopted relevant strategic plans and all of the provincial governments have adopted and have been implementing local disaster risk reduction strategies in line with the relevant national strategy.

Compared with the period from 2010 to 2015, significantly more comprehensive disaster reduction policies were made during 2016-2020.

China has built a rather full-fledged disaster reduction system on the basis of the Sendai Framework. From 2010 to 2022, national and provincial disaster prevention and reduction policy measures existed in all the four priority areas of the Sendai Framework, with the main focus on enhancing disaster risk awareness and preparedness and measures that correspond to the Sendai Framework's priority areas: understanding disaster risk and enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

Compared with the period from 2011 to 2015, China actively promoted the implementation of the Sendai Framework from 2016 to 2020, with particular emphasis on strengthening disaster risk governance and enhancing disaster preparedness. A series of policy measures were formulated, such as enhancing disaster risk management capacity and constructing early warning systems. The Chinese strategy for disaster prevention and reduction shifted its stress from post-disaster relief to prevention and preparedness, and from targeting single and specific disaster to comprehensive disaster reduction, and from disaster loss reduction to disaster risk reduction (Figure 6-3).

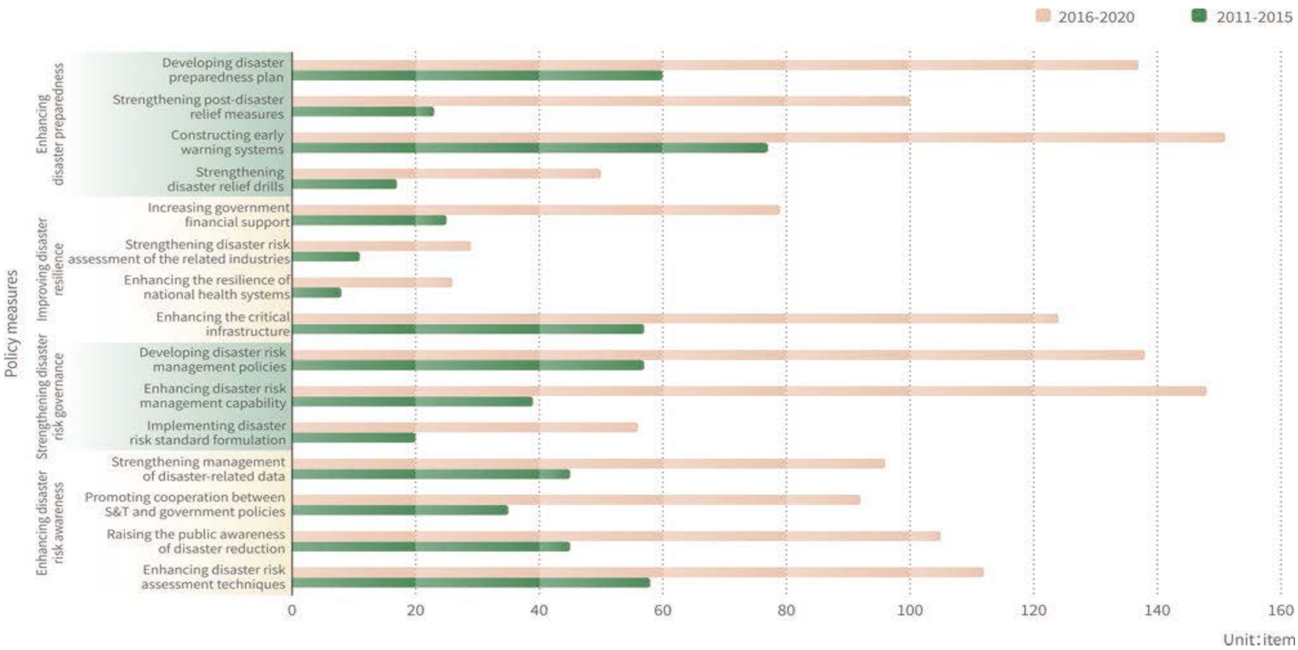


Figure 6-3. Numbers of disaster prevention and reduction policy measures in China introduced from 2011 to 2015 and from 2016 to 2020

Long-term Early Warning for Climate Change

Ocean warming causes more extreme weather events such as typhoon and hurricane and raises the global sea level. Ocean temperature and stratification increases reduce the efficiency of ocean carbon uptake, leave more CO_2 in the air and exacerbate global warming. Moreover, stronger ocean vertical stratification inhibits the vertical exchange of oxygen, leading to ocean deoxygenation and threatening ocean life, which is a long-term threat to the sustainable development of island and coastal countries.

Ocean physical environment changes in the context of global warming

Target: 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.

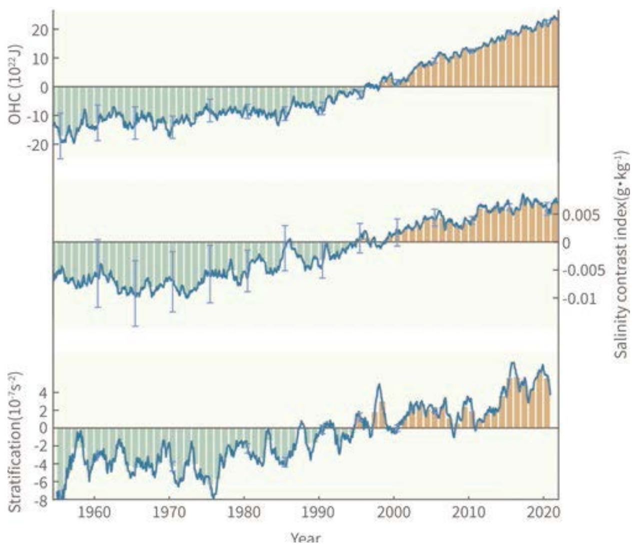
This study applied quality-control, bias correction and mapping to the ocean *in situ* temperature and salinity observations to reconstruct gridded temperature and salinity data sets with 1°×1° horizontal resolution, on the basis of which heat content, salinity contrast index and stratification were calculated (Cheng *et al.,* 2022). The ensemble optimal interpolation approach with dynamic ensemble is capable of unbiased reconstruction of the spatiotemporal variability of ocean changes (Cheng *et al.,* 2017). Moreover, A new long-term and multi-level global ocean surface temperature remote sensing data set was reconstructed using convolutional long short-term memory neural network, which combined satellite remote sensing observations (sea surface height, temperature and wind field) and Argo float observations (Su *et al.,* 2021; 2022). Here, we combined the self-developed data products to analyze the impact of climate change on the ocean physical environment.

As the upper 2,000 m of global ocean gets warmer at a faster speed, the fresh gets fresher and the salty gets saltier in much of the ocean, and vertical stratification is increasing significantly. From 1955 to 2021, the upper 2,000 m of global ocean experienced a significant increase in ocean heat content (OHC), with a linear rate of 5.7×10^{22} J/10a (Figure 6-4). From 1991 to 2021, the rate was 9.5×10^{22} J/10a, four times the rate of increase from 1955 to 1990.

For the 1955-2021 period, the salinity contrast index of the upper 2,000 m increased by 1.6%, with the saltier regions (than global mean salinity) getting saltier while the fresher regions (than global mean) getting fresher (Figure 6-4).

From 1955 to 2021, global upper 2,000 m stratification increased by 5.3% (Figure 6-4). The increase of vertical stratification was mainly caused by stronger upper ocean warming than the deep ocean, but the contribution of salinity change is also crucial locally (Li *et al.,* 2020).

All ocean basins are significantly warming and there are stronger signals of warming of the subsurface and deeper ocean (SDO), which is absorbing and storing more and more heat.



↑ Figure 6-4. Ocean heat content, salinity contrast index and stratification change of the upper 2,000 m of global ocean (1955-2021)

All ocean basins have dramatically warmed over the past 30 years as climate change, and the global ocean warming demonstrates a certain degree of spatial heterogeneity (Figure 6-5). The ocean warming signal exhibits a distinctive vertical evolution characteristic from the upper layer to the subsurface and deeper layers, indicating that more and more heat is sequestered and stored by the SDO, and the SDO is playing an increasingly important role in regulating energy balance of the Earth climate system.

Ocean physical environment changes caused by global warming will threaten ocean ecosystems and their sustainable development. Driven by climate change, the physical environment of oceans is changing systematically. Notably, since the ocean's response to increased greenhouse gases features slowness and hysteresis, ocean warming and stratification increases caused by past carbon emissions will go on for at the least hundreds of years (Abraham *et al.,* 2022). The ocean is therefore critical in achieving the SDGs and combating climate change.

SDG 13

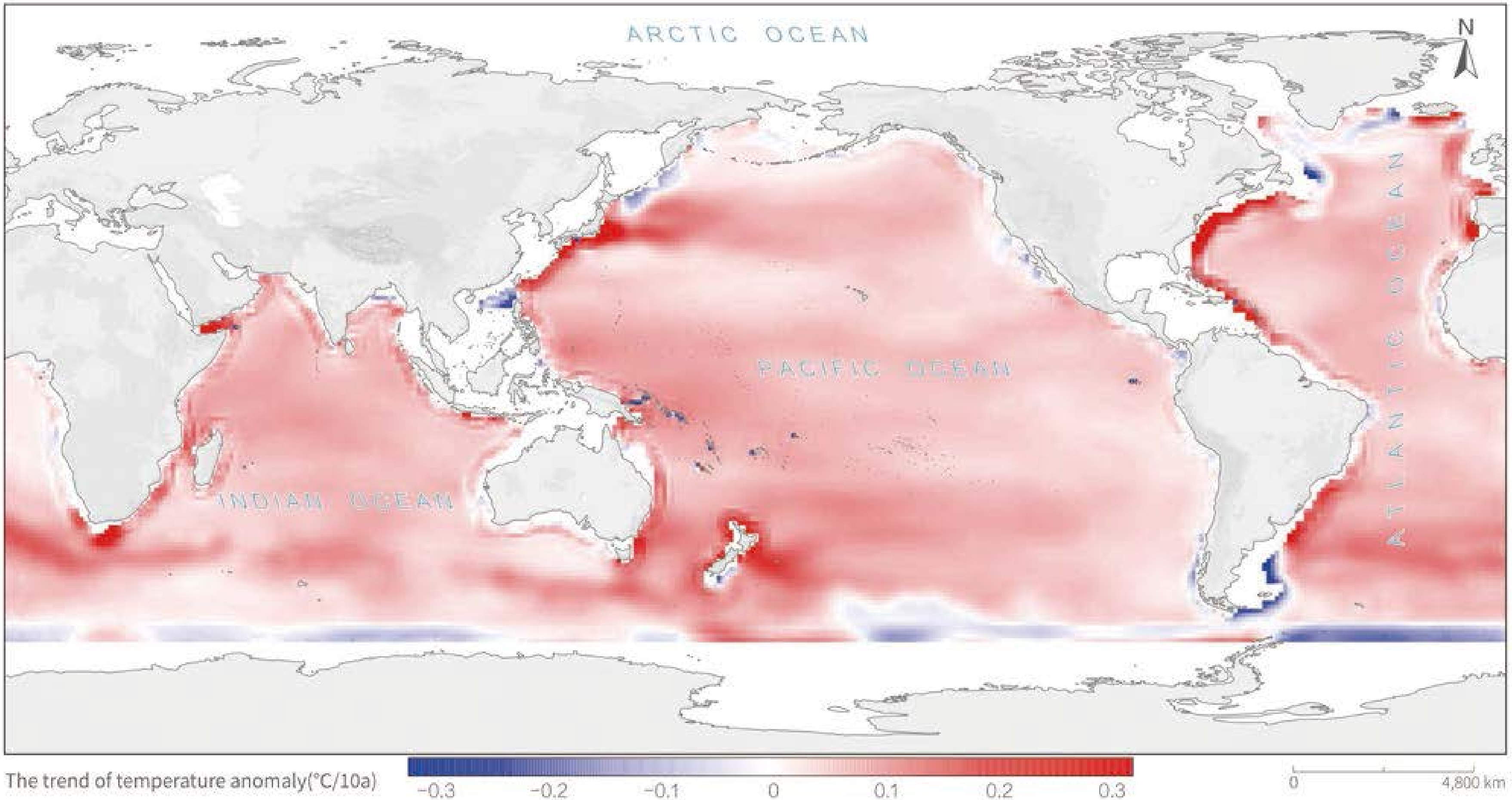


Figure 6-5. The trend of temperature anomaly in the upper 2,000 m of global ocean from 1993 to 2020 (Baseline: 1993-2012)

Global Terrestrial/oceanic Carbon Sink Estimation

With the rise of global average temperature and greenhouse gas concentration, the role of terrestrial and marine ecosystems in global carbon neutralization is worth studying. Terrestrial net ecosystem productivity (NEP) and partial pressure of carbon dioxide (pCO_2) in the surface seawater are important parameters for quantitative estimation of carbon sink intensity of terrestrial and oceanic ecosystems, but there is still great uncertainty in the relevant researches. Big earth data technologies have been fully explored to develop studies on the carbon sinks of the global terrestrial and oceanic ecosystems, and quantitatively analyze the spatiotemporal changes and drivers of these key parameters to support response to climate change with methods and data.

Variability of global ocean carbon budget in the recent three decades

Target: 13.2 Integrating climate change measures into national policies, strategies and planning.

A new machine learning method for the reconstruction of partial pCO_2 in surface ocean was established on the basis of self-organizing map (SOM) neural network and stepwise feedforward neural network algorithms (Zhong *et al.,* 2022). Based on the reconstructed monthly global 1°×1° gridded pCO_2 data, global ocean CO_2 flux was estimated to identify the variability of global ocean carbon budget in the recent three decades.

Asynchronous increases of surface ocean pCO_2 and atmospheric CO_2 concentration. As suggested by the inter-annual variability of surface ocean pCO_2 from 1992 to 2020 (Figure 6-6), global surface ocean pCO_2 increased as atmospheric CO_2 rose, but in an asynchronous manner. Since 2000, the former had increased more slowly than the latter, leading to an increasing sea-air pCO_2 difference across the interface. The surface ocean pCO_2 and its growth rate varied significantly in different regions. On the basin scale, the average surface ocean pCO_2 was the highest in the Indian Ocean and the lowest in the Arctic. The average growth rate of surface ocean pCO_2 was the highest in the Southern Ocean and the lowest in the Arctic. These differences caused the different carbon sink capacities across oceans.

Global ocean carbon sink had major fluctuations due to El Niño and La Niña events and continuously strengthened since 2008. The annual average global ocean carbon sink intensity from 1992 to 2020 was estimated to be 1.61 PgC/a, with the majority taking place in the temperate oceans and the subpolar North Atlantic Ocean while the equatorial Pacific was the leading carbon source (Figure 6-7).

The global ocean was overall a carbon sink in the recent nearly three decades. However, the ability of CO_2 uptakes has not been continuously strengthening along with the rising atmospheric CO_2, but been significantly fluctuating. The fluctuations were mainly in the Pacific Ocean, followed by the Southern Ocean. They were the result of El Niño and La Niña events on the equatorial Pacific carbon source. The enhanced upwelling in the eastern equatorial Pacific Ocean transported more deep waters with a high concentration of dissolved inorganic carbon to the surface, leading to the enhancement of the carbon source there and the corresponding weakening of the global ocean carbon sink. Since 2008, the continuously strengthening carbon sinks in the Indian Ocean, Atlantic Ocean, and the Southern Ocean drove expanded ocean carbon sink, which increased by 0.98 PgC/a to 2.22 PgC/a from 2008 to 2020.

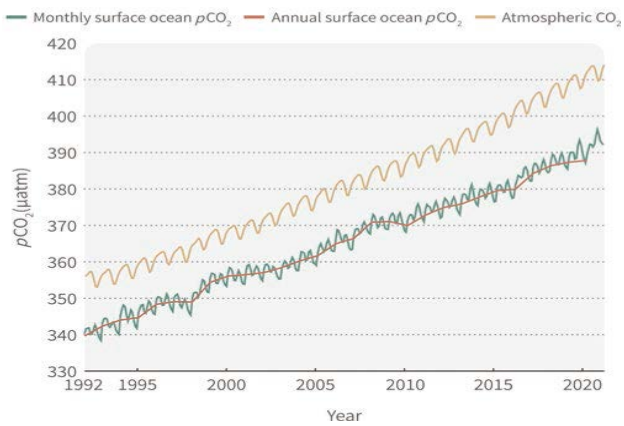


Figure 6-6. Variability of global surface ocean pCO_2 in the recent three decades

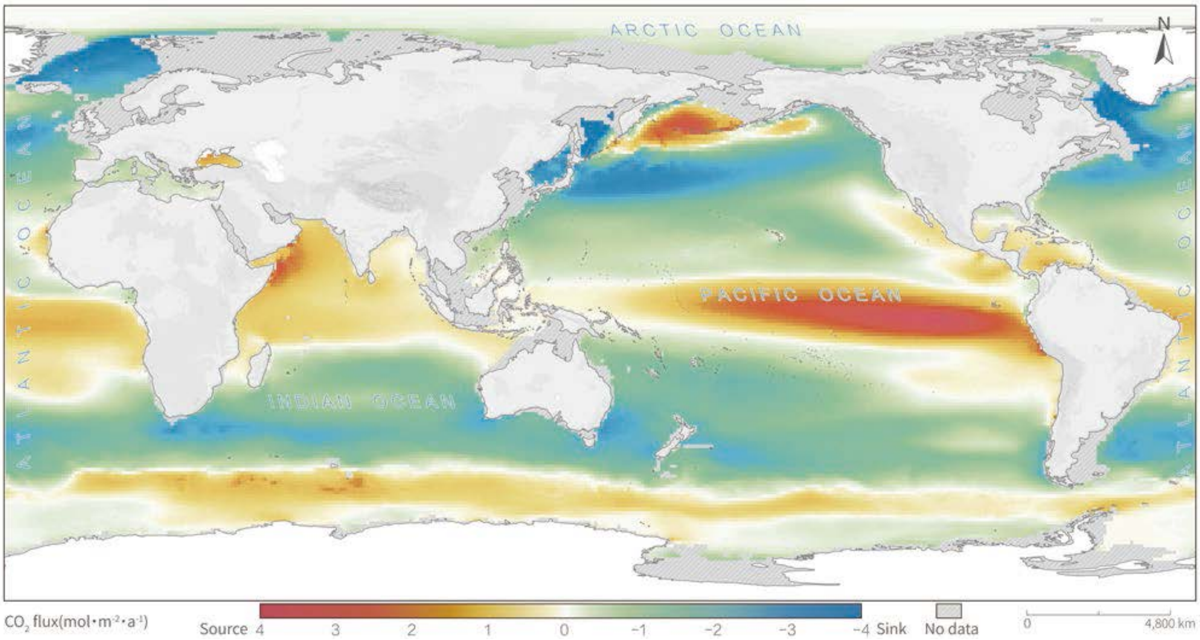


Figure 6-7. Average CO_2 flux of oceans from 1992 to 2020

Analysis of spatiotemporal changes of global terrestrial net ecosystem productivity from 2000 to 2020

Target: 13.2 Integrating climate change measures into national policies, strategies and planning.

First, the global terrestrial NEP was estimated by using a spatial big data-driven random forest model based on observation data from the global flux network and data of environmental factors affecting the spatiotemporal changes of NEP (Huang *et al.,* 2021). Then, the study produced global terrestrial NEP products for 2000 to 2020 with a spatial resolution of 1 km and without considering the impacts of logging, fire and other interference factors. Finally, the time change trend of NEP estimations was analyzed and tested, and the response of NEP to climate and land cover factors was analyzed with the partial correlation method.

High values of global terrestrial NEP from 2000 to 2020 were from tropical, subtropical and cold temperate forests. Obvious spatial variations exist in annual average of terrestrial NEP from 2000 to 2020 (Figure 6-8). Tropical NEP was the largest, accounting for 69.9% of the total global terrestrial NEP, followed by the temperate zone (20.6%), cold zone (7.8%) and polar regions (1.4%), and arid climate zone with the lowest NEP (0.3%).

The total global terrestrial NEP has been increasing significantly from 2000 to 2020. Global terrestrial NEP showed a significant trend of increase from 2000 to 2020 (0.05 PgC/a, $p<0.05$), with the largest increase in the tropical zone, followed by arid areas, temperate and cold zones. The NEP of the polar regions decreased, but the decrease was not statistically significant. The areas where NEP increased were larger than those that experienced decreases during the past 20 years. Areas with significant increase accounted for 22% of the total global terrestrial NEP while those with significant decreases accounted for only 10%.

The spatiotemporal changes of global terrestrial NEP were mainly affected by the increases in temperature and forest coverage. At the global scale, NEP showed a significant correlation with air temperature and forest coverage. Therefore, the increase of global terrestrial NEP during the recent 20 years was mainly due to the increases of global temperature and forest coverage. Through comparison and analysis of the partial correlation coefficient, it was found that NEP changes in tropical zone and arid areas were more affected by the climate factor, those in the polar climate zones were more affected by the land cover factor, and those in temperate climate zones were jointly affected by climate and land cover factors.

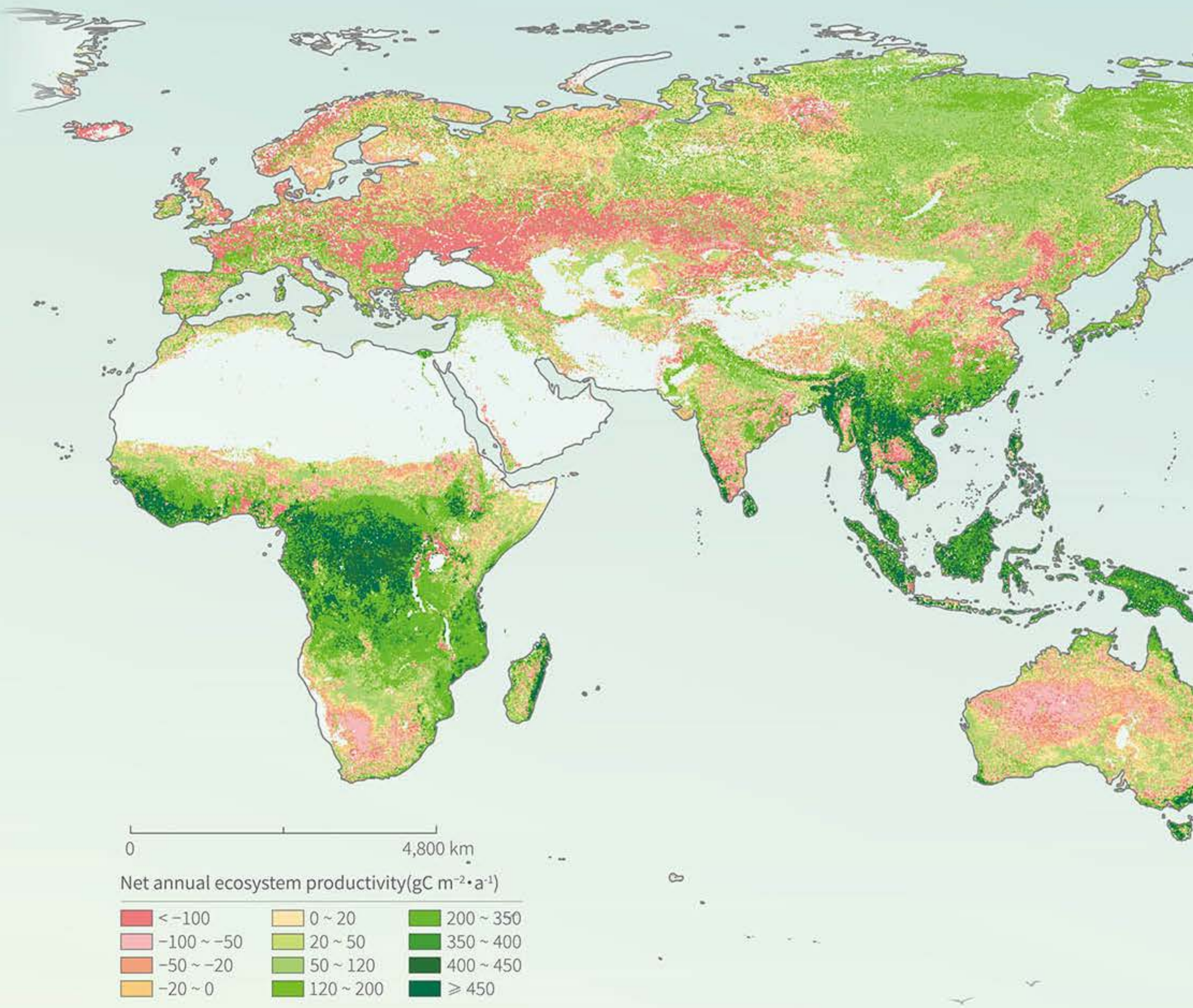
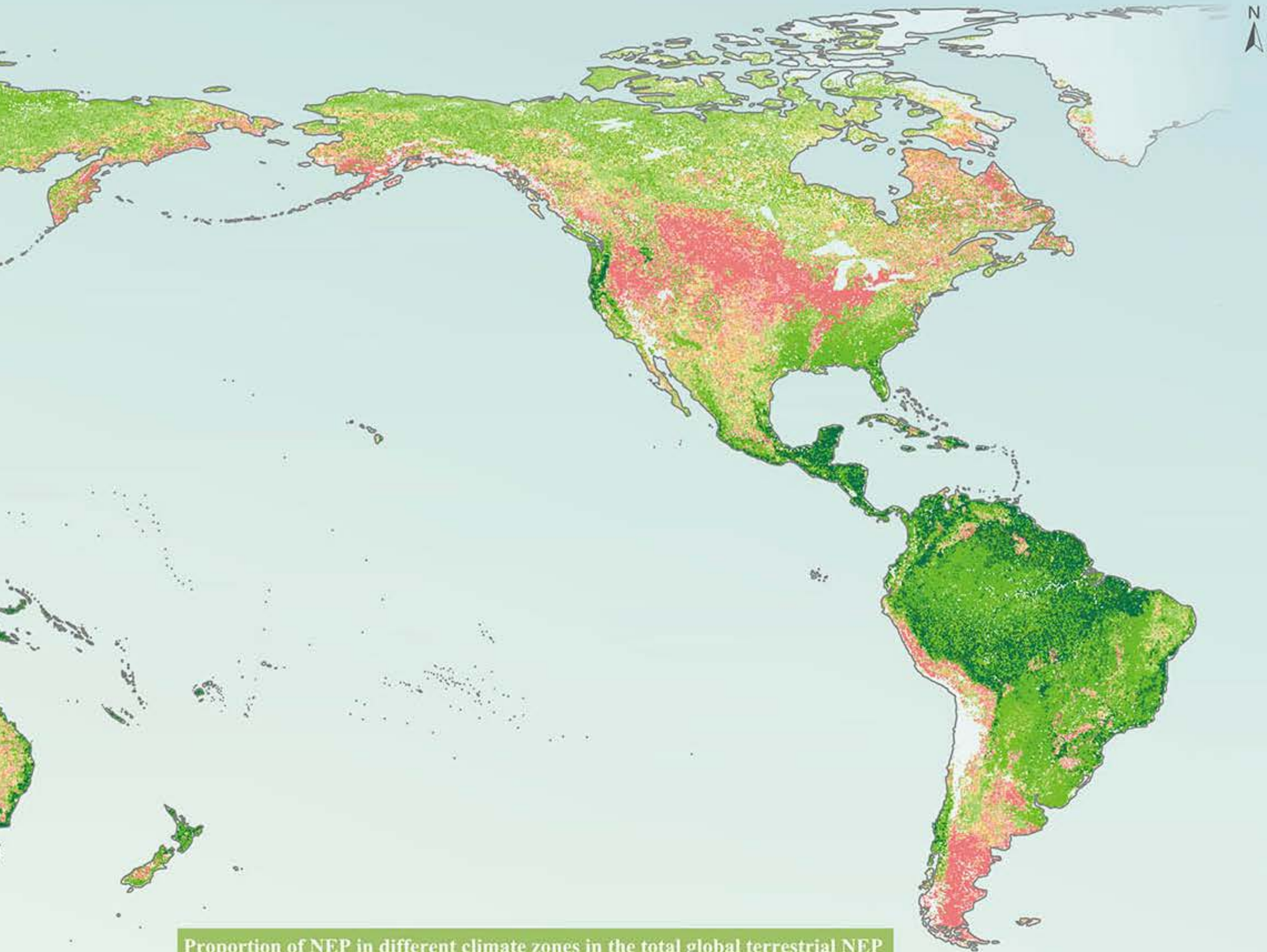


Figure 6-8.

Spatial variations of annual average terrestrial NEP from 2000 to 2020



Proportion of NEP in different climate zones in the total global terrestrial NEP

Climate zone	Proportion
Tropical zone	69.9%
Temperate zone	20.6%
Cold zone	7.8%
Polar region	1.4%
Arid region	0.3%

Climate Change Education

Enabling teenagers to voluntarily reduce their carbon footprint through climate change education is an important measure to implement the United Nations SDGs. Only by popularizing basic climate change knowledge among students and strengthening climate change education can we be better prepared to address the long-term challenges of climate change in the future.

A survey on climate change education in China

Target: 13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

China has all along been devoted to green development, taken proactive measures to advance its carbon peaking and neutrality objectives, and developed ecological civilization education basics supported by government policies and practised in schools in light of local and school conditions. To understand the state of climate change education in China in terms of policy, curriculum, teacher training and student evaluation, a questionnaire survey was conducted in May 2022 to assess the relevant teaching and learning, knowledge and actions, and future participation intention in basic education. Convenience sampling and the Internet were used to distribute and retrieve the questionnaire, with 3,675 valid responses from students in grades 7 to 9 and 486 from their teachers.

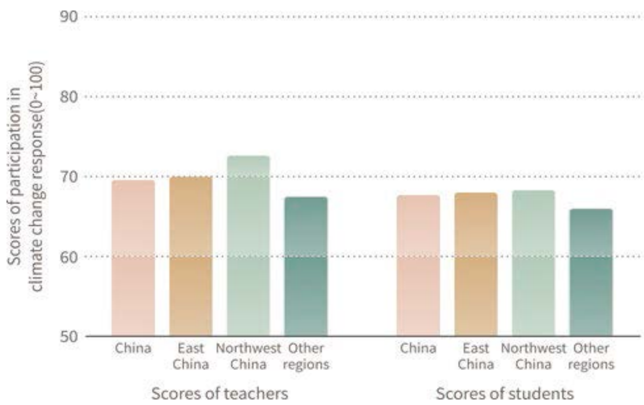


Figure 6-9. Scores of Chinese teachers and students participation in climate change assessment in 2022

Mass media and social networks are the primary channels for teachers and students to obtain climate change information. Most teachers in basic education had graduated from normal colleges and faced difficulty in understanding climate change knowledge. Students with strong learning motivation mostly rely on social media instead of classes to acquire climate change knowledge. Generally speaking, curriculum design and hands-on activities need improvement.

The natural and economic conditions of their home cities are a significant influencing factor for students and teachers. The average participation score (range from 0 to 100) is 69.6 for teachers in China, with the Northwest region registering the highest score of 72.6, followed by 70 points for East China and 67.5 for the rest regions. The average participation score of students is 67.7 (68.3 for Northeast, 68 for East and 66 for the rest). The difference test showed that the evaluation scores of teachers in Northwest China were relatively higher than those in other regions (Figure 6-9). Interviews with teachers and students in Gansu, Ningxia and other northwestern provinces revealed a greater sensitivity to and awareness about climate change and protection among the local teachers and students due to the existing harsh natural environment.

Improved policies and well-organized pedagogical resources are the key to strengthening climate change education. Teachers, as leading disseminators of knowledge, affect the outcome of climate change education negatively when they are not properly trained and lack teaching materials. Overall, although both teachers and students need to improve their knowledge and understanding of the climate action goal and its targets, they tend to have a high approval of the climate change agenda and act correspondingly in daily life.

Recommendations and Outlook

The chapter focuses on four themes of SDG 13 climate action, including disaster monitoring and reduction actions, long-term early warning for climate change, estimation of global land/ ocean carbon sinks, and climate change education. Progresses of four indicators under SDG 13, including disaster impact (SDG13.1.1), national disaster reduction strategy (SDG 13.1.2), local disaster reduction strategy (SDG 13.1.3), and climate change education (SDG 13.3.1) were monitored in China with the Big Earth Data method. Global climate change and carbon budget data products were generated in the studies to inform decision-making for climate action.

Based on the above studies, we offer the following recommendations:

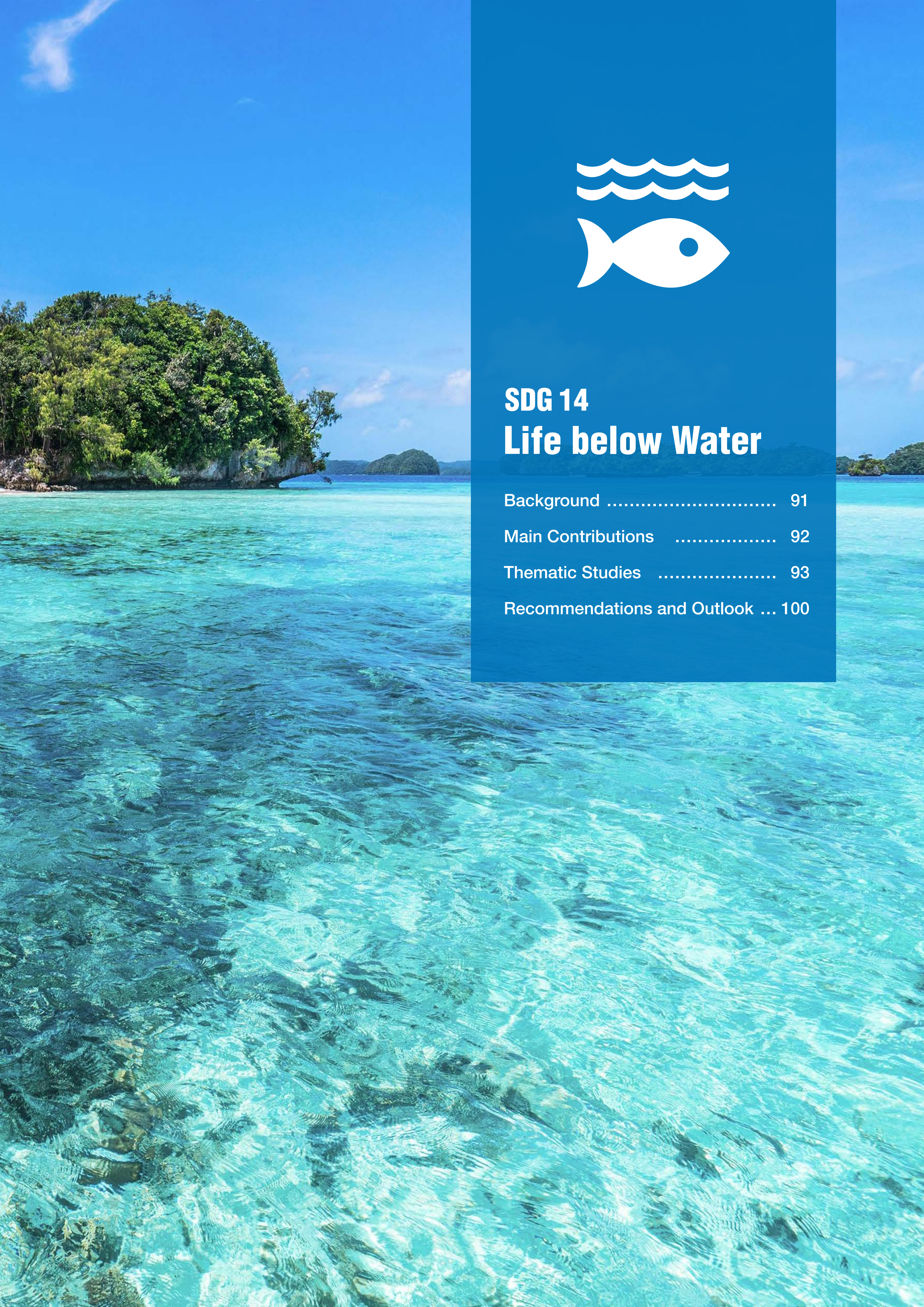
(1) Studies related to SDG 13.1.1, SDG 13.1.2 and SDG 13.1.3 showed that the area affected by water-logging in China in an extreme year was 2.6 times that in an average year and that the frequency and intensity of heat waves across lands in the world increased. Although China has established a relatively full-fledged disaster reduction system, much remains to be done to enhance preparedness for climate disasters in the near term and improve early warning for long-term changes. Disaster resilience must be enhanced, with additional scientific and technological means.

(2) The case studies relevant to greenhouse gas (SDG 13.2.2) showed that with global warming, increased forest coverage and higher atmospheric carbon dioxide concentration, the carbon sink capacity of the world's land and oceans is also increasing. On the one hand, these changes reflect the necessity of continued afforestation. On the other, we should not ignore the risk that the increase of marine carbon sink may lead to ocean acidification. In the future, we need to pay attention to systemic problems of land and marine ecosystem changes.

(3) For SDG 13.3.1, climate change and sustainable development education bears on our future but remains insufficient. It is essential to strengthen policy-making, develop resources for better curriculum design and teacher training, and further motivate students to engage in hands-on activities.

Big Earth Data demonstrated obvious advantages in monitoring the progresses of SDG 13 indicators. In the future, monitoring of greenhouse gases needs to be explored. Analysis of climate and sustainable development education via a sample survey may not be sufficient to reflect the reality of a super-large population. In the future, it is still necessary to explore new big data methods for greater sample universality.


SDG14



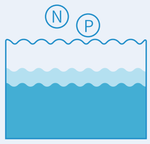
SDG 14

Life below Water

Highlights

Reduction of Marine Pollution

The concentration of nutrients in the coastal water of China has decreased significantly in the recent decade and more, and the reduction of terrestrial nitrogen and phosphorus input is the main reason for the decrease in the concentrations of dissolved inorganic nitrogen and dissolved inorganic phosphorus in China's coastal water.



Discharge of terrestrial nitrogen and phosphorus into the sea **reduced**

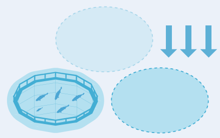
Protection of Marine Ecosystems

The median value of the typhoon protection and disaster relief function provided by the coastal wetlands was CNY 14.06 million/km^2; the China-ASEAN marine coral reef bleaching thermal environment warning system that has been developed provides strong scientific and technological support for countries in the region to understand the bleaching environment faced by coral reefs and formulate coral reef protection measures in a timely manner.

Develop for the China-ASEAN Seas
Thermal environmental warning system for coral reef bleaching

Protection of Coastal Areas

From 2010 to 2020, the pace of returning enclosures to sea and wetlands continuously accelerated in China's coastal areas. The average annual area returned from aquaculture enclosures was 3.72 km^2, 4.77 km^2 and 21.62 km^2 in the 2010-2015, 2015-2018 and 2018-2020 periods respectively, representing remarkable results in the control and management of land reclamation through returning enclosures to sea and wetlands.



Land reclamation control and management **achieved remarkable results**

Background

Covering 71% of the Earth's surface, the oceans are the largest ecosystems on Earth and home to more than 80% of the world's life. SDG 14, as part of the 2030 Agenda and its 17 transformative goals, emphasizes the need to conserve and sustainably use the sea and marine resources. Globally, however, the implementation of most of the SDG 14 targets has been unsatisfactory. The UN's *Second World Ocean Assessment* released in April 2021 reported that many pressures from human activities have continued to degrade the oceans since 2015, including important habitats such as mangroves and coral reefs (UN, 2021). In July 2022, the UN Ocean Conference adopted the Lisbon Declaration, calling for increased science and innovation-based action to address current ocean emergencies.

Derived mainly from large-scale marine scientific experimental devices with spatial properties, detection equipment, remote sensors, socioeconomic observations and computer simulation processes, Big Earth Data has become the 'new key' to our understanding of the oceans and the 'new engine' of knowledge discovery. In recent years, Chinese research institutions, universities and government departments have made great efforts and explorations by using Big Earth Data and its related technologies and methods to serve SDG 14 implementation, and have accumulated rich practical experience in the production of datasets and the construction of evaluation models.

In the past three years' reports, we conducted long sequential, dynamic monitoring and integrated assessments at the Chinese and typical regional scales for eutrophication in typical marine waters, offshore marine litter and micro-plastics, mangroves, typical bay ecosystem health, offshore rafting and coastal aquaculture ponds and other aspects. In this year's report, with a focus on the three themes of reducing marine pollution, protecting marine ecosystems and protecting coastal areas, we have further improved the monitoring methods for SDG 14 targets, built corresponding technical and modeling systems, and provided refined monitoring and assessment products, with a view to better promoting the achievement of SDG 14.

Main Contributions

This chapter evaluates the progress of SDG 14.1, SDG 14.2 and SDG 14.5 in China and its surrounding regions through six case studies. The main contributions are as follows (Table 7-1).

Table 7-1 Cases and Their Main Contributions

Theme	Target	Case	Contributions
Reduction of Marine Pollution	SDG 14.1	Analysis of long-term variations and trends of nutrient concentrations in coastal waters of China	**Data product:** Datasets on field observations of nutrient concentrations in the coastal waters of Eastern China from 1978 to 2019 **Decision support:** Provide information support for the prevention and control of eutrophication and comprehensive decision-making in China's coastal waters
		High-precision monitoring of green tide biomass in offshore China through remote sensing	**Data product:** Spatial and temporal datasets of green tide biomass in the Yellow Sea of China **Method and model:** A multi-source remote sensing inversion model of green tide biomass
Protection of Marine Ecosystems	SDG 14.2	High-precision dynamic monitoring of China's coastal tidal flats	**Data product:** 10 m resolution datasets of spatial distribution of China's coastal tidal flats in 2016 and 2020 **Method and model:** Automated tidal flat extraction using Maximum Spectral Index Composite (MSIC) and Otsu Algorithm
		Assessment of the value of China's coastal wetlands for typhoon protection and disaster reduction	**Data product:** Coastal wetlands' aggregated typhoon protection value datasets for 2010, 2015 and 2020 in China **Method and model:** A logarithm-transformed linear environmental economic model for valuing typhoon protection
		Thermal environmental monitoring and early warning of coral reef bleaching in China-ASEAN seas	**Data product:** Thermal environmental monitoring and early warning dataset for coral reef bleaching in China-Association of Southeast Asian Nations (China-ASEAN) seas **Method and model:** A computational model for the thermal environment of coral reef bleaching **Decision support:** Support environmental assessment, protection and policy development for coral reefs in marine areas
Protection of Coastal Areas	SDG 14.5	Dynamic monitoring on China's efforts to return enclosures to the sea and wetlands	**Data product:** 1:100,000 scale vector data products for 2010-2015, 2015-2018 and 2018-2020 for returning enclosures to the sea and wetlands in China's coastal areas **Decision support:** Support the assessment of the effectiveness of reclamation control and management

Thematic Studies

Reduction of Marine Pollution

With high population density and rapid economic development, China's coastal areas are facing serious challenges in the prevention and control of marine environmental pollution. The Chinese government attaches great importance to marine pollution prevention, control and management, and has introduced a series of relevant laws and regulations, laying a good foundation for the prevention and reduction of various types of marine pollution. The current monitoring data of SDG 14.1 on nutrient pollution are mainly reflected through the correlation values of chlorophyll a. Considering the complexity of eutrophication and the spatial and temporal distribution of nutrients in coastal waters of China, this theme provides a high-precision method for monitoring green tide biomass in coastal waters of China through Big Earth Data-based systematic analysis of the changes of nutrient concentration and structure over time and its controlling factors. It provides better support for the achievement of SDG 14.1 through the fine characterization of nutrients and green tide biomass.

Analysis of long-term variations and trends of nutrient concentrations in coastal waters of China

Target: 14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.

Based on the field measured concentration data of various species of nutrients in the coastal waters of Eastern China, the statistical data including the national fertilizer application amount, sewage discharge, sewage treatment rate and sewage total nitrogen and total phosphorus discharge from 1978 to 2019, an analysis is made on the long-term variations of nutrient concentrations through the method of linear regression and binomial regression. The global nutrient transport model (IMAGE-Global Nutrient Model, IMAGE-GNM) was used to comprehensively analyze the contributions to the total nitrogen and total phosphorus in China's coastal waters by external sources, including river input, atmospheric deposition and mariculture input, and their long-term variations.

The nutrient concentrations in Eastern China's coastal waters have decreased significantly in the recent decade and more. The long-term variation trend of different nutrients in the coastal waters of Eastern China shows that concentrations of dissolved

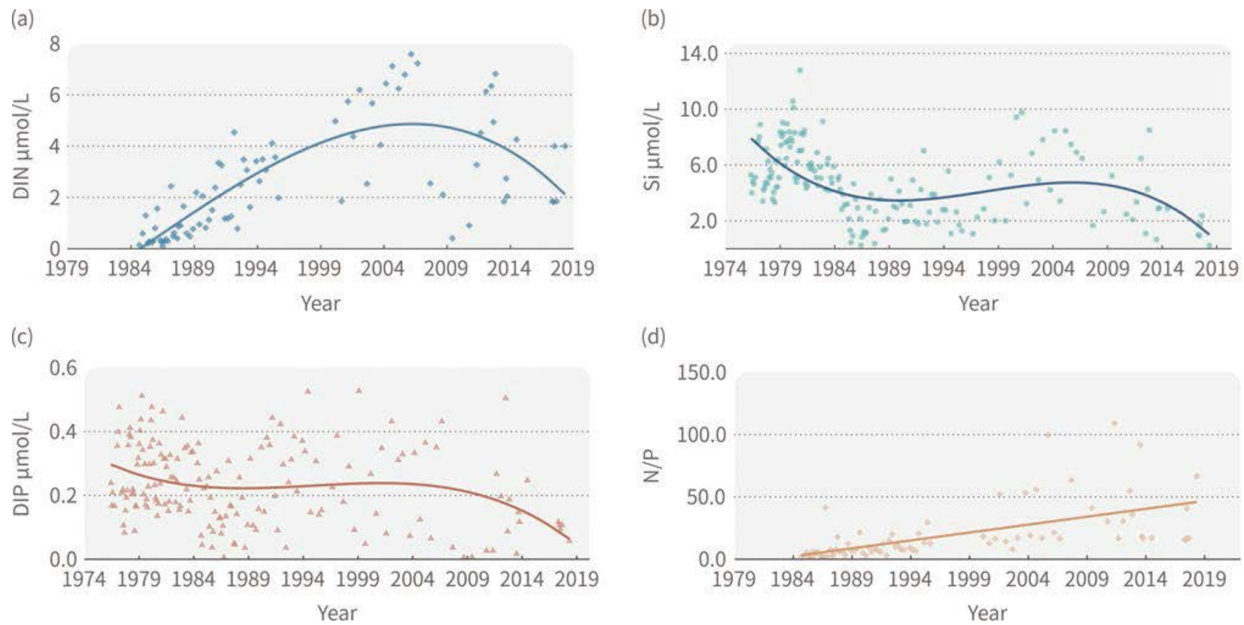


Figure 7-1. Long-term variation of nutrient concentrations in the Southern Yellow Sea

inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP) and silicate have decreased significantly in the recent decade and more. The N/P ratios have continuously increased, considerably higher than the Redfield ratio (N:P=16:1). Take the southern Yellow Sea for example, with the changes indicated by Figure 7-1.

The main reason for the decrease in nitrogen and phosphorus concentrations in the coastal waters of China is the reduction of the terrestrial nitrogen and phosphorus input. Based on the IMAGE-GNM model, a comprehensive analysis of the total nitrogen and total phosphorus contributions by external sources, including river input, atmospheric deposition and mariculture input, and their long-term variations shows that the concentrations and structure of nutrients in the coastal waters of China are highly correlated with terrestrial input, and river input is the most important among all external sources. A verification through the field measured data on the Yangtze River shows that the decrease of nitrogen and phosphorous input from the Yangtze River is consistent with the trend of decreasing concentrations of dissolved inorganic nitrogen and dissolved inorganic phosphorous in coastal waters of China, thus justifying the foregoing analysis. Over the past decade and more, China has followed the concept of green development and achieved certain reductions in chemical fertilizer application and slow increase in sewage discharge, with an over 95% sewage treatment rate (Figure 7-2a). In 2016, the national total nitrogen and total phosphorus discharge from sewage decreased by 1/2 and 4/5 respectively compared with that in 2015, and total nitrogen and phosphorus discharge from sewage have been relatively low and remained stable since 2016 (Figure 7-2b). The management of coastal waters of China nutrient pollution has been highly effective.

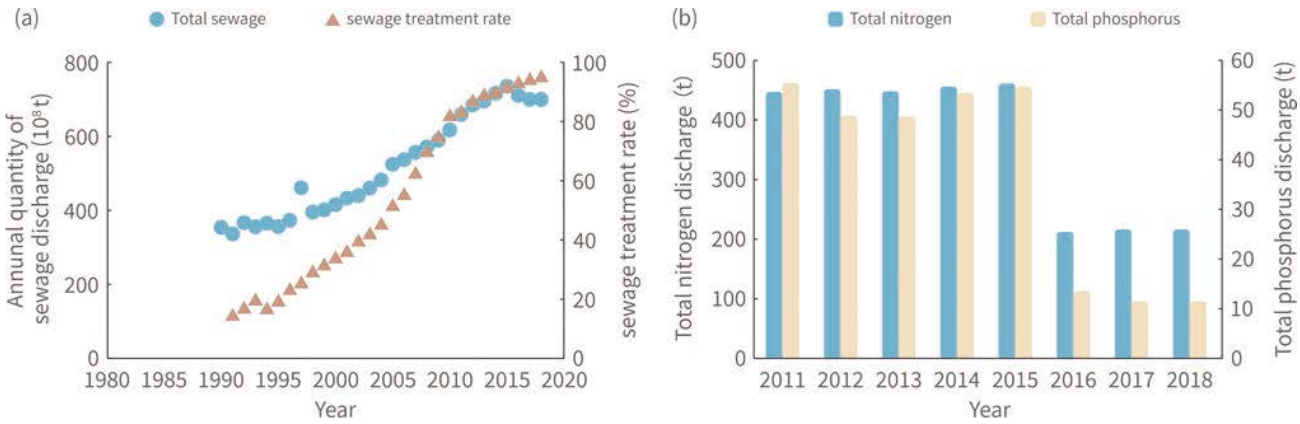


Figure 7-2. Interannual variations in China's annual sewage discharge, sewage treatment rate and total nitrogen and phosphorus discharge

High-precision monitoring of green tide biomass in offshore China through remote sensing

Target: 14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.

Green tide biomass is a key parameter to accurately describe the spatial and temporal distribution patterns and variations of offshore green tide disasters. Based on multi-source optical remote sensing data, such as China's HaiYang-1C/D (HY-1C/D) satellite data, this case proposes green tide biomass estimation models and methods applicable for different satellite data to produce high-precision remote sensing-based green tide biomass datasets, which can provide information support for accurate management of marine and coastal ecological environment.

Proposal of estimation methods for offshore green tide biomass applicable for remote sensing data with different spatial resolution. In light of the features of the optical remote sensing data, such as the Coastal Zone Imager (CZI) onboard China's HaiYang-1C/D (HY-1C/D) satellites, the MODIS onboard Terra/Aqua satellite of the United States, and the MultiSpectral Instrument (MSI) onboard Sentinel-2 satellites of the European Space Agency and based on the simulation of the green tide biomass variation and observed verification data, this case proposes optical remote sensing estimation models and calculation methods for green tide biomass that are applicable for different load data (Hu *et al.,* 2019; Lu *et al.,* 2019; Liu *et al.,* 2022). This method can effectively reduce the uncertainty in green tide monitoring results and the divergence of scale effect included in the area parameters and provide accurate reference for quantification and assessment of marine eutrophication (Figure 7-3).

Development of high spatial and temporal resolution green tide biomass data products. With coordinated monitoring based on CZI data and MODIS data from 2019 to 2021, a spatial-temporal data product for green tide biomass in offshore China has been produced. This product has not only high temporal resolution, but also fine spatial resolution, thus better reflecting the annual variation of green tide biomass in offshore China (Figure 7-4), and showing the spatial distribution pattern and variation trend of green tide biomass. In particular, the ability for capturing tiny patches of floating algae facilitates the fine observation of the process of the generation, extinction and movement of green tide, thus providing information support for monitoring and early warning of offshore green tide disasters.

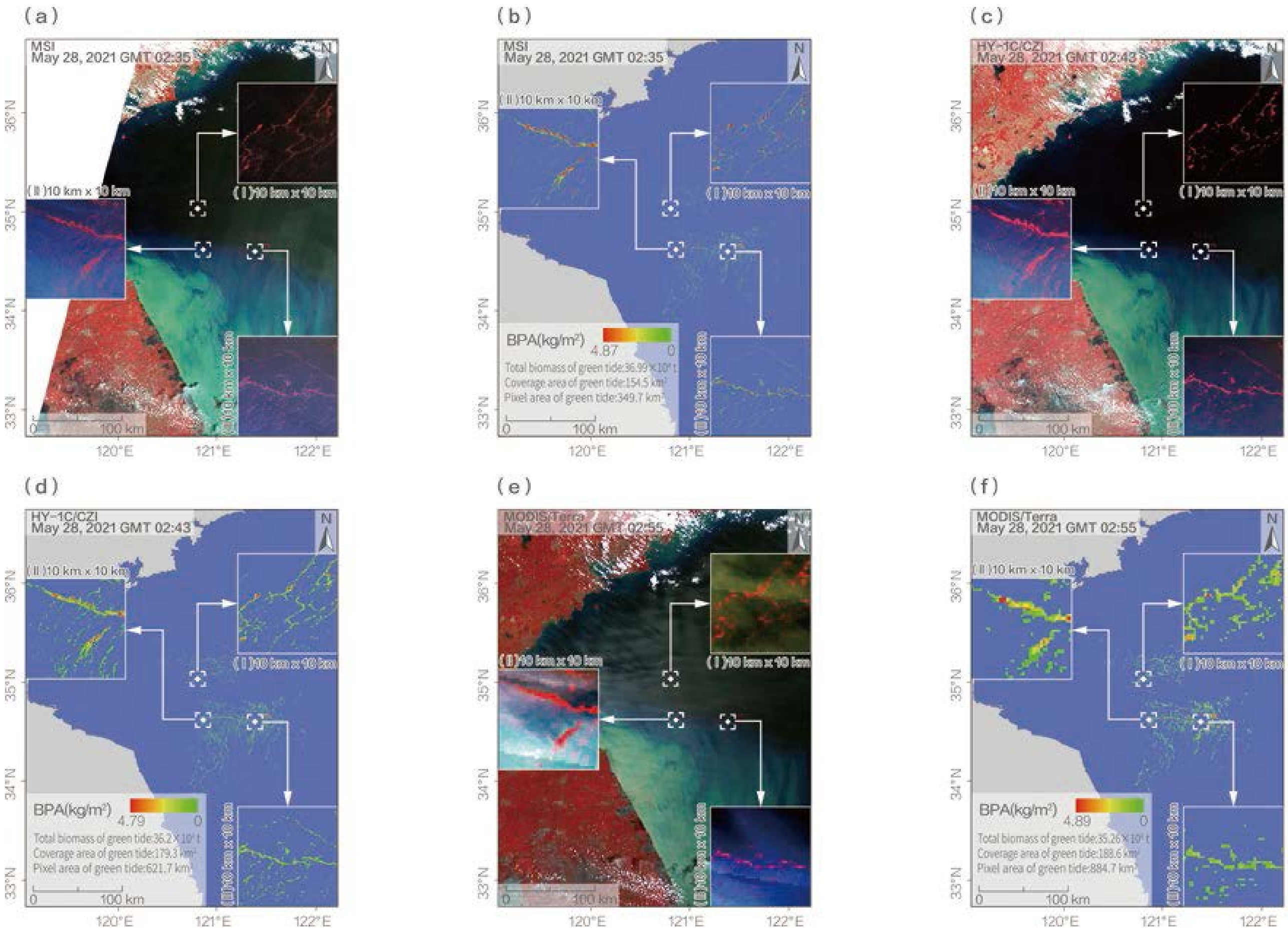


Figure 7-3. Quasi-synchronous false color composite images and distributions of green tide biomass per area (BPA) on 28 May 2021 covering the Yellow Sea of China (a) MSI false color composite image (R: 865 nm G: 665 nm B: 560 nm), (b) Distributions of green tide BPA derived from MSI data, (c) CZI false color composite image (R: 825 nm G: 650 nm B: 560 nm), (d) Distributions of green tide BPA derived from CZI data, (e) MODIS false color composite image (R: 859 nm G: 645 nm B: 555 nm), (f) Distributions of green tide BPA derived from MODIS data

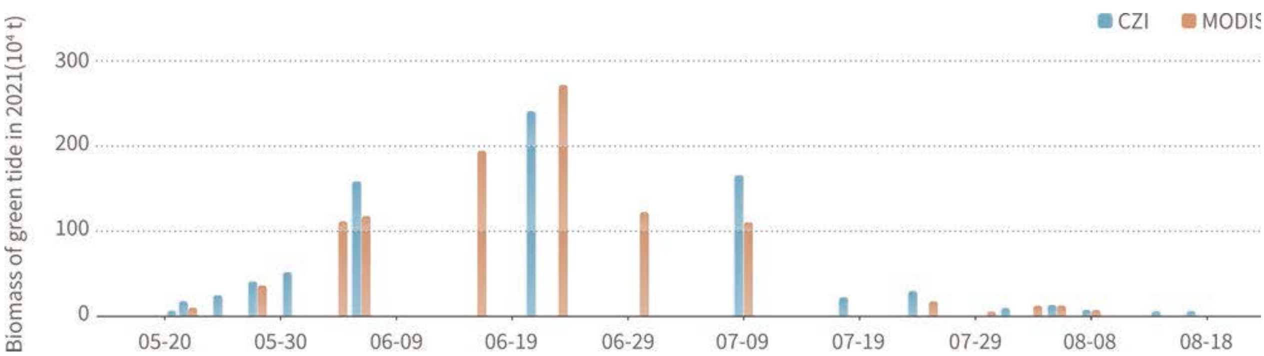


Figure 7-4. Coordinated monitoring of offshore China green tide biomass

Protection of Marine Ecosystems

The latest tier classification for the 2022 Global SDG Indicators shows that SDG Indicator 14.2.1 (the number of countries using ecosystem-based approaches to manage marine areas) is still in Tier II status (internationally established methodology and standards are available, but data are not regularly produced by countries). This section uses the Big Earth Data technology to compensate for the lack of monitoring data in order to achieve accurate monitoring and analysis of changes in typical marine ecosystems such as coastal mudflats, objectively assess the value of coastal wetlands for typhoon protection and disaster reduction, and provide monitoring and early warning for the thermal environmental elements that cause coral reef bleaching.

High-precision dynamic monitoring of China's coastal tidal flats

Target: 14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.

Tidal flats, including intertidal mudflats, rocks, and sands, are transition zones between marine and terrestrial environments. Not only do they provide unique ecosystem services, such as defending against storm surges, maintaining shorelines, filtering pollutants, and promoting carbon storage, they also serve as important habitats and breeding grounds for migrating birds, fishes and other marine wildlife. Carrying out accurate and full remote sensing monitoring of coastal tidal flats to obtain the high-precision dynamic monitoring data is a significant decision-making basis for the detailed management of coastal zones and the implementation of relevant SDGs.

Development of 10 m spatial resolution dynamic monitoring data products for China's coastal tidal flats with an accuracy of over 92%. Coastal tidal flats are defined as non-vegetated areas between the maximal and minimal tidal inundations, and the key to monitoring is to obtain the extent between the highest and lowest tides. Therefore, in this case, a fully automated extraction method for tidal flats based on the MSIC and the Otsu algorithm was constructed by use of 10 m resolution dense time series Sentinel-2 images as the data source. The method was used to develop, for the first time, high-precision dynamic monitoring data products for China's coastal tidal flats with a spatial resolution of 10 meters. Based on the error matrix derived from ground survey samples and sub-meter high resolution images for validation, the overall classification accuracy of China's coastal tidal flats monitoring in 2016 and 2020 was 92% and 94% respectively.

Varying trends of the areas of tidal flats in coastal provinces (autonomous regions and municipalities) from 2016 to 2020. The coastal tidal flats in China are widely distributed around various estuaries, with larger areas of tidal flats located at the estuaries of the Liao River, Hai River, Yellow River, Yangtze River and Pearl River. In 2020, Jiangsu Province had the largest tidal flats area (about 24% of China's total coastal tidal flats area), followed by Shandong and Liaoning, the three together accounting for about 50% of the total coastal tidal flats in China. The coastal tidal flats in Jiangsu Province have a large patch area and great seaward depth, while in Fujian there are many bedrock shorelines and tidal flats appear in narrow and small patches along the coasts (Figure 7-5). In different coastal provinces (autonomous regions and municipalities), the changes in the areas of coastal tidal flats varied from 2016 to 2020. The tidal flat patches along the coasts of Shandong, Guangdong, Hainan, Liaoning, Taiwan and Fujian slightly shrank, while the coastal tidal flat patches in Zhejiang, Jiangsu, Guangxi, Tianjin, Hebei and Shanghai slightly increased.

↑ Figure 7-5. Spatial distribution of coastal tidal flats in China in 2020

SDG 14

Assessment of the value of China's coastal wetlands for typhoon protection and disaster reduction

Target: 14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.

A logarithm-transformed linear environmental and economic model (Costanza *et al.,* 2021; Liu *et al.,* 2019) was built, based on a series of datasets including the national Land-Use and Land-Cover Change (Land Use/Cover Change, LUCC) and long sequential (1989-2020) typhoons, economic damage, population and GDP. The proposed model to evaluate the typhoon protection and ecological service functions provided by coastal wetlands per unit area, including rivers, lakes, reservoirs, ponds, tidal flats, beaches and marshes in the LUCC. Integrating the annual frequency of typhoons hitting China's coasts, the model was used for estimating the annual economic value of coastal wetlands for defense against typhoons, protection of properties and reduction of disaster-related losses nationwide.

The median value of China's coastal wetlands for typhoon protection and disaster reduction estimated to be CNY 14.06 million/km^2. Coastal wetlands provide significant social benefit and economic value for mitigating damages of typhoons. In the context of global climate change, in particular, as extreme weather events become more frequent and there are more and stronger typhoons landing China, coastal wetlands will play an even bigger role in ecological service, such as typhoon protection and disaster mitigation. The log-linear environmental and economic model based on the 138 typhoons hitting China's coasts and causing economic losses in the past 30 years showed that the coefficient of coastal wetlands is negative and significant, which demonstrated that coastal wetlands played a positive role in defending against typhoons and mitigating economic damages caused by disasters. That is, the bigger the area of coastal wetlands in the typhoon-hit regions, the less relative economic losses caused by typhoons. The marginal value of the typhoon protection and ecological service function of coastal wetlands varied with the intensity of typhoons, with a median of CNY 14.06 million/km^2.

Continuous increase in the service value of China's coastal wetlands for typhoon protection in 2010, 2015 and 2020. Although the frequency and intensity of typhoons hitting China increased from 2010 to 2020, the direct economic losses from the typhoons decreased. This is closely related to the fact that with increasingly recognized value and thanks to stronger protection efforts, China's coastal wetlands have played an important role in defending against typhoons and mitigating disasters. Taking into account the frequency of typhoons landing China's coasts, it was estimated that the service value of China's coastal wetlands for defending against typhoons was CNY 92.69 billion in 2010, rose to CNY 211.9 billion in 2015 and hit CNY 295.97 billion in 2020 (Figure 7-6).

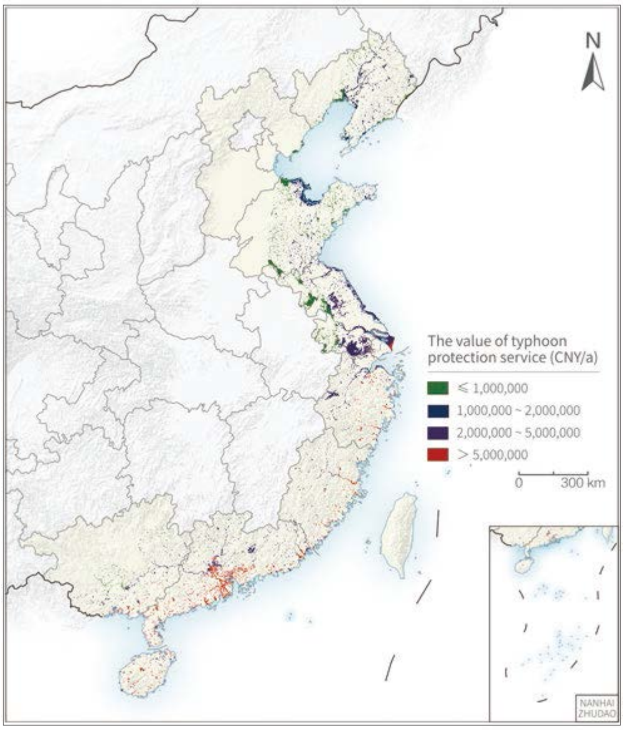


Figure 7-6. Distribution of the service value provided by China's coastal wetlands for defense against typhoons in 2020 (Note: no data for Hong Kong, Macao and Taiwan)

SDG 14

Thermal environmental monitoring and early warning of coral reef bleaching in China-ASEAN seas

Target: 14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.

Coral reefs are one of the most important marine ecosystems in the world, supporting hundreds of thousands of marine species and providing food and income for hundreds of millions of people (Burke *et al.,* 2011). In the context of global warming and ocean acidification, coral reef bleaching in the ocean is gradually intensifying along with the increasingly frequent and intense phenomenon of extreme heat in the oceans. The China-ASEAN seas is a core area of coral reefs in the world, with the richest coral reef ecology. Field observation data over the years have shown that coral reef bleaching in this area is grave. This case, through satellite observation of sea surface temperatures and ocean numerical model products, produced a coral reef bleaching thermal environment dataset and built a real-time online thermal environment warning system for coral reef bleaching in China-ASEAN seas.

Development of a 3D coral reef bleaching thermal environment calculation method by integrating satellite monitoring and ocean reanalysis data. Using the satellite-monitored sea surface temperature (SST) data and the reanalyzed ocean temperature data products from the wave-tide-circulation Coupled Ocean Model developed by the First Institute of Oceanography, Ministry of Natural Resources of China, the 3D coral bleaching thermal environment parameters in China-ASEAN seas were calculated, and with coral bleaching heat stress hot spot and coral bleaching heat stress degree heating week, the daily average coral reef bleaching risk classification was formed. This method can comprehensively analyze the environmental conditions of coral reef bleaching in the studied areas and provide a scientific basis for a comprehensive grasp of the thermal environmental conditions of coral reef bleaching.

Development of a thermal environmental warning system for coral reef bleaching in the China-ASEAN seas as strong information support for regional coral reef environmental evaluation and protection. Through the above method, a real-time early warning system for coral reef bleaching thermal environment in China-ASEAN seas (http://144.123.38.62:2018/#/) was developed, thus achieving real-time assessment and forecast for coral reef bleaching thermal environment (Figure 7-7 and Figure 7-8). The system has been connected to the official website of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) Sub-Commission for the Western Pacific, providing real-time daily early warning updates for coral reef bleaching thermal environment in China-ASEAN seas. It serves as strong scientific and technological support for regional countries to gain timely understanding of the bleaching environment faced by coral reefs and formulate measures for coral reef protection. Since the system was launched, it has received positive feedback from countries like Thailand, Malaysia and Cambodia, and has become a platform for cooperation in promoting the development, research and protection of coral reef resources in the region.

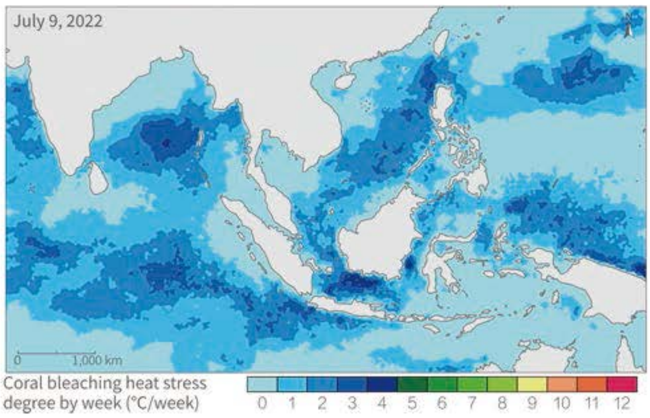


Figure 7-7. Thermal environmental warning system for coral reef bleaching in China-ASEAN seas (weekly heat on July 9, 2022)

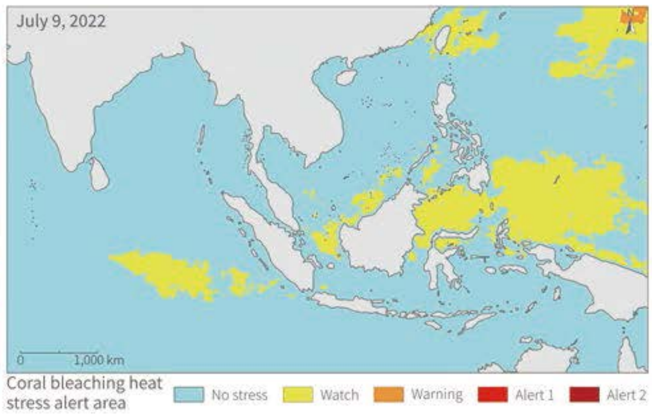


Figure 7-8. Thermal environmental warning system for coral reef bleaching in China-ASEAN seas (bleaching heat stress alert area on July 9, 2022)

SDG 14

Protection of Coastal Areas

Along with the continuous development of the marine economy, the exploitation and use of marine and coastal spatial resources have increased significantly in scale and extent, bringing certain negative impacts on the coastal belt environment and ecosystems, which has attracted much attention from the international community. This section details the dynamic monitoring on China's efforts to return enclosures to the sea and wetlands through the Big Earth Data technology system, demonstrating the effectiveness of the measures to promote the coordinated development of land and sea and strengthen the management of reclamation in China.

Dynamic monitoring on China's efforts to return enclosures to the sea and wetlands

Target: 14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information.

The spatial distribution of measures to return enclosures to the sea and wetlands in coastal China for the periods of 2010 to 2015, 2015 to 2018 and 2018 to 2020 was acquired on the basis of multiple phases of Landsat TM/OLI 30 m resolution multispectral satellite images and supplementary data such as the spatial distribution of coastlines, and with the man-machine interactive interpretation method. In the process of remote sensing interpretation, early remote sensing images of mariculture breeding ponds and other enclosures that turned into later remote sensing images of seas, tidal flats, mangrove wetlands and other natural terrains are classified as measures to return enclosures to the sea and wetlands (Figure 7-9).

Continuous acceleration of the pace of returning enclosures to the sea and wetlands in coastal China from 2010 to 2020. The annual average area returned from mariculture breeding enclosures in coastal China was about 3.72 km^2 from 2010 to 2015, 4.77 km^2 from 2015 to 2018 and 21.62 km^2 from 2018 to 2020. From 2010 to 2020, the pace of returning mariculture enclosures to the sea and wetlands consistently increased. The 2018-2020 period registered the largest area returned from mariculture enclosures, accounting for 56.77% of the total from 2010 to 2020 (Figure 7-10).

During the 2010-2015 and 2015-2018 periods, the Bohai Sea and the Yellow Sea registered more area returned from mariculture enclosures, together accounting for 83.29% and 85.37% of the two periods respectively. From 2018 to 2020, the area returned from mariculture enclosures increased notably in all seas, with the largest returned area in the Eastern Sea at 21.40 km^2, followed by the Bohai Sea at 12.31 km^2, respectively accounting for 49.49% and 28.48% of the total returned area in the same period.

China's notable progress in coastal reclamation control and management. The Chinese government has always attached much importance to coastal reclamation control and management. The *Notice of the State Council on Strengthening Coastal Wetlands Protection and Strictly Controlling Reclamation* issued in 2018 requires adherence to the strictest ecological and environmental protection system with a commitment to prioritizing ecology and green development, ending the approach of "land reclamation", strictly control new reclamation, strengthen ecological protection and restoration, and achieve strict protection, effective restoration and intensive use of marine resources, promotion of "blue bays" and gradual restoration of the damaged coastal wetlands through returning enclosures to the sea, returning breeding grounds to tidal flats and returning reclaimed farmlands to wetlands. The series of remote sensing monitoring showed that the pace of returning enclosures to the sea and wetlands significantly quickened from 2018 to 2020 and China achieved notable progress in reclamation control and management.

Figure 7-9. Example of remote sensing monitoring of measures to return enclosures to the sea and wetlands

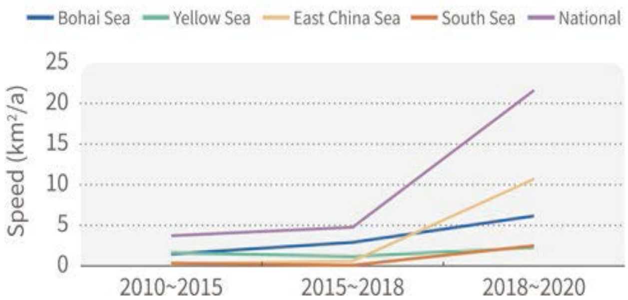


Figure 7-10. Pace variations of measures to return enclosures to the sea and wetlands in coastal China from 2010 to 2020 monitored through remote sensing

14 LIFE BELOW WATER

Recommendations and Outlook

In this chapter, we carried out monitoring on underwater biological indicators from the three aspects of reducing marine pollution, protecting marine ecosystems and protecting coastal areas, and developed relevant case studies at Chinese and regional scales. Compared with the previous three years' reports, we have systematically carried out monitoring of nutrient pollution and green tide hazards in China's coastal waters, and expanded the thematic studies on typical marine ecosystems in China and surrounding regions. We have also conducted a dynamic analysis of the status of restoring enclosures to the sea and wetlands in China.

Based on the above studies, we offer the following recommendations:

(1) For SDG 14.1 of reducing various types of marine pollution, the study shows that the key payloads of China's ocean color satellites have the advantages of large coverage, high spatial resolution and high temporal phase observation technology, which can provide information support for accurate management of marine and coastal ecological environment, and thus can subsequently be disseminated and applied globally and regionally.

(2) For SDG 14.2 of sustainable management and protection of marine ecosystems, the study shows that the technologies and methods related to Big Earth Data can play an important supporting role in the dynamic monitoring and early warning services for typical marine ecosystems such as mudflats and coral reefs. Follow-up, consideration can be given to refining and adding some indicators for monitoring and assessing typical marine ecosystems under 14.2 to solve the current problem of missing monitoring data.

(3) For SDG 14.5 of protecting coastal and marine areas, the study shows that regional development strategies and control measures play an important role in promoting coastal protection and restoration. Follow-up, studies can focus on on the relationship between the implementation of policies and regulations and the realization of SDG 14.5, exploring how to build a policy and institutional system that combines zoning control, categorized control and tiered control to promote better protection of coastal and marine areas.

In the future, we will continue to improve the sharing and application capacity of Big Earth Data in the field of sustainable marine development, and promote timely sharing and dissemination of data and knowledge by building data sharing platforms, online computing platforms and data service platforms to enhance the development of the blue economy and innovation of marine science and technology.


Sustainable Development Science Satellite 1 (SDGSAT-1)


SDG15

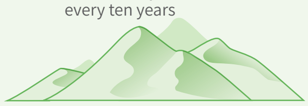
SDG 15
Life on Land

Highlights

Combating Desertification and Land Degradation

China has achieved remarkable results in land degradation management, with rapid progress in land degradation monitoring, early warning and management capabilities. From 2000 to 2020, the average ten-year growth rate of fixed sand dunes (lands) in China was 13.47%, higher than the global average (9.90%); carbon sink potential by desertification control increased 578.7 million tons in China from 2005 to 2019, with notable carbon sink effect of desertification control; the high-risk area of degradation accounted for about 11.70% of black soil in Northeast China, and it is urgent to strengthen protection to prevent degradation; the tool underpinned by big data for building the Great Green Wall of Africa provided effective support for desertification control in Africa, which has been recognized by the Pan Africa Agency of the Great Green Wall, the United Nations and the Chinese government.

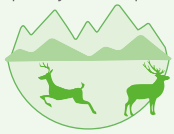
2000-2020
Fixed sand dunes (lands)
increased by **13.47%**
every ten years



Protecting Mountain Ecosystems

A large proportion of mountain ecosystems in China are under protection, with their spatial distribution to be further optimized. China's mountain protected areas provide important natural habitats for about 2/3 of the wildlife under priority national protection and cover 87% of ecosystem types in mountainous areas under priority protection. The conservation practice in these protected areas has informed a series of conservation strategies.

Mountain protected areas in China provide important habitats for about **two-thirds** of priority wildlife species



Prevention, Control and Management of Invasive Alien Species

China has achieved remarkable outcomes in the prevention and control of major invasive alien species. The distribution of 71 invasive alien species in China shows a decreasing trend from the southeast coast to the northwest inland. The main invasive alien species, such as smooth cordgrass and ragweed, have been effectively controlled, and formed a series valuable prevention and control technology system.

71 invasive alien species showed **a decreasing trend** from the southeast coast to the northwest inland

Background

Nature and its vital contributions to humankind are collectively embodied in biodiversity as well as ecosystem functions and services, but they are deteriorating worldwide. Since the UN Sustainable Development Goals were introduced seven years ago, there are unprecedented pressures and opportunities to protect terrestrial ecology, with the acceleration of direct and indirect drivers of change. For example, global forest area (SDG 15.1.1) is still declining (FAO, 2020), about 75% of the world's land is still degraded (SDG 15.3.1) (IPBES, 2019), and the proportion of globally important biodiversity sites under protection has increased (SDG 15.1.2, SDG 15.4.1), but the Red List Index (SDG 15.5.1) continues to decrease (UNEP, 2021a), and at the current rate, it will be difficult to achieve SDG 15 by 2030 (UN, 2019).

For better implementation of SDG 15, scientific, credible, independent and up-to-date assessments on SDG progress and the drivers behind it are urgently needed to improve evidence-based decision-making and actions at the national, regional and global levels. With improved data availability and technical methodologies, 8 of the 14 indicators covered by SDG 15 are in Tier I (with methods and data). However, the methods for obtaining data on these indicators are primarily statistical, lacking scalability across scales, and many countries less capable of data acquisition are unable to provide data on a regular basis. Moreover, ecosystem change is influenced by the interaction of multiple factors at multiple scales. Accurate portrayal of its status, changes and drivers requires the support of advanced technical tools such as big data.

In the past three years, we have conducted Chinese and global scale analyses on forest conservation and restoration, land degradation and restoration, mountain ecosystem conservation, and important species habitats. In this year's report, we focus on three themes – combating desertification and land degradation, protecting mountain ecosystems, and prevention, control and management of invasive alien species. We have conducted assessments at different scales to develop a series of data products and decision support tools for SDG 15 key indicators, providing important support for global implementation of SDG 15 and other goals.

15 LIFE ON LAND

Main Contributions

This chapter evaluates the progress of SDG 15.3, SDG 15.4 and SDG 15.8 in China and globally through six cases. The main contributions are as follows (Table 8-1).

Table 8-1 Cases and Their Main Contributions

Theme	Target	Case	Contributions
Combating Desertification and Land Degradation	SDG 15.3	Dynamic monitoring on global sand dunes (lands)	**Data product:** Global 30 m sand dunes (lands) distribution and change data products for 2000, 2010 and 2020, with overall accuracy greater than 80% **Decision support:** The average ten-year growth rate of fixed sand dunes (lands) in China is 13.47%, higher than the global average (9.90%)
		Carbon sink effect of desertification control in China	**Decision support:** Carbon sink effect of desertification control is notable, and carbon sink potential increased by 578.7 million tons by desertification control in China from 2005 to 2019
		Status and risk assessment of black soil degradation in Northeast China	**Model and method:** Early warning indicator system for degradation of northeastern black soil **Decision support:** Identify the spatial distribution of erosion rate of northeast black soil, the erosion camp force is dominated by wind in the west and water in the east. High-risk area of degradation accounted for about 11.7% of northeast black soil
		The Great Green Wall of Africa supported by Big Earth Data	**Data product:** First intercontinental-scale 30 m spatial resolution land productivity dynamics product from 2013 to 2020 of Pan Africa Agency of the Great Green Wall member countries **Decision support:** The Great Green Wall Big Data Facilitator (GGW-BDF) online tool provides important support for land degradation monitoring, reporting and control in Africa
Protecting Mountain Ecosystems	SDG 15.4	Assessment of conservation status of mountain biodiversity in China	**Decision support:** Mountain protected areas provide important natural habitats for about two-thirds of the national priority wildlife species and cover 87% of the priority ecosystem types protected in mountains, providing reference for relevant departments in formulating conservation strategies
Prevention, Control and Management of Invasive Alien Species	SDG 15.8	Risk assessment, control and management of invasive alien species	**Data product:** Spatial distribution map of spreading risks of major invasive alien species in China

Thematic Studies

Combating Desertification and Land Degradation

Land degradation is a global challenge. *Global Land Outlook 2* released in 2022 stressed that as much as 40% of global land has been degraded, directly affecting half of the world population and posing a threat to about half of the global GDP (USD 44 trillion) (UNCCD, 2022). Combating desertification and land degradation stands at the center of SDG 15.3. Achieving land degradation neutrality by 2030 has been fully accepted and recognized by the international community, for which monitoring is a prerequisite if we are to realize this goal. At present, monitoring on land degradation neutrality still faces many challenges, such as monitoring with low spatial and temporal resolution, scanty indicators, poor representativeness, and monolithic benefit monitoring, especially in developing countries. Leveraging Big Earth Data, we explored the dynamic monitoring on global sand dunes (lands) in medium and high resolution, established a localized land degradation assessment system for black soil in Northeast China, evaluated the carbon sink effect of desertification control in China, and developed an online tool supported by big data for combating land degradation in Africa, with a view to providing new data and new means to solve the above challenges.

Dynamic monitoring on global sand dunes (lands)

Target: 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.

Few studies focused on monitoring global sand dunes (lands) with remote sensing techniques, resulting in a lack of comparable, high-resolution, and global-scale data products. By extracting the spectra, spectral indexes, multi-temporal NDVI, texture, topography and multi-source mapping features from satellite remote sensing data, multi-source land surface mapping products, and land cover sample sets, this study presents the methods for mapping high resolution and global-scale sand dunes and generating high-quality multi-temporal samples for the mapping. The global sand dunes (lands) datasets (Figure 8-1) at 30 m resolution for 2000, 2010, and 2020 were hence developed, with overall classification accuracy higher than 80%.

Global sand dunes (lands) accounted for 6.83%-6.95% of total land area. Shifting sand dunes (lands) occupied the largest area, followed by semi-fixed sand dunes (lands), while the area of fixed sand dunes (lands) was the smallest. Among the six continents (excluding Antarctica), Africa had the largest area of sand dunes (lands), accounting for 18.42%-18.67%. Asia was ranked second (6.14%-6.34%). Oceania had the highest area proportion of sand dunes (lands), reaching 19.80%-20.09%.

Conversion from semi-fixed to fixed sand dunes (lands) was the main trend. Area of shifting sand dunes (lands) fluctuated slightly, with an increase of 0.37% from 2000 to 2010 and a decrease of 0.63% from 2010 to 2020; area of semi-fixed sand dunes (lands) decreased by 2.16% and 1.70%; and area of fixed sand dunes (lands) increased by 8.39% and 11.42% in the two periods. The average ten-year growth rate of fixed sand dunes (lands) in China was 13.47%, higher than the global average (9.90%).

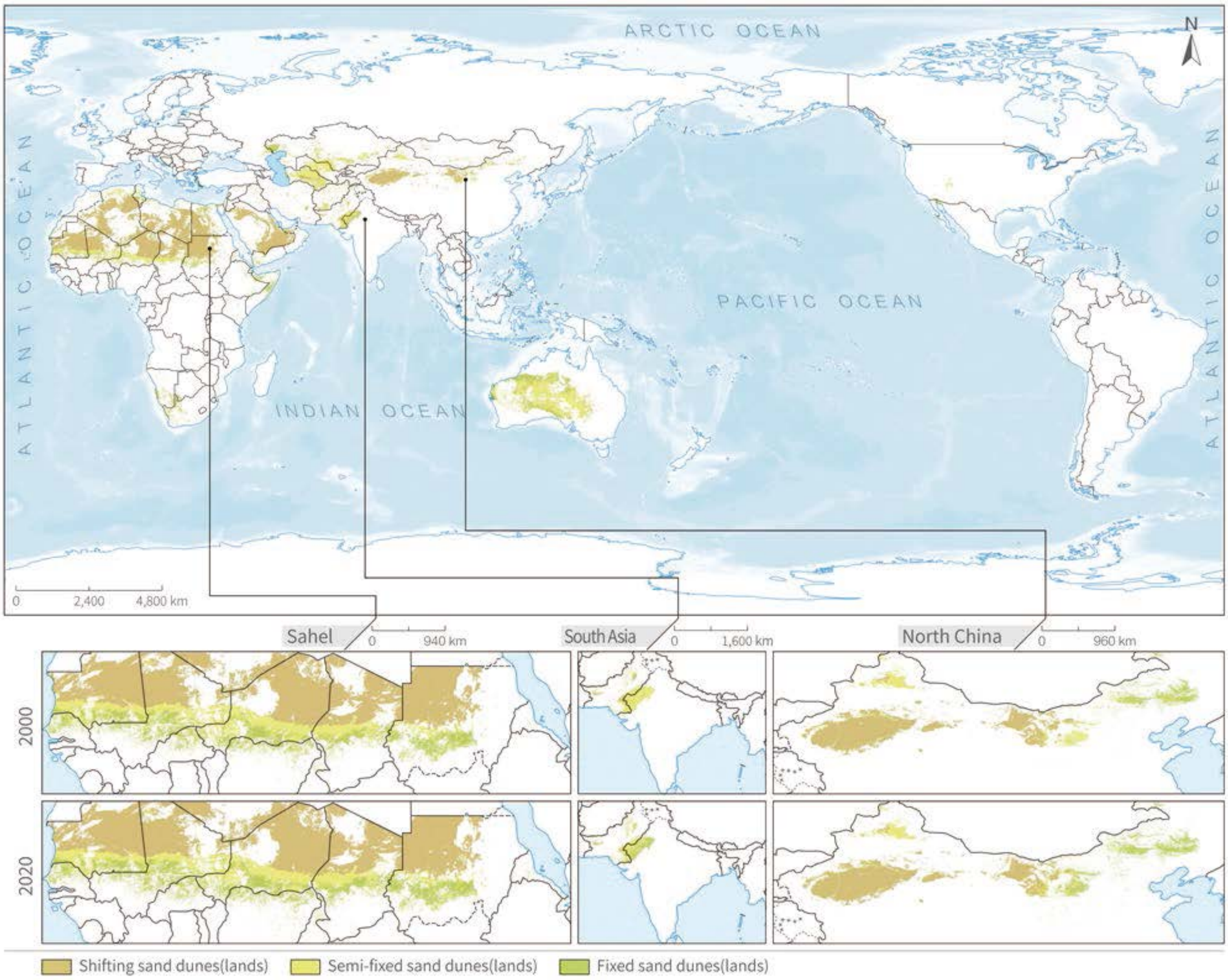


Figure 8-1. Spatial distribution of global sand dunes (lands) in 2020 and changes in typical regions from 2000 to 2020

Carbon sink effect of desertification control in China

Target: 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.

Vegetation restoration is an important way in combating desertification to sequestrate carbon and increase carbon sink in arid and semi-arid areas of Northwest China. The study on carbon sequestration of desertification control in China can provide reference for assessing the role of desert ecosystem in responding to climate change, and clarify the contribution of ecological construction in desertified region of China to "carbon peaking" and "carbon neutrality". In this case, MODIS-NDVI data combined with the ground survey data and the national soil survey data were used to develop a method for estimating the carbon storage of desert ecosystem in China. Based on the national monitoring data of desertified and sandy desertified lands, combined with literature and ground survey data, we estimated the carbon sink potential increased by desertification control in China.

The carbon storage of desert ecosystem in China was about 7,062.8 million tons in 2020. Deserts in China are mainly distributed in the inland basins and plateaus between 75-106 ° E and 35-50 ° N, starting from the western end of the Tarim Basin in the west to the Helan Mountain in the east. According to the *1:10,000,000 Vegetation Atlas of China*, the distribution range of desert ecosystem in China was determined, with a total area of 2.0837 million km^2, accounting for about 21.70% of China's total land territory. In 2020, the vegetation aboveground biomass of desert ecosystem in China was about 227.9 million tons (Figure 8-2), the total biomass of vegetation about 1,481.3 million tons, the carbon storage of vegetation about 740.6 million tons, the storage of soil organic carbon 6,319.9 million tons, and the storage of biological soil crust carbon 2.3 million tons. The carbon storage of desert ecosystems in China was 7,062.8 million tons.

The carbon sink potential increased by desertification control in China were 578.7 million tons from 2005 to 2019. Since 2000, desertified land area in China has been decreasing, with carbon sink potential increasing by desertification control. From 2005 to 2019, carbon sink potential increased by 578.7 million tons in total, with an average annual increase of about 38.6 million tons. The impact of ecological construction on carbon sink potential in China varied with climate areas in different periods. Carbon sink potential increased mainly in semi-arid and sub-humid arid areas in 2005-2009 and 2010-2014; arid, semi-arid and sub-humid arid areas made contributions to carbon sink potential to different degrees in 2015-2019.

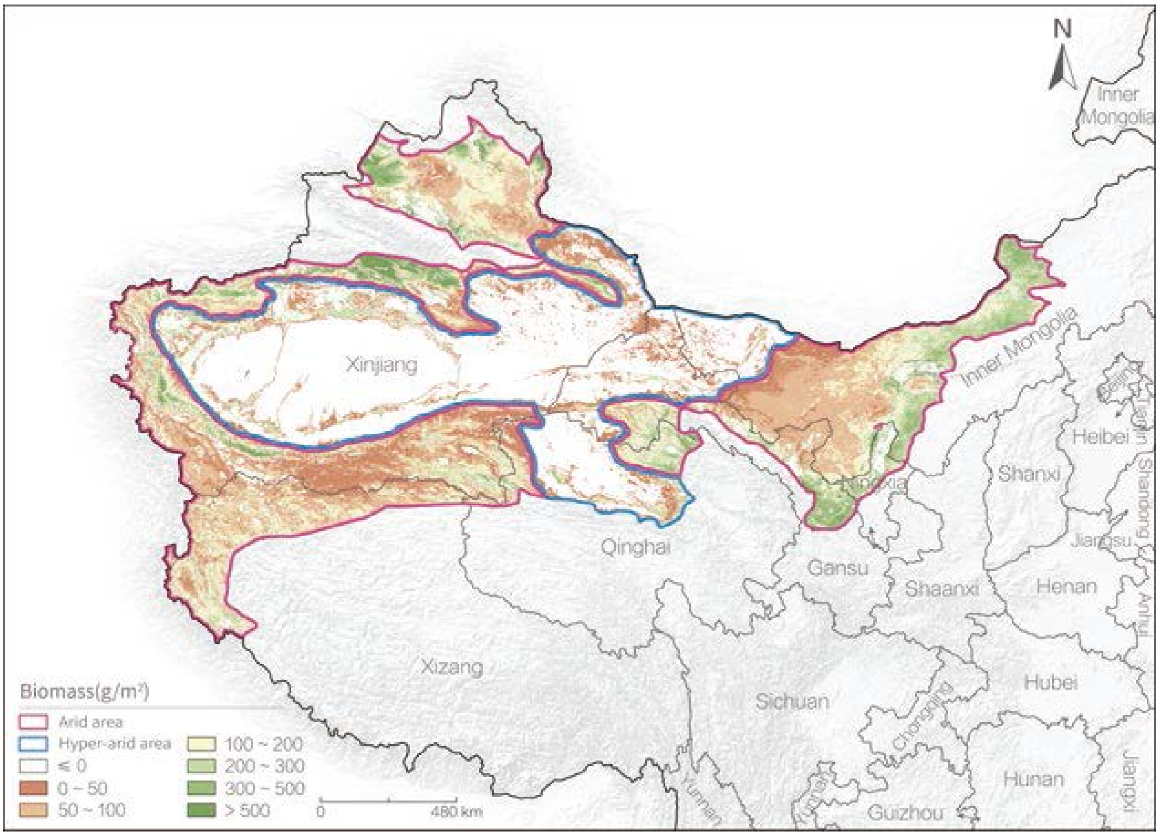


Figure 8-2. Distribution of vegetation aboveground biomass of desert ecosystem in China in 2020

Status and risk assessment of black soil degradation in Northeast China

Target: 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.

Black soil protection in Northeast China is vital to maintaining ecological equilibrium and ensuring food security for China. By field investigation and laboratory analyses, we examined the relationship between changes in soil properties (e.g., magnetic susceptibility, soil grain size and soil erosion) /fertility (expressed by the average grain yield across China) and total organic carbon (TOC) content. Then, a new early warning indicator system of soil degradation was established and a tipping point or critical threshold for soil degradation was determined. Further, based on the distribution of TOC for surface soil (0-30 cm) in Northeast China, we obtained the spatial distribution of soil degradation level for the black soil in Northeast China, together with proportion of land degraded over total land area in the region. Our finding can inform decisions and strategies on ensuring food security in black soil and protecting black soil from further degradation.

TOC content of less than 0.5% was established as a tipping point for soil degradation. TOC content and thickness of black soil in Northeast China increased overall from southeast to northwest, with a gradual decrease in erosion rate observed clearly from west (>3 mm/a) to east (0–3 mm/a) across the black soil region. In addition, a mean erosion rate of 2.22 mm/a was obtained for the black soil in Northeast China, where wind erosion dominated in the west and water erosion in the east. The compiled TOC contents of soil sections in the region showed that soils shifted rapidly into a degraded and infertile state when TOC is less than 0.5% (Figure 8-3). These results, together with the evaluation of other indicators, enabled us to develop a new early warning indicator system of black soil degradation in Northeast China (Table 8-2).

High-risk degradation areas accounted for 11.7% of black soil in Northeast China, which deserves close attention. Synthesis of TOC contents, thickness and erosion rates for the black soil in Northeast China enabled us to develop a new early warning indicator system for black soil degradation. Then, risk assessment on black soil degradation in Northeast China was accomplished based on the distribution of TOC for surface soil (0-30 cm). The results (Figures 8-4) showed that degraded black soil areas totaled 2,000 km^2 (0.7%), high-risk and low-risk areas 26,000 km^2 (11.7%) and 131,000 km^2 (57.8%), and safe areas 67,000 km^2 (29.8%) in Northeast China.

Table 8-2 An early warning indicator system of black soil degradation in Northeast China

Level of soil degradation#	TOC (%)	Thickness (cm)	Erosion rate (mm/a)*	Basis for the indicator system
Degraded	< 0.5	No consideration	No consideration	Soils are degraded.
High-risk	0.5-1.0	< 10	> 4	Soil begins to degrade slowly; or its thickness cannot sustain food production; or its erosion rate exceeds the corresponding value of soil loss tolerance.
Low-risk	1.0-2.0	> 10	< 4	Little soil is degraded, with relatively high level of food production.
Safe	> 2.0	> 10	< 4	Healthy and fertile soil can sustain food production.

#If the indicator meets any of the conditions of a higher degradation level, it is classified into this level of soil degradation.

*Assuming that soil loss tolerance is 50 t • ha^{-1} • a^{-1}, and that the average bulk density of black soil is 1.25 g • cm^{-3}, the corresponding erosion rate is 4 mm/a.

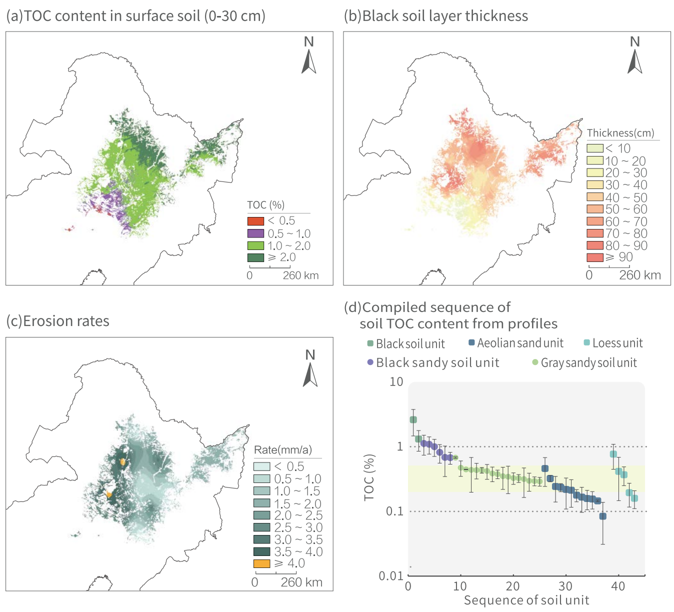


Figure 8-3. Distribution of TOC content of topsoil (a) and thickness of black soil layer (b) and erosion rates (c) for the black soil in Northeast China, together with the compiled sequence of soil TOC content from sections (d) in the region

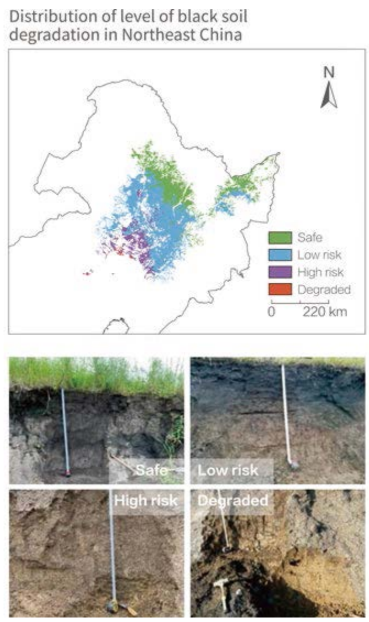


Figure 8-4. Distribution of levels of black soil degradation in Northeast China

The Great Green Wall of Africa supported by Big Earth Data

Target: 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.

Land productivity dynamics (LPD) is one of the key indicators for SDG 15.3.1 monitoring adopted by the United Nations Inter-agency and Expert Group on SDG Indicators. Currently, the JRC and the FAO have developed global land productivity dynamics products, but with spatial resolutions ranging from 250 to 1,000 m. There was no global application of LPD products with higher resolution in large regions. This case developed a 30 m LPD calculation tool based on SDG big data platform, providing high quality vegetation index dataset with 30 m spatial resolution and 8-day temporal resolution for LPD calculation through high spatial and temporal resolution image fusion algorithm. It used the algorithm based on steadiness index, baseline level and state change proposed by JRC to ensure comparability with other global LPD products. This tool is the first LPD calculation tool with 30 m spatial resolution in the world, capable of calculating 30 m spatial resolution LPD in specified spatial range and specified time window globally, thus providing important support for global land degradation monitoring.

To serve China's policy to support land degradation control in Africa, the International Research Center of Big Data for Sustainable Development Goals (CBAS) developed the Great Green Wall Big Data Facilitator (GGW-BDF), an online tool to support the building of the Great Green Wall in Africa. The online tool integrates the first 30 m spatial resolution LPD product at the intercontinental scale from 2013 to 2020 (Figure 8-5) and a knowledge base for desertification control, and covers 11 member countries of the Pan African Agency of the Great Green Wall (PAGGW). Users can easily browse land productivity dynamic data at the medium and high spatial resolution, conduct statistical analysis on areas of interest, and send in queries on China's technology and experience in building its Great Green Wall. This tool was launched during the event with which China marked the 28th Day to Combat Desertification and Drought, where its value was positively commented by the representatives of China's National Forestry and Grassland Administration and the United Nations Convention to Combat Desertification (UNCCD) secretariat.

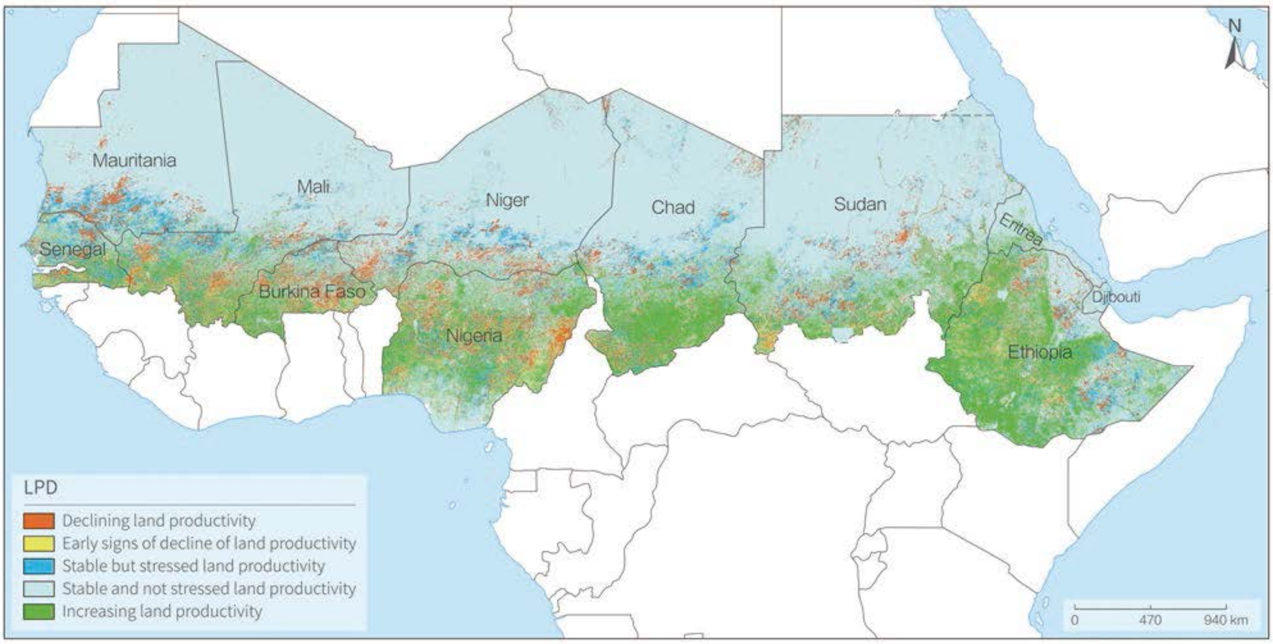


Figure 8-5. PAGGW national land productivity dynamics (LPD) product

Protecting Mountain Ecosystems

Mountain is one of the basic forms of land surface, playing a key role in the balance of the global ecosystems. 75% of the countries in the world have mountains. Mountain ranges form an interconnected network for wildlife migration, critical for checking the decline in biodiversity. However, industrialization continues apace, mountain ecosystems are deteriorating – shrinking resources, massive species loss and increased soil erosion are taking place in most of the world's mountain areas. In response to such grim realities, the 76th United Nations General Assembly declared 2022 as the International Year of Sustainable Development in Mountain Regions, calling international attention to mountain conservation and sustainable development. Assessing the conservation status of mountain biodiversity in China, a mountainous country, can help promote SDG Targets 15.1 and 15.4, and provide scientific support for protecting mountain biodiversity and optimizing the spatial distribution of national protected areas.

Assessment of conservation status of mountain biodiversity in China

Target: 15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.

In the first step of this case, we defined the spatial scope of mountainous areas in China through the Digital Elevation Model (DEM), where the number of species was counted according to scientific survey reports of protected area and Catalogue of Life China: 2021 Annual Checklist, in order to confirm the importance of mountains to species protection. Second, we calculated proportions of areas of forest, shrub, grassland, wetland, desert, and other ecosystems in mountains to total same-type areas in China, using the 30 m national ecosystem survey assessment data for 2020, in order to evaluate the importance of mountains in protecting the ecosystems. Lastly, we examined the spatial overlaying of mountainous protected areas (PAs) on priority ecosystems, in an attempt to identify conservation gaps and make recommendations on optimization of the PA layout.

Mountains are important for national biodiversity conservation. Mountains account for 69.27% of China's land territory, with about 500 species of mammals, 1,200 birds, 300 reptiles, 250 amphibians and 26,700 higher plants, accounting for 89%, 83%, 65%, 52% and 70% of their total numbers in China. There are 634 types of natural vegetation in mountains, accounting for 90.7% of the total number of terrestrial natural vegetation types in China (Figure 8-6).

Most of China's PAs are located in mountainous areas, but the spatial layout needs to be further improved. By 2020, more than 6,300 PAs, including national parks, nature reserves and natural parks, with the total area of 1,159,900 km^2, were in mountains, accounting for about 70% of the total number of PAs, over 60% of the national total area of PAs, and 17.4% of the total mountainous areas. The first batch of five national parks in China established in 2021 are all in mountainous areas. These PAs provide important natural habitats for about two-thirds of China's priority wildlife species, covering 86.9% of the total types of mountainous priority ecosystems. However, the spatial layout of PAs is not entirely rational and there are still conservation gaps, given that a small number of habitats of endangered species and priority ecosystems are not yet protected.

Spatial layout of PAs in mountains needs to be optimized. Given major challenges facing mountain biodiversity conservation, we recommend that spatial layout of PAs be optimized to cover national priority animal and plant species and priority ecosystems that are not yet protected adequately and areas where conservation is missing. We recommend that based on the development, improvement and integration of a PA system centered on national parks, more national parks be set up and PA layout be optimized in mountainous areas such as the Qinghai-Tibet Plateau, Tianshan Mountains, Taihang Mountains, Nanling Mountains and Changbai Mountains with rich wildlife fauna and flora, typical ecosystems and important ecological functions, in order to enhance national capacity for ecological security.

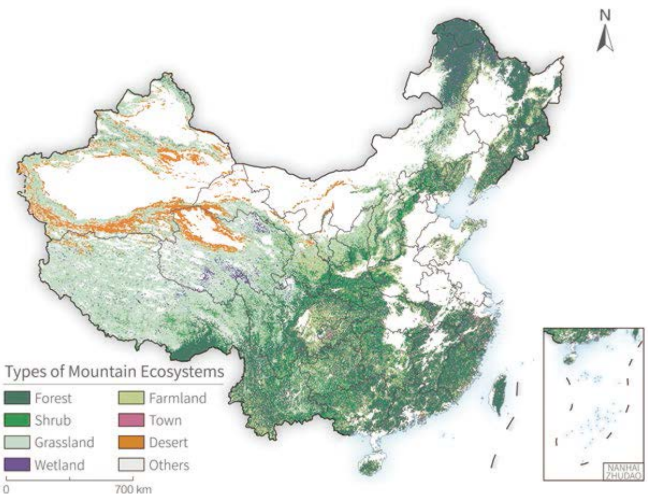


Figure 8-6. Distribution of mountain ecosystem types of China in 2020

SDG 15

Prevention, Control and Management of Invasive Alien Species

Invasive alien species are recognized as one of the main factors leading to the loss of biodiversity. Many alien species have been introduced into China, and some of them have invaded ecosystems such as forest, farmland, river, wetland and grassland. China attaches great importance to the management of invasive alien species, and incorporated it into the "Biosecurity Law of the People's Republic of China". In 2022, the Ministry of Agriculture and Rural Affairs, the Ministry of Natural Resources, the Ministry of Ecology and Environment, and the General Administration of Customs of the People's Republic of China jointly issued the "Regulations on Invasive Alien Species", which further clarified the division of duties and responsibilities of various government departments, launched the national census of invasive alien species, and promoted joint prevention and control. The Ministry of Science and Technology has launched basic research projects on invasive alien species and R&D projects on prevention and control technologies as part of major national research programs. Local governments also give active support for the prevention and control of invasive alien species. Some invasive alien species have been effectively controlled.

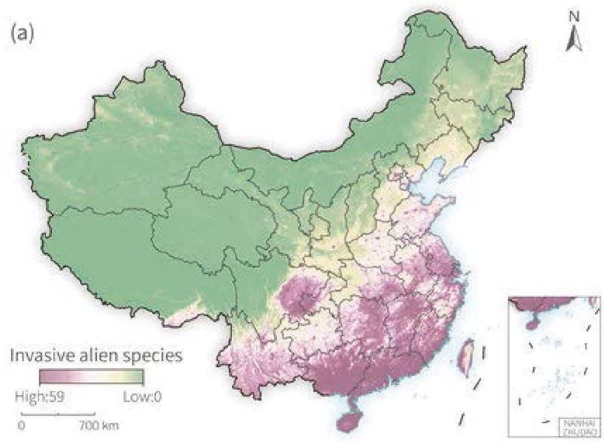
Risk assessment, control and management of invasive alien species

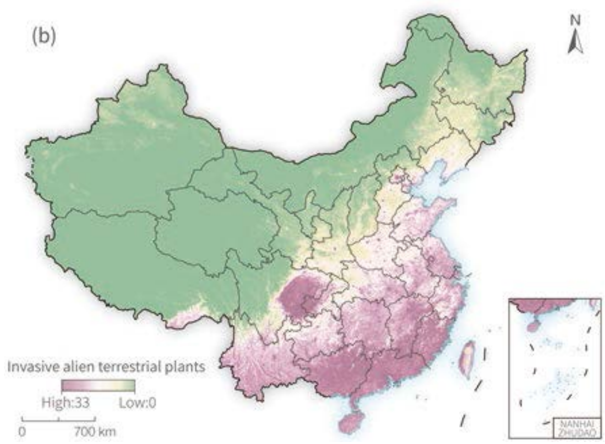
Target: 15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species.

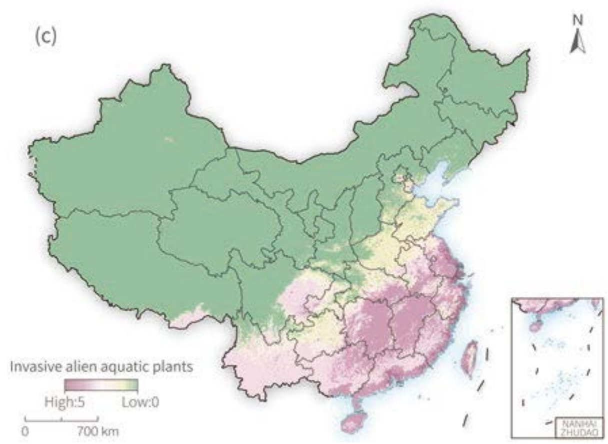
This case takes the 71 invasive alien species on the list issued by the Ministry of Ecology and Environment of China as the research object. Based on published literature, monographs, databases and field investigations, the distribution information of each species is obtained. Then this case simulated the suitable areas of the 71 invasive alien species based on the MaxEnt niche model, analyzed the spread risk of major invasive alien species, summarized successful experiences, and put forward recommendations on future prevention and control.

The main invasive alien species showed a decreasing trend from the southeast coast to the northwest inland. The distribution patterns of invasive alien species in China show substantial divergence. Invasive alien terrestrial plants and invasive alien aquatic plants are concentrated in southwest and southeast China; there are a large number of invasive alien terrestrial animals in southern coastal regions such as Guangdong, Guangxi, Fujian, and Hainan; invasive alien aquatic animals are mainly found in the middle and lower reaches of the Yangtze River and southeastern coastal areas (Figure 8-7).

Prevention and control on major invasive alien species







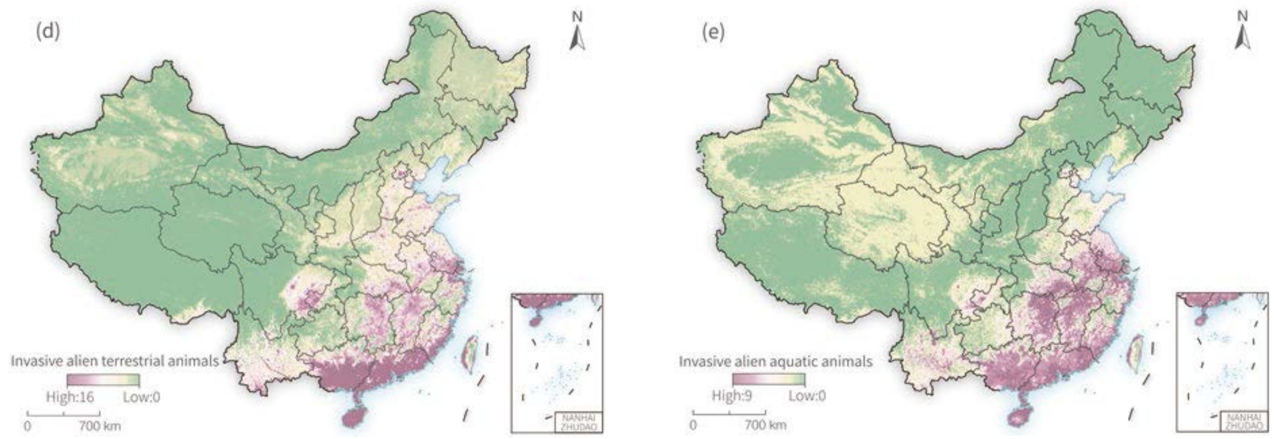


Figure 8-7. Suitable area for major invasive alien species in China (a) Invasive alien species, (b) Invasive alien terrestrial plants, (c) Invasive alien aquatic plants, (d) Invasive alien terrestrial animals, (e) Invasive alien aquatic animals

achieved remarkable results.

The Shanghai Municipal government and the National Forestry and Grassland Administration invested 1.16 billion yuan to implement the "Ecological control of smooth cordgrass (*Spartina alterniflora*) and improvement of bird habitat in Chongming Dongtan Bird National Nature Reserve", and explored a set of integrated techniques for controlling smooth cordgrass, including "fencing, cutting, flooding, drying, planting and adjusting" (Figure 8-8). Through ten years of efforts, smooth cordgrass has been effectively controlled in the 50,000 m^2 ecological restoration demonstration area, native plants have gradually recovered, and the number of bird populations has gradually recovered. In the project area, birds were observed 83,149 times, a number tripled compared to 2016. Moreover, 23 rare and protected bird species have returned to Dongtan for wintering, such as *Ciconia boyciana, Grus monacha*, *Cygnus columbianus* and *Platalea minor*. In order to reduce the risk of re-invasion, we continuously monitored the restoration demonstration area and the surroundings and promptly controlled small patches of smooth cordgrass.

For the invasive plant ragweed (*Ambrosia artemisiifolia*), which is widely distributed in China, biological control and regional joint control technologies were adopted; integrated biological control technology of *Epiblema strenuana* and *Ophraella communa* were developed based on the complementary ecological niche; natural enemies were released to effectively control the population of ragweed in the invaded region; 300 km intercepting band was built, and native plants were planted to replace ragweed. Up to now, prevention, control and management measures have been taken in 19 provinces, and ragweed has been effectively controlled.

Joint prevention and control of invasive alien species needs to be strengthened. In the future, we recommend strengthening the research on the spread pathway and interception technology of invasive alien species to effectively prevent the spread of invasive alien species; strengthening the promotion and application of successful prevention and control technologies, implementing joint prevention and control, to effectively control major invasive species, and reduce their impacts on biodiversity.

Figure 8-8. Restoration of bird populations in smooth cordgrass (*Spartina alterniflora*) prevention and control demonstration area (left picture), small patches before (middle picture) and after prevention and control (right picture)

Recommendations and Outlook

Focusing on "tapping the value of Big Earth Data and promoting the implementation of SDG 15", this chapter analyzes the progress in SDG 15 indicators related to three themes: combating desertification and land degradation, protecting mountain ecosystems, and prevention, control and management of invasive species at both global and Chinese (including typical regions) scales. We developed key spatial data products for the three themes, made scientific assessment on the multiple benefits of important projects and initiatives such as desertification land prevention and management, and nature reserves in China, and developed an online tool integrating China's sustainable land management experience with SDG 15 spatial data products, which can strongly support the implementation of SDG 15 globally and in China.

Based on the above studies, we offer the following recommendations:

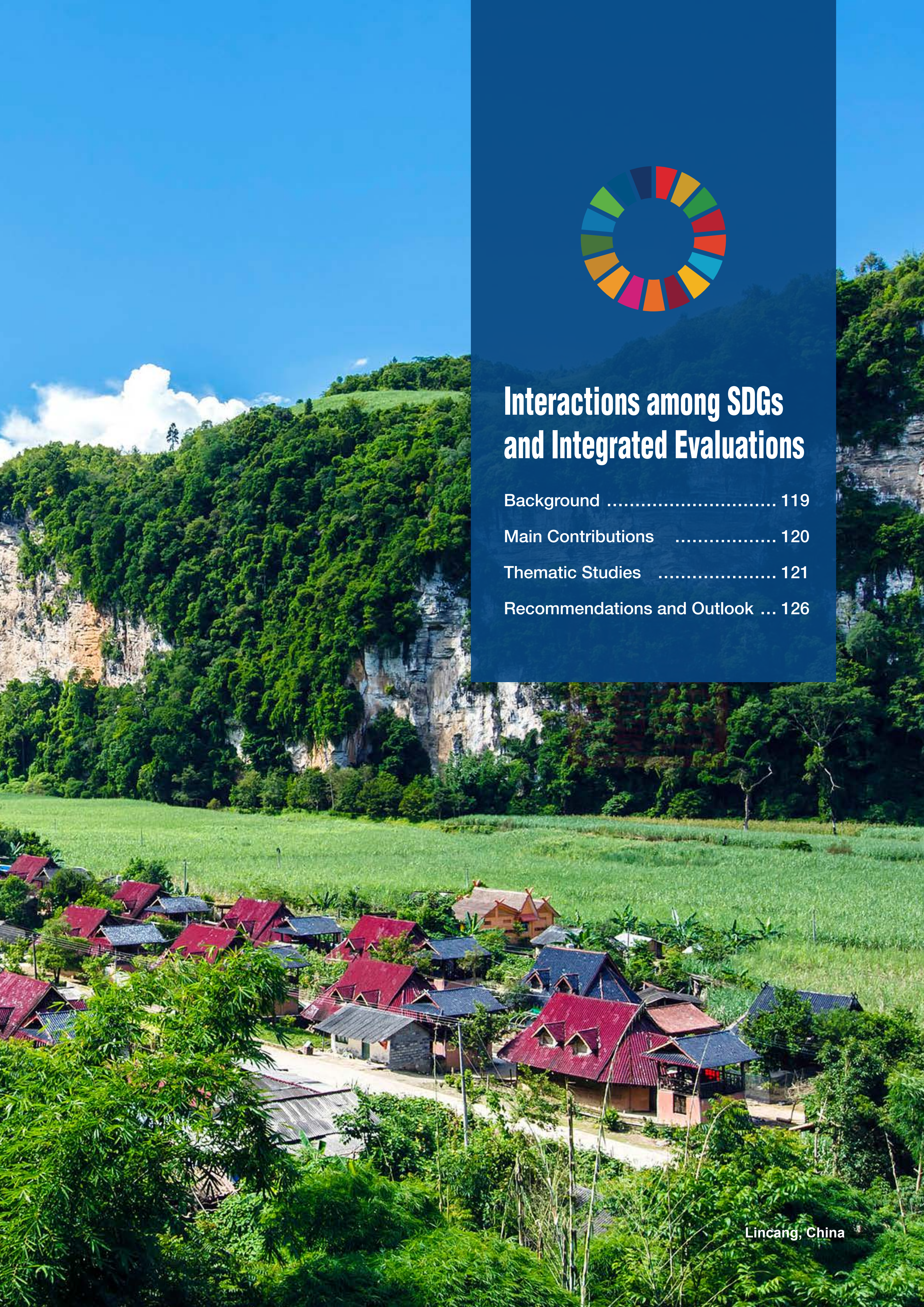
(1) For SDG 15.3 on combating desertification and land degradation, we need to conduct localized assessment on high-resolution land degradation neutrality, develop public products of high-confidence land degradation assessment indicators, and develop online tools for land degradation neutrality reporting/planning, to promote the global implementation of land degradation neutrality.

(2) For SDG 15.1 and SDG 15.4 on ecosystem conservation, we need to carry out essential biodiversity variables (EBVs) monitoring by remote sensing, global conservation effectiveness assessment and gap analysis, and research on the coupling mechanism between ecosystem and human activities, to provide a basis for the implementation of the Post – 2020 Global Biodiversity Framework.

(3) For SDG 15.8 on invasive alien species control and management, we need to strengthen the investigation, monitoring, and analysis of invasive alien species dispersal mechanisms in China, and integrate and promote the successful experience in invasive alien species prevention and control, to provide support for effective control of invasive alien species.

In the future, we need to make full use of big data infrastructure and cutting-edge technologies to provide more countries and regions with online support such as data products and decision analysis under the framework of the Global Development Initiative, and strengthen training, talent development and other capacity building, to better serve the implementation of SDG 15 in China and other countries.

Interactions among SDGs and Integrated Evaluations



Lincang, China

Highlights

Interactions among SDGs

Significant spatial and temporal change exists in China's provincial SDGs' synergistic and trade-off relationships. SDG 6 and SDG 15 are more susceptible to trade-offs from other SDGs in most provinces of China. In the past 20 years at the provincial level, relationships of about 27% of the trade-off indicator pairs have changed to synergistic ones, and about another 18% of the trade-off indicator pairs have seen their trade-off intensity mitigated. High-frequency targets/indicators in the synergistic circular network, including domestic material consumption (SDG 12.2.2), water resource management (SDG 6.5.1), universal primary and secondary education (SDG 4.1.2) and other indicators, are recommended to be priority indicators for development.

SDGs Integrated Evaluations

Overall sustainable development in different regions of China continues to improve. Since 2015, Hainan Province has made significant progress in ecological conservation. It has registered a high score on SDG 15 and made noticeable improvements on SDG 2 and SDG 11. In addition, 81% of the 70 SDG indicators under evaluation for Lincang City, Yunnan Province have seen progress or are close to the target. In Guilin City, Guangxi Zhuang Autonomous Region, the sustainable development index of ecotourism resources has increased from 0.46 in 2010 to 0.71 in 2020. The average annual growth rate of the Gross Ecosystem Product in Shenzhen, Guangdong Province, stands at 2.29%.

Background

There are complex interactions among SDGs, which manifest as synergies or trade-offs. When there are synergies between indicators, the achievement of one indicator facilitates the improvement of others. In other words, synergistic indicators promote one another. Trade-offs and counterbalances occur when an indicator is achieved at the expense of others. In addition, the factors affecting the sustainable development at different scales and types of regions are not completely consistent. Therefore, it is of great significance to track and understand the interactions among SDGs, targets, and indicators, and conduct integrated evaluations, which could be a useful guide in adjusting sustainable development paths to realize the United Nations 2030 Agenda.

Research on interactions among SDGs and integrated evaluations has been carried out by relevant organizations and the academic community at different scales since the SDGs were proposed (Sachs *et al.,* 2022; UNEP, 2021a). Big Earth Data integrates data produced by satellite observations, near-ground observations, and ground surveys. It is magnanimous, multi-source, and features multi-temporal equality, and thus provides important data and technical support for SDG monitoring and evaluation (Guo Huadong, 2019; 2020a; 2020b). Earth observation data and geographic information data can provide important supplements or substitutes for official statistics collected by conventional means. Their continuous spatial and temporal coverage can promptly capture changes in surface elements in SDG monitoring, overcoming inconsistencies in statistical data between countries. Moreover, geographic information modeling and simulation methods based on spatial analysis and other technologies can help sort out the interactions among SDGs, predict future development trends, and conduct integrated evaluations to provide a basis for suitable policy recommendations.

An initial discussion was made in last year's report on the research methods of interactions among SDGs supported by Big Earth Data. It was found that interactions among SDGs vary on different spatial and temporal scales. To this end, exploring the synergistic and trade-off relationships among SDGs on different spatial scales and studying their variations on time scales is necessary. Meanwhile, social, economic, natural endowment, and other local conditions need to be considered in making sustainable development evaluations for different regions to find a sustainable development path suitable for them. Therefore, this year's report will explore the synergistic and trade-off relationships among SDGs at China's provincial level and evaluate the sustainable development process of typical regions in China, which may inform regional decision-making and efforts for sustainable development.

Main Contributions

This chapter analyzes the progress in interactions among SDGs and integrated evaluations supported by Big Earth Data through two cases. The main contributions are as follows (Table 9-1).

Table 9-1 Cases and Their Main Contributions

Theme	Case	Contributions
Interactions among SDGs	Analysis of the synergies and trade-offs among SDGs in China	**Model and method:** using spatio-temporal geo-weighted regression to construct complex networks with directions and weights among SDGs, and to explore their synergistic and trade-off relationships and variation of the interactions **Decision support:** providing references for Chinese provinces in making proper decisions on setting priority development goals and mitigating the SDGs trade-offs that exist in development
SDGs Integrated Evaluations	Integrated evaluation of SDGs in typical regions of China (Hainan Province, Lincang of Yunnan Province, Guilin of Guangxi Zhuang Autonomous Region, Shenzhen of Guangdong Province)	**Model and method:** building sustainable development evaluation indicator systems according to the characteristics of different regions in pursuing sustainable development, and carrying out SDGs integrated evaluations for typical regions in China **Decision support:** providing decision-making support for sustainable development of the "national ecological conservation pilot zone", namely Hainan Province, "innovation-driven development in multi-ethnic underdeveloped border areas", namely Lincang City, Yunnan Province, "landscape resource-based sustainable utilization" demonstration area, namely Guilin City, Guangxi Zhuang Autonomous Region, the demonstration zone for "leading sustainable development of super-large cities through innovation", namely Shenzhen, Guangdong Province, and offering good practices and reference for similar regions

Thematic Studies

Interactions among SDGs

The existing analysis of synergistic and trade-off relationships among SDGs often overlooks the spatio-temporal variability and the directionality of interactions among SDGs by primarily focusing on statistically significant positive and negative correlations. The spatio-temporal non-stationarity of SDG indicators can be taken into account based on the geospatial-temporal analysis method of Big Earth Data. The methods of spatio-temporal geographically weighted regression and complex network analysis are used to explore the spatio-temporal variation characteristics of the interactions among SDGs so as to inform policy-making.

Analysis of the synergies and trade-offs among SDGs in China

Based on data on 65 SDG indicators for 31 provincial-level administrative regions from 2000 to 2020, complex networks with directions and weights among these SDG indicators are constructed using the method of spatio-temporal geographically weighted regression. This study identified typical synergistic and trade-off indicator pairs in each province, analyzed the transformation of trade-off indicator pairs for each province in China, explored the typical virtuous cycles, and selected important indicators that promote synergistic development of SDGs.

There is significant spatial variability in synergies and trade-offs of SDG pairs on the provincial scale in China, with SDG 6 and SDG 15 more susceptible to trade-offs from other SDGs. SDG 9 (Industry, Innovation, and Infrastructure) exhibits a synergistic contribution to SDG 11 (Sustainable Cities and Communities) in the southwest and southern China, and SDG 11 has a trade-off and inhibiting effect on SDG 15 (Life on Land) in northeast China (Figure 9-1). In most provinces, SDG 6 (Clean Water and Sanitation) and SDG15 are more susceptible to trade-offs from other SDGs. Therefore, it is necessary to improve meticulous management of water resources and enhance terrestrial ecosystem protection in pursuing sustainable development in China.

Between 2000 and 2020, 27.02% of the trade-off indicator pairs in Chinese provinces shifted to synergistic relationships, and 18.30% of the trade-off indicator pairs had their trade-

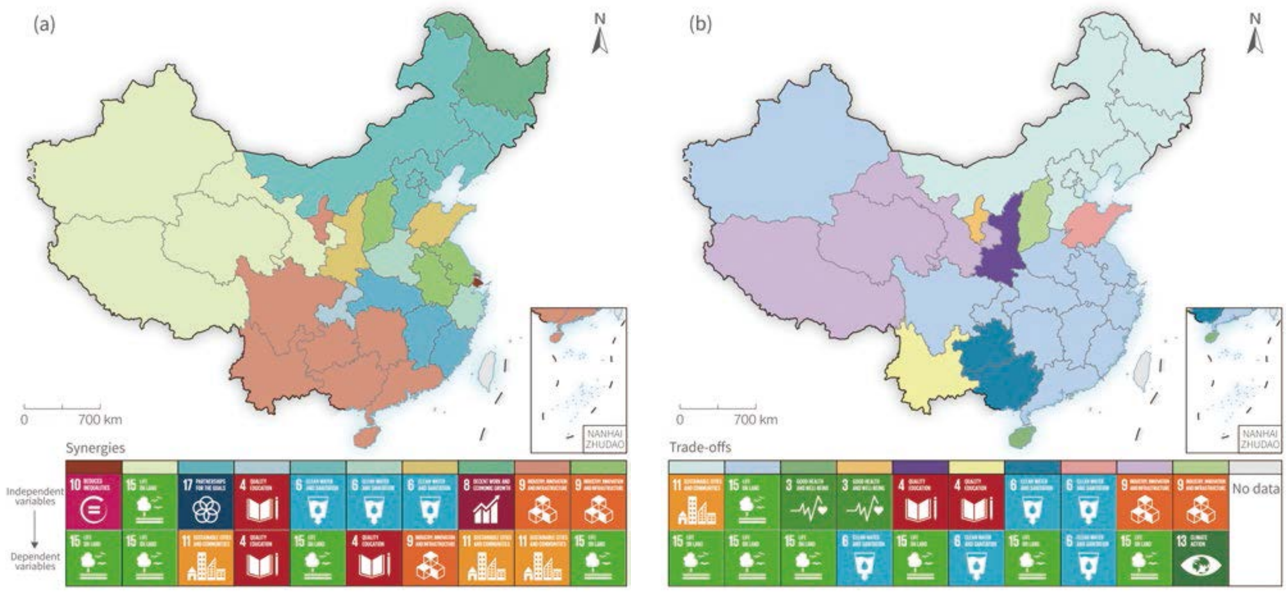


Figure 9-1. Spatial distribution of typical synergy and trade-off SDG pairs in China

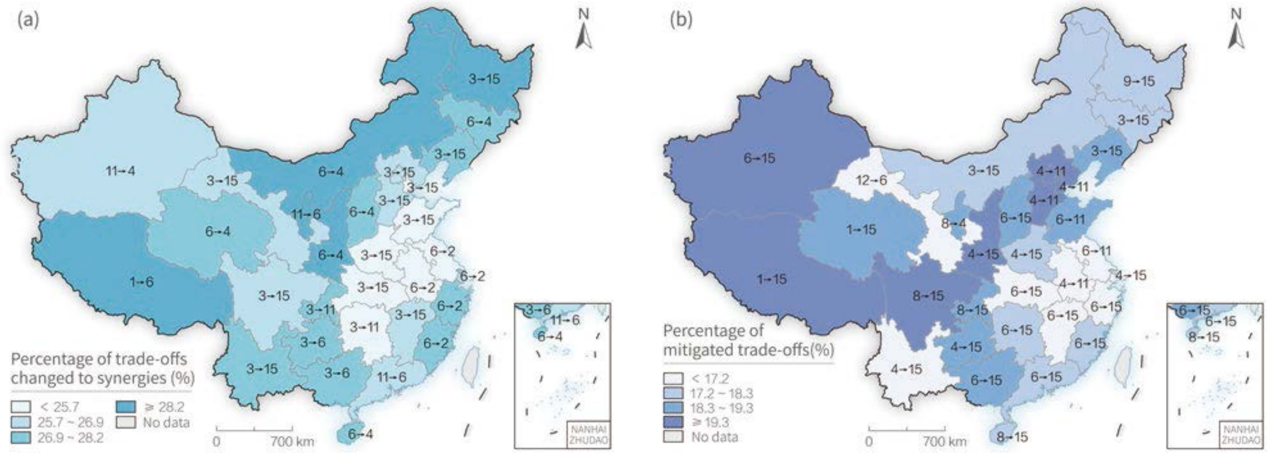


Figure 9-2. Mitigation of trade-offs in each province of China (the "→" symbol indicates a typical SDG indicator pair and direction of their impact)

offs mitigated. Among the SDG pairs changed their relations from trade-off to synergy, the widest area of changes occurred in SDG 3 (Good Health and Well-being) to SDG 15 (Life on Land), mainly due to the implementation of China's air pollution prevention and control law and the rising awareness of green and low-carbon living. At the same time, SDG 6 (Clean Water and Sanitation) to SDG 2 (Zero Hunger) saw a greater change in the Yangtze River Delta region than in other regions, mainly due to measures such as strengthening water management resources, implementing water-saving irrigation, and increasing the irrigated area of arable land and food production. Among the SDG pairs with reduced trade-off intensity, 23 provinces showed a decrease in the intensity of trade-offs on SDG 15 from other SDGs. For example, the implementation of the *Water Pollution Prevention and Control Action Plan* has ensured the basic security of water sources in China's major provinces of abundant water resources, good restoration of water ecology, and significant improvement in groundwater quality, which in turn has contributed to the synergistic contribution of SDG 6 to SDG 15 (Fig 9-2).

Domestic material consumption (SDG 12.2.2), water resource management (SDG 6.5.1), universal primary and secondary education (SDG 4.1.2) and other targets/indicators are recommended as priorities. The closed loop in a synergistic network makes a virtuous circle. Optimizing one indicator in this virtuous circle can promote the harmonious development of all the remaining indicators in the circular network. The analysis results show that the virtuous cycle network is featured by spatial concentration. Therefore, optimizing energy production and consumption patterns (SDG 12.2.2), strengthening the comprehensive management of water resources (SDG 6.5.1), increasing investment in education and the construction of educational facilities (SDG 4.1.2, SDG 4.b.1 SDG 4.a.1) can further promote sound and efficient synergistic development of SDGs (Figure 9-3).

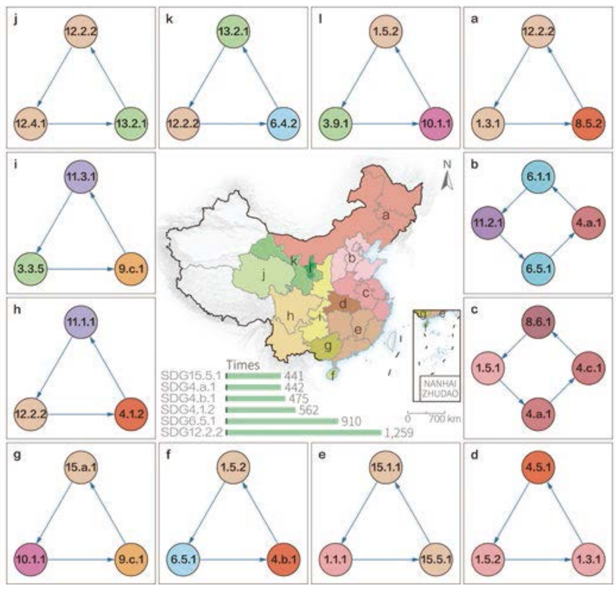


Figure 9-3. Spatial distribution of typical virtuous cycles in China

SDGs Integrated Evaluations

Due to differences in natural resource endowments and social and economic development levels, different regions have different sustainable development paths. Integrated evaluation of SDGs can systematically sort out SDG indicators that characterize unique features of different regions, evaluate the state of sustainable development of the region as a whole and its internal spatial units, explore the path of sustainable development in different regions, inform decision-making for the realization of regional sustainable development, provide guidance for regional sustainable development, and offer good practices and references for similar regions.

Integrated evaluation of SDGs in typical regions of China

Since 2018, China has successively established national demonstration zones for sustainable development agenda through innovation in Shenzhen of Guangdong Province, Guilin of Guangxi Zhuang Autonomous Region, and Lincang of Yunnan Province, providing Chinese experience for the global endeavor of sustainable development. In 2019, China designated Hainan Province as a national ecological conservation pilot area to provide good practices for boosting green development and improving ecological conservation. Different regions have different sustainable development focuses. For example, the focus of Lincang is innovation-driven development in multi-ethnic underdeveloped border areas, the focus of Shenzhen is to lead sustainable development of super-large cities through innovation, and the focus of Guilin is sustainable utilization of landscape resources. In this case, based on the Big Earth Data technology and relevant statistical data of SDG indicators in different regions, a regional sustainable development evaluation indicator system was constructed for each of the above four typical regions, and an integrated evaluation of SDGs was carried out based on the evaluation method of UN SDSN.

Figure 9-4. Results of integrated evaluations of SDGs for cities and counties of Hainan in 2020 (not including Sansha City)

Hainan Province has made big progress in ecological conservation. It has scored high on SDG 15, and has significantly improved on SDG 2 and SDG 11. But progress is uneven among cities and counties. The SDG scores of cities and counties in Hainan rose between 2015 and 2020. Of the 18 counties and cities participating in the evaluation (not including Sansha City), 14 scored significantly higher, 2 (Haikou City and Ding'an County) had stable scores relatively the same, and 2 (Tunchang County and Lingao County) scored slightly lower on individual goals (Figure 9-4). Compared with 2015, general improvements had been made on SDG 2 in 2020 (Zero Hunger), but there is still room for improvement; the evaluation results on SDG 8 (Decent Work and Economic Growth), SDG 11 (Sustainable Cities and Communities) and SDG 6 (Clean Drinking Water and Sanitation) improved significantly, and SDG 15 (Life on Land) remained at a high level. Therefore, coordinated development in the eco-environment and socio-economy has been preliminarily achieved. Lingao and Tunchang counties have improved in terms of socio-economic indicators (e.g., disposable income of rural residents (SDG 2.3) and per capita GDP (SDG 8.1) and environmental indicators (e.g., the aggregate value of $PM_{2.5}$, PM_{10} and number of good air quality days (SDG 11.6). Overall, Hainan has achieved good results in protecting its ecological environment, but there is still room for improvement in certain areas.

Lincang City of Yunnan Province has achieved greater balance between its economic and social progress and protection of ecological environment. It is recommended that the follow-up work focuses on the implementation of relevant policies that will help consolidate and expand the achievements of poverty alleviation in mountainous areas and continuously improve the level of regional medical and health care. From 2015 to 2020, Lincang City of Yunnan Province performed well on SDGs. 81% of the 70 indicators evaluated saw progress or were close to the target. The SDGs related to the eco-environment remained stable, and socio-economy-related SDG indicators grew significantly (Figure 9-5). In 2020, the GDP of Lincang increased by 3.7%, and 94,000 households, or 369,000 people in the city, were lifted out of poverty. The forest coverage rate reached 70.2%. The forest resources grew in both quantity and quality. Major progress was made in converting farmland to forests. As a result, Lincang became a national model for the high-quality development of forests and grasslands. The synergistic relationship (accounting for 39.63%) was significantly higher than the trade-off relationship (accounting for 5.49%) among the SDG indicators in Lincang. Synergies between SDG 1 (No Poverty) and SDG 3 (Good Health and Well-being) were the most prominent, while trade-offs between SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) were the most pronounced. Since Lincang belongs to economically underdeveloped areas, it is recommended that priority be given to implementing relevant policies that will help consolidate and expand the achievements of poverty alleviation in mountainous areas and continuously improve the quality of medical and health care in this region. It is also necessary to increase the protection of terrestrial and aquatic ecosystems, improve the development level of indicators central to synergistic relationships, and give full play to the synergy effect of all the goals, targets, and indicators, to enhance the sustainable development of Lincang and explore a "Lincang model" on sustainable development for underdeveloped mountainous areas that can inform efforts in southwest China and similar regions in South Asia and Southeast Asia.

The sustainable development index for landscape resources in the Lijiang River Basin of Guilin has continued to improve, providing an empirical reference for the sustainable development of tourist cities facing conflicts between ecological protection and economic development. The trade-offs and synergistic relationships among the SDGs of the eco-tourism resources in the Lijiang River Basin of Guilin City (Figure 9-6) show that trade-offs among SDG 6 (Clean Water and Sanitation), SDG 15 (Life on Land), SDG 8 (Decent Work and Economic Growth) and SDG 11 (Sustainable Cities and Communities) are high. The trade-off is also high in the network of indicators, including the urban fine particulate matter ratio (SDG 11.6.2), material consumption ratio (SDG 8.4.2), forest cover (SDG 15.4.1), biodiversity conservation input (SDG 15.a.1), water monitoring (SDG 6.6.1), and the proportion of important biodiversity sites (SDG 15.1.2). Therefore, coordinating the SDGs with higher trade-offs and focusing policies on them helps promote sustainable development in Guilin. From 2010 to 2020, the average sustainable development index for eco-tourism in the Lijiang River Basin of Guilin increased from 0.46 to 0.71. The index grew fast from 2010 to 2015. Tourism income has been affected by COVID-19

Figure 9-5. SDGs progress in Lincang City, Yunnan Province

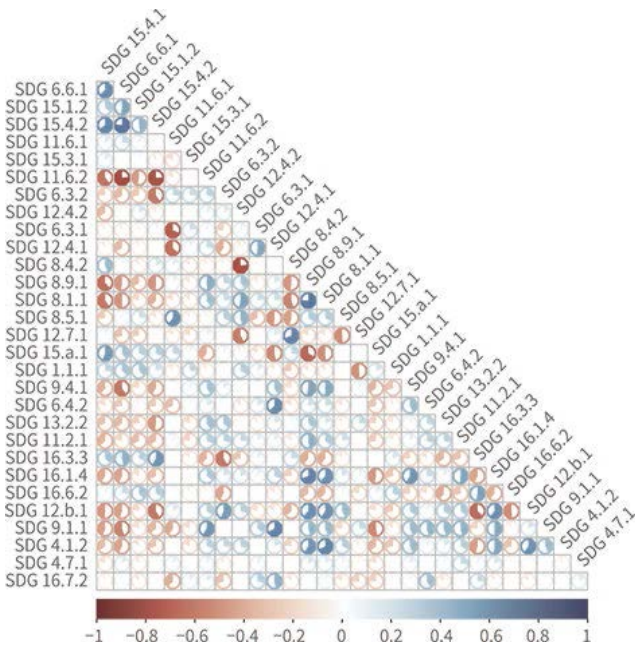


Figure. 9-6 Heat map of correlations between the SDG indicators of the eco-tourism resources in the Lijiang River Basin (high trade-off to high synergy as represented by -1 to 1)

since 2020. But thanks to the local measures such as raising the employment rate of residents in the Lijiang River Basin (SDG 12.b.1), improving inhabitants' livelihood (SDG 1.1.1), and reasonable development of landscape resources at tourist destinations (SDG 15.4.1), the demonstration zone has kept an upward trend of sustainable development of landscape resources in the Lijiang River Basin, which may inform policies on sustainable development in other tourist cities under the impact of COVID-19.

Shenzhen City of Guangdong Province integrates SDG indicators into the Gross Ecosystem Product accounting system, which can serve as a toolkit for decision making on

mega city's urban planning and a demonstration for solving problems associated with big cities.

From 2016 to 2020, the average annual growth rate of Gross Ecosystem Product (GEP) in Shenzhen was 2.29%, and the value of regulating services that support urban ecological security kept an annual growth rate of 3.41%. The spatial distribution of GEP in Shenzhen in 2020 is shown in Figure 9-7. By hardening the ground in the low GEP value areas first, Shenzhen may reduce GEP losses from 3 940 to 572 million yuan each year under the goal for urban development by 2025. About 6.2 billion yuan per year in value-added can be created by the storming runoff retention service and the climate adjustment service by creating vertical green space, old town renewal, and other measures of adding urban green space. By improving the ecosystem service supply capacity, Shenzhen's GEP can also be effectively enhanced. Taking the roadside and square green space project as an example, when the sponge function of the green space is given full play, the value of the storming runoff retention service may increase by about 2.38 billion yuan in the duration of the project (10 years).

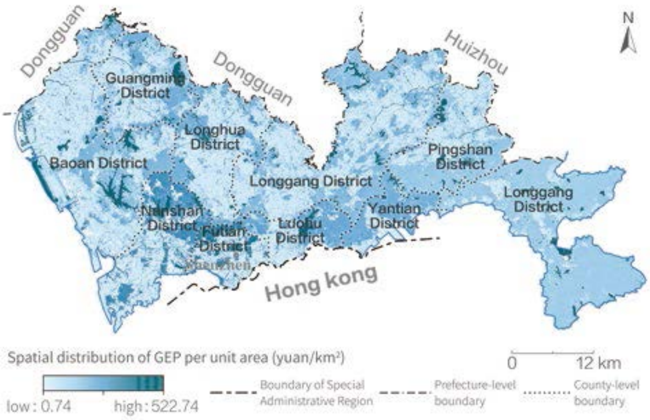


Figure9-7. Spatial distribution of GEP in Shenzhen in 2020

Recommendations and Outlook

This chapter analyzes the synergistic and trade-off relationships among SDGs at the provincial scale in China and integrated evaluations of SDGs in typical regions. It is found that there are significant temporal and spatial differences in the synergistic and trade-off relationships between SDGs at the provincial level, and the overall status of sustainable development continues to improve throughout the country. The conclusions of this chapter can inform decision-making in different regions of China, including establishing proper priority development goals, mitigating trade-offs of SDGs in development, and optimizing sustainable development paths. However, due to the limitations of the SDGs data used and the complexity of the interactions among SDGs, the analytic results in this chapter may have certain limitations.

Based on the findings of this chapter, we offer the following recommendations:

(1) Deepening research on methods of interactions among SDGs. Use the spatial analysis and deep learning methods of Big Earth Data to study synergistic and trade-off relationships between SDGs and their spatial spillover effects, so as to provide methodologies for interactions among SDGs and integrated evaluations;

(2) Promoting simulation studies on future sustainable development scenarios based on the interactions among SDGs. Explore the mechanism that drives the interaction between SDG indicators and other social, economic, and environmental factors to provide a practical path to coordinated and high-quality regional development;

(3) Carrying out research on spatial breakout of non-spatial statistical SDG indicators. Spatialize non-spatial statistical SDG indicators based on spatial data such as population and land use to facilitate the integrated evaluation of SDGs with high spatial resolution, and provide technical support for decisions and recommendations on the path to meeting SDGs in different regions.

Interactions among SDGs and integrated evaluations are important means to explore and optimize the path of regional sustainable development and comprehensively evaluate the process of regional sustainable development. In the process of meeting the sustainable development goals, all regions in China need to pay attention to the possible trade-offs between economic and social indicators and environmental indicators, and promote the realization of indicators paired up in a synergistic relationship.


China Remote Sensing Satellite Ground Station (Kashi Station)

Summary and Prospects

I. Summary

This report presents case studies of Big Earth Data supporting the evaluation of SDG indicators for seven SDGs (Zero Hunger, Clean Water and Sanitation, Affordable and Clean Energy, Sustainable Cities and Communities, Climate Action, Life below Water and Life on Land) and the interactions among SDGs. The studies generate data products, methods and models and decision support recommendations.

Data Products: 31 data products were developed at the global and Chinese scales. Some have narrowed the data gaps in SDG monitoring. For example, the dataset of global urban built-up areas with a population above 300,000, the data on the boundaries of World Heritage sites, the data on global sand dunes (lands) distribution, the data on the carbon intensity of Chinese cropland soil, the dataset on water stress level of Chinese provinces, and spatial distribution map of spreading risks of major invasive alien species in China. On the other hand, some products have raised the spatial fineness of SDG monitoring and evaluation. For example, datasets or data products of global cropping intensity at 30 m resolution, global heat waves at 1 km resolution, global electrified built-up areas at 500 m resolution, global urban greenness at 250 m resolution, change in Chinese groundwater reserves with spatial resolution 0.5°, and spatial distribution of China's coastal tidal flats at 10 m resolution.

Methods and models: 21 methods and models were developed based on Big Earth Data. Some have closed gaps in terms of how to monitor SDG progress. For example, the method for evaluating water-use efficiency based on multi-source data combined with the crop growth process, and the collaborative forward modeling integrating gravity satellite and groundwater level data. In addition, some provide optimized solutions to SDG evaluation. For example, a saline-alkali soil identification and classification model, sustainability index of water resources development and protection, and estimation of carbon dioxide flux absorbed by global oceans based on self-organizing map (SOM) neural network and stepwise feedforward neural network (FFNN) algorithms. Furthermore, spatio-temporal geo-weighted regression was used to explore the synergies and trade-offs among SDG indicators; integrated evaluations of SDGs were done at the local scale with sustainable development evaluation indicator systems constructed according to local features in pursuing sustainable development.

Decision support: spatial and temporal analyses of sustainable development indicators using the above data and methods led to 33 decision support recommendations for sustainable development both in China and globally. Specifically, under SDG 2 are increasing grain output, reducing saline alkaline land, sustainable grain production, and policy on emission reduction in agriculture; under SDG 6 are improving water quality, water-related sectoral restructuring, integrated water resources management, and water resource exploitation and utilization; under SDG 7 are electrification policy-making and investment, and international energy cooperation and training; under SDG 11 are improving urban land use efficiency and urban greening, reducing urban disasters; under SDG 13 are reducing losses from water-logging, building a disaster reduction system, and strengthening education on climate change; under SDG 14 are prevention and control of offshore eutrophication, protecting coral reef's environment, and reclamation control and management; under SDG 15 are sand dune fixation, early warning for land degradation, protecting mountainous ecosystems, and prevention and control of invasive alien species. In addition, the study's outcomes on interactions among SDG indicators and integrated evaluations can inform Chinese local governments in setting priority development goals, easing tensions between SDGs and adopting optimal paths toward sustainable development.

II. Prospects

Over the past four years, the Chinese Academy of Sciences (CAS) has conducted exploratory research in monitoring and evaluating SDG indicators and pinpointed that Big Earth Data had high application potential and promotion value in supporting many SDGs (Guo, 2019, 2020a, 2020b) although many challenges involved, such as the shortage of spatiotemporal data important for SDG evaluation, unharmonized data sharing standards and ineffective protection of data security. Therefore, to facilitate the implementation of the UN 2030 Agenda, we recommend redoubling efforts in the following areas.

1. Building a global collaborative observation network for SDGs

There are more and more satellites launching into the space, resulting in the rapid growth of the satellite and its application industries. On 5 November 2021, China successfully launched SDGSAT-1, the world's first sustainable development science satellite, and then committed to sharing its data to the world. Responding to the "leaving no one behind" commitment of the 2030 Agenda, we propose to speed up the construction of a collaborative Earth observation network for SDGs to improve the service capacity of space-based observations, develop a standardized international space-based observation system, and provide joint data support to address unbalanced development and reduce the digital divide.

2. Improving the spatiotemporal dimensions to SDG progress assessment

Statistical surveys are among the primary methods of obtaining global SDG monitoring and evaluation data. However, due to the differences of policy and ability in the development of statistical survey systems across the world, the survey data often suffer unevenness of qualities, insufficient spatiotemporal scales, and lack of data availability in some developing countries. We therefore propose to make full use of Big Earth Data and other technologies in terms of increasing data acquisition methods and obtaining high-quality and spatiotemporally consistent global SDG data through open access to data computing and storage facilities and adoption of advanced data processing methods, with the goal to make SDG progress evaluation timely and more accurate.

3. Sharing public data products for SDG monitoring

Due to the lack of consensus in the policies on data sharing, and no unified technical standards in terms of data structure and security, many users have no access to the data owned by other institutions, or the data generated by specific statistical agencies and excluded to other users. We propose to improve new information infrastructure that combines data applications and open services, provide real-time data access, on-demand pooling, integration, open sharing and analysis services, and public data services and products to support the monitoring and evaluation of SDGs .

4. Promoting exemplary studies on big data supporting SDGs

Due to the differences in natural resources and socio-economic development, various regions face individual difficulties in their efforts towards sustainable development. The Big Earth Data, featuring multiple spatial and temporal scales, can provide important support for SDG implementation evaluation in different regions. We propose to promote exemplary studies on Big Earth Data supporting SDGs, strive to build a sustainable development indicator system with different spatial scales, and develop innovative and comprehensive demonstration systems with regional features to inform the realization of the SDGs around the world.

Data Sources

Remote sensing

1-km resolution harvesting areas for three staple crops in China (2000-2019). http://www.nesdc.org.cn/sdo/detail?id=627dfc4b7e28172589c2df9b

1-km resolution land use in China (2020). https://www.resdc.cn/

5-km resolution gross primary productivity inverted from solar-induced chlorophyll fluorescence in China (2000-2020). https://globalecology.unh.edu/data/GOSIF-GPP.html

CAS Mangroves 2.0. National Earth System Science Data Center. http://www.geodata.cn/thematicView/wetland2020.html

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Acronyms & Abbreviations

BPA	biomass per area
BUAs	built-up areas
CAS	Chinese Academy of Sciences
CASEarth	CAS Big Earth Data Science Engineering Program
CBAS	International Research Center of Big Data for Sustainable Development Goals
China-ASEAN	China-Association of Southeast Asian Nations
CIECPs	China's international energy cooperation projects
CZI	Coastal Zone Imager
DEM	Digital Elevation Model
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
EBVs	essential biodiversity variables
EF-LUE	Evaporative Fraction-Light Use Efficiency
ERA5	the fifth generation ECMWF reanalysis for the global climate and weather; ECMWF: the European Centre for Medium-Range Weather Forecasts
ET	Evapotranspiration
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization of the United Nations
FFNN	feedforward neural network
FGOALS-g3	Flexible Global Ocean-Atmosphere-Land System Model-Grid Point Version 3
GDP	Gross Domestic Product
GEP	Gross Ecosystem Product
GGW-BDF	Great Green Wall Big Data Facilitator
GPM	Global Precipitation Measurement
GPP	Gross Primary Productivity
GRACE	Gravity Recovery and Climate Experiment
GRP	Gross Regional Product
GUB	Global Urban Boundaries
GW	gigawatts
IMAGE-GNM	Integrated Model to Assess the Global Environment – Global Nutrient Model
IOC-UNESCO	Intergovernmental Oceanographic Commission of United Nations Educational, Scientific and Cultural Organization
JRC	European Commission's Joint Research Centre

LCRPGR	ratio of land consumption rate to population growth rate
LPD	land productivity dynamics
LUCC	Land-Use/Cover Change
MODIS	Moderate Resolution Imaging Spectroradiometer
MSI	MultiSpectral Instrument
MSIC	Maximum Spectral Index Composite
NDVI	Normalized Difference Vegetation Index
NEP	net ecosystem productivity
OBIA	object-based image analysis
OHC	ocean heat content
PAs	protected areas
PAGGW	Pan African Agency of the Great Green Wall
pCO_2	partial pressure of carbon dioxide
PV	photovoltaic
SDGs	Sustainable Development Goals
SDGSAT-1	Sustainable Development Science Satellite 1
SDO	subsurface and deeper ocean
SMAP	Soil Moisture Active and Passive satellite
SOM	self-organizing map
SST	sea surface temperature
TOC	total organic carbon
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UN-Habitat	United Nations Human Settlements Programme
UNIDO	United Nations Industrial Development Organization
WHO	World Health Organization
WUE	water-use efficiency

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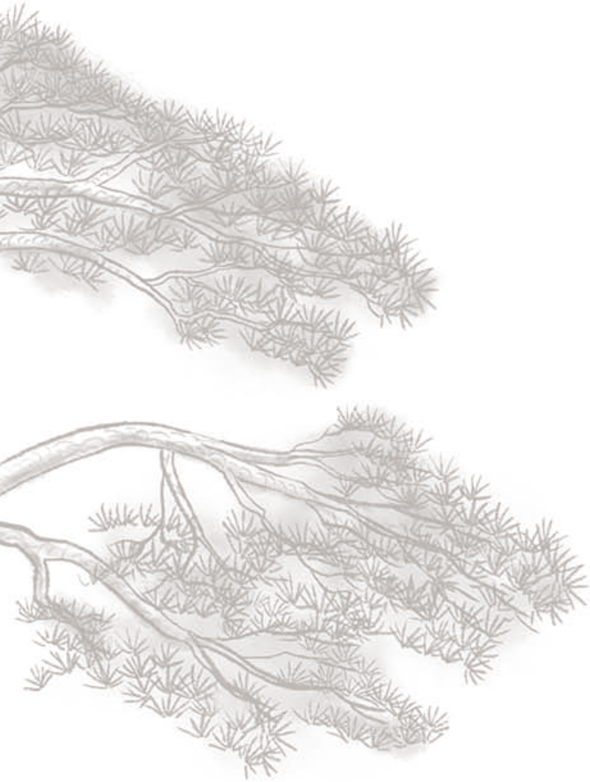

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