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Urban natural resource accounting based on the system of environmental economic accounting in Northwest China: A case study of Xi'an

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ABSTRACT

Drawing lessons from the System of Environmental and Economic Accounting Central Framework (SEEA-CF) and Experimental Ecosystem Accounting (SEEA-EEA), China is carrying out a pilot project for ecosystem accounting at the provincial level. Compiling and applying the principles, methods and ecosystem accounts of natural capital accounting in Northwest cities are new explorations. This study considers the degradation and fragility of the urban ecosystem in Xi'an and discusses urban natural resource (NR) accounting in terms of the physical quantity and monetary value. We took Xi'an as a case to demonstrate how to use the SEEA to analyze NR changes and the effectiveness of local eco-environmental management policies based on the characteristics of cities. The results show that, compared with using the physical quantity, calculating the monetary value according to NR restoration obligation, NR maintenance obligation better reflects the utilization level of urban NR, measures resource depletion and degradation, and maximizes the utility of the accounting results. This study focuses on using NR accounting methods for urban water resources, land resources and mineral resources, and evaluating ecosystem services for purposes of ecological restoration. It lays a foundation for consolidating urban gross ecosystem product accounting results in line with the SEEA and provides support for future study.

1. Introduction

Northwest China is a typical developing region, with deep-inland locations and geomorphic features dominated by mountains, basins and deserts, including the Gobi Desert. It contains 7.33% of the population and 32.25% of the territory of China, with 52.19% of the region's population living in cities or towns. The northern part of Shaanxi Province is the Loess Plateau, which accounts for 40% of the province's land area, and the southern part is the Qinba Mountains. The terrain, which is higher in the north and south, and lower in the center, is composed of plateaus, mountains, plains and basins. Shaanxi Province crosses the Yellow River and the Yangtze River, spanning three climatic zones, with large climatic differences between north and south. Located in the Guanzhong Plain in the central part of Shaanxi Province, Xi'an is a typical river valley city and the largest city in Northwest China. From the northern part of the Qinling Mountains to the southern part of the loess, the geomorphology and land use types differ significantly. In addition, serious ecological damage, such as leveling mountains and building cities in Yan'an (The Ministry of Natural Resources of China, 2017), Shaanxi Province, and environmental pollution in the protected areas of the Qilian Mountains in Gansu Province, has occurred frequently in Northwest China. The conflict between resource shortages and urban development has become increasingly prominent (Li et al., 2012). The utilization of natural capital (NC) faces the dual challenges of industrial transformation and upgrades and a high population concentration. The construction of ecological civilization has not kept pace with the development of the socio-economic (Zhang et al., 2020). Owing to the historical experience of urban recessions caused by resource and environmental problems during industrialization periods in developed countries, cities in Northwest China, represented by Xi'an, have gradually realized that it is necessary to achieve a balance between the socio-economic and NC, and to practice sustainable development of urban ecosystems (Onofri et al., 2017; Sutton and Anderson, 2016). To transform the urban development strategy into ecological priority and green

Abbreviations: ES, Ecosystem services; GDP, Gross domestic product; GEP, Gross ecosystem product; NBS, National Bureau of Statistics; NC, Natural capital; NRBS, Natural resources balance sheet; NR, Natural resource; SEEA, System of Environmental and Economic Accounting; SEEA-CF, System of Environmental and Economic Accounting Central Framework; SEEA-EEA, System of Environmental and Economic Accounting Experimental Ecosystem; SNA, System of National Accounting; UN, United Nations; WTP, Willingness to pay.

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development, it is imperative to develop a natural resources balance sheet (NRBS) based on SEEA to dynamically monitor and predict urban NC and form a scientific basis for urban spatial development and governance.

NC is a natural asset that provides ecosystem services (ES) to enhance human well-being (Costanza and Daly, 1992). However, the basis of achieving goals of efficiency, fairness and sustainability is the estimation of value (De Groot et al., 2012). The traditional system of national accounting (SNA) cannot accurately measure the contribution of NC and the impact of socio-economic activities on NC. It is also impossible for the SNA to calculate the importance to the sustainability goals of public goods and services provided by the ecosystem; in particular, it ignores the loss of the positive externalities of the ecosystem after land use conversion (Costanza, 2020). This creates the illusion of increased income, which leads policymakers and researchers to ignore the fact that natural wealth is declining. In 1993, the United Nations (UN) and the World Bank added natural resource (NR) and the environment to the national economic accounts, and issued SEEA-1993 which uses physical value quantity (physical quantity) to describe economy-environment interactions in various fields. In the following 20 years, the accounting establishment, accounting methods, practice specifications and other content continuously improved, and the resource and environmental accounting statistical standards of the System of Environmental and Economic Accounting Central Framework (SEEA-CF) were formed. The UN added the accounting of ES to the accounting of ecological assets and published the System of Environmental and Economic Accounting Experimental Ecosystem (SEEA-EEA) in 2014 (United Nations System of environmental economic accounting, 2012). In practice, North American and European countries place more emphasis on the accounting of the value of ES based on the SEEA-EEA. The similarity between the SEEA-CF and SEEA-EEA is that they both follow the basic “flow-stock” accounting framework. In the division into physical accounting and value accounting, asset stock and service flow are the basic focus. However, the SEEA-CF emphasizes the material flow of a certain type of environmental asset. The SEEA-EEA emphasizes ecological function from the perspective of the ecosystem. In terms of valuation method, the SEEA-CF mainly evaluates individual resources. The valuation method is closer to that of economic accounting methods. In contrast, the SEEA-EEA mainly estimates the value of ES. In terms of content structure, the SEEA-CF includes components such as the physical flow of environmental assets to the economy and environmental economic transactions, while the SEEA-EEA does not include economic transactions related to ecosystem protection. The SEEA-CF and SEEA-EEA have significant reference value and significance for China’s implementation of NC accounting. In February 2013, China launched the gross ecosystem product (GEP) accounting project (United Nations, 2013), which measured the final output value of a certain regional ecosystem for economic and other human activities in a specific period. It provides an important reference for quantifying the ability of NR to provide ES and their contribution to human well-being. In the same year, China first proposed exploring the compilation of NRBS and proposed auditing departing leaders for eco-environmental responsibility (Song et al., 2019). On this basis, China is establishing a lifelong accountability system for environmental damage. In December 2015, China promulgated and implemented the “Experimental Compilation System for Natural Resources Balance Sheet (Compilation Guidelines)”, which laid a legal foundation for cities to compile and use NRBS. The National Bureau of Statistics (NBS) began to carry out pilot ecosystem accounting in Guangxi Zhuang Autonomous Region and Guizhou Province in 2017. During this time, the NBS developed close cooperation with the UN Statistics Division, the UN Environment Programme and the European Union on Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) to strengthen the guidance of national NRBS in relation to the physical and ecological value of land, forest and water ecosystems in Guangxi and Guizhou Province (United Nation, 2020). However, the compilation and application of ecosystem accounts, accounting principles and methodology of the SEEA-EEA still require testing in urban contexts in terms of applicability, implementation and policy in developing countries including China.

NRBS compilation is the latest attempt at NC accounting (Blignaut, 2019). Using the SEEA’s NRBS framework to calculate the physical quantity of NR is a relatively mature theoretical approach. On the basis of improving the physical quantity of land resource accounts (Geng et al., 2015), water resource accounts (Naspolini et al., 2020), forest resource accounts (Shi et al., 2018), and mineral and energy resource accounts (Ji and Liu, 2016), cities in western China started to compile NRBS (Jiao et al., 2018). However, due to the stringent statistical data requirements of the SEEA-CF, it is difficult to obtain the necessary data, and these efforts are seriously lagging (Yan et al., 2017). Therefore, whether the SEEA’s NRBS is suitable for China in the period studied and how it can be applied to the current status of urban resources are difficult questions. In most developing countries including China, NC accounts are rarely used for public policy decisions (Recuero Virto et al., 2018), but the compilation of NRBS and their applications are far-reaching. NRBS compilation not only provides baseline data for the effective management of NR (Norton et al., 2018), but also contributes to the establishment of a national NR asset management system (Yan and Bi, 2018). Chinese scholars have produced useful investigations. Through the improvement of the form, data measurement methods and assessment indexes of land accounting, this study analyses the problems of auditing departing leaders for eco-environmental responsibility in land accounting in NRBS. In addition, it probes the relationship between compiling an NRBS and auditing departing leaders for eco-environmental responsibility (Geng and Wang, 2014). In China, local governments are responsible for meeting environmental protection goals. Thus, the leaders of local governments bear important environmental protection responsibilities (You, 2016). Auditing departing leaders for eco-environmental responsibility is an important mechanism for supervising local leaders in fulfilling their eco-environmental protection responsibilities. China is piloting the inclusion of GEP in the performance evaluations of local officials. Although auditing departing leaders for eco-environmental responsibility based on an NRBS is still controversial in terms of the subject, scope, content and methods of such audits, it has an important impact on the NR property system, the ecological red line, the environmental protection accountability system, and NR in general (Cai and Bi, 2014).

Managers and users of NR need to understand the relationship between element attributes and values (Smith et al., 2016). The key issue of this study (Fig. 1) is how to grasp the status of resources in a timely manner, measure the depletion and degradation of resources and then maximize the utility of the NR accounting results. The data presented in an NRBS represent only the appearance of accounting for the resource environment.

The value of this study is it delves deeply into the policy significance behind the data to maximize the utility of the NR accounting results. Although NC accounting and valuation are in the early stage of research and application in China, the NBS provides policy and guidelines for guiding NRBS, GEP is being applied in pilot provinces and scholars are adapting dynamic assessment methods of ES values for China (Xie et al., 2017). Although these initiatives play a fundamental role in applying and popularizing the SEEA-EEA in northwestern cities, whether the SEEA’s NRBS is suitable for these cities is a crucial question that has not yet been answered.

2. Methods and data

2.1. Definition and assumptions

NR assets refer to NR that have clear ownership, effective control by the owner, and direct or indirect economic benefits through possession or use (Geng et al., 2015). NR liabilities refer to the consumption or degradation of NR, with their value being related to expenses arising

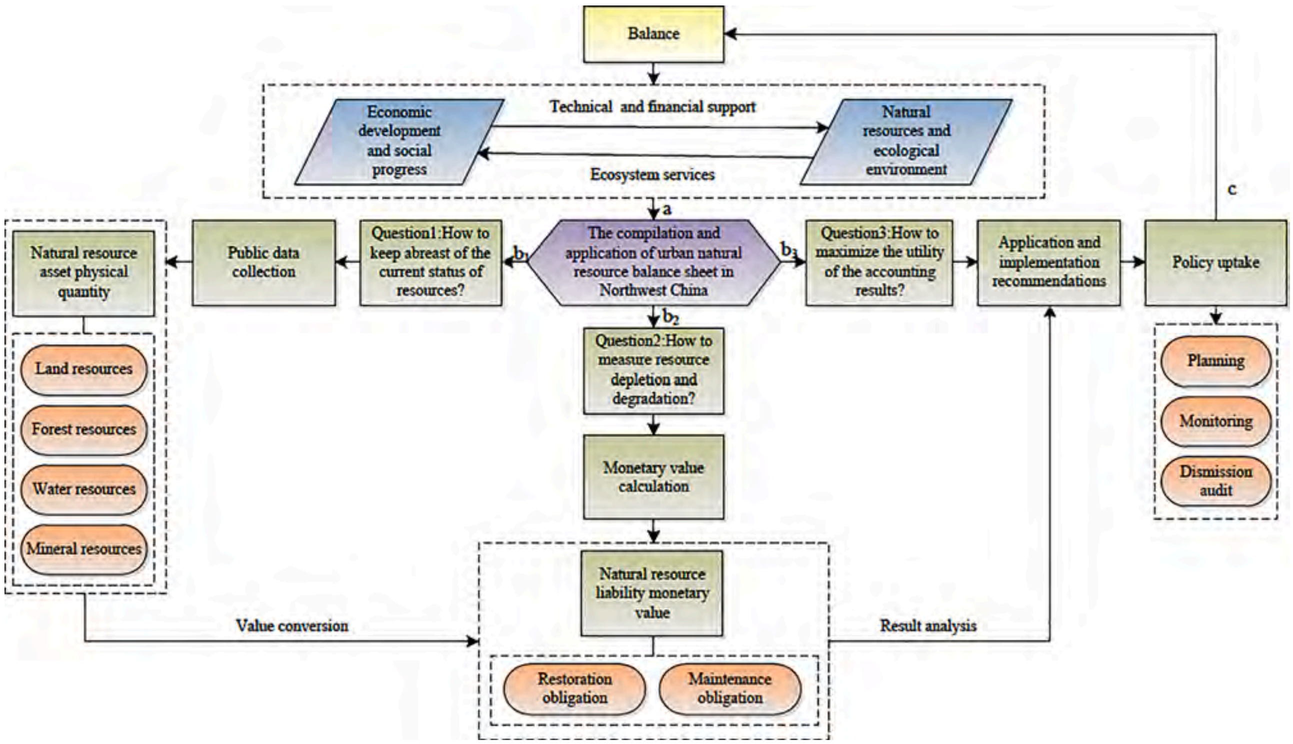

Fig. 1. Research framework. Note: In the flow descriptors, the research started at point (a) and led to 3 streams (b_1/b_2/b_3) of investigation.

from compensation for degraded NR or ecological environments. This value specifically includes the cost of restoration and maintenance NR when environmental pollution and damage are caused in the process of resource development and utilization as well as all economic losses caused by ecological restoration and environmental governance (Yan and Bi, 2018). The NR restoration obligation is based on the concept of ecological restoration, which is a method of comprehensively restoration the NR environment through capital investment (Blignaut et al., 2014). The NR maintenance obligation refers to the obligation to adopt maintenance guarantees to avoid the depletion or degradation of NR. Recognizing the value of NC is the basis for NRBS compilation. In addition to using NC in standard cost-benefit calculations (Antoine, 2018), Li (1990) established the basic NC formula based on the principle of rent. Drawing on the basic accounting assumptions of "accounting entity, accounting stage, monetary measurement, and sustainable operation" (Rui, 2015), the following assumptions regarding the NRBS compilation are proposed:

Firstly, the government entity assumption. The government fulfills the obligation of managing NR and reasonably plans the development and utilization of these resources under the scrutiny of the public in China. One important objective of compiling an NRBS is to assess how well the leading cadres meet their ecological responsibilities. As the main entity responsible for compiling an NRBS, the government is also the main entity using it.

Secondly, the sustainable development assumption. This assumption plays a continuous controlling role in the natural and social environment in realizing sustainable development and utilizing resources and the environment. This assumption is based on the premise that the national government, as the main body of statement compilation, will always exist.

Thirdly, the value measurement assumption. This assumption is reflected mainly by physical quantity and monetary value. Physical quantity accounting directly expresses the quantity of NR through accounts reflecting reserves and utilization status. Monetary value accounting is based on physical quantity data, expressing the value of NR in monetary terms and unifying the accounting units of different.

Lastly, the accounting staging assumption. This assumption is divided into two situations: calendar year and fiscal year. The natural cycle usually refers to a natural year. NRBS is often regularly prepared on the basis of natural cycles. However, because government agencies and their administrative functions are the main body of NR management, preparing an NRBS with a management cycle limited to the leadership term reflects the quality of resource and environmental management. Meanwhile, it also lays the foundation for auditing departing officials for eco-environmental responsibility.

2.2. Account settings and accounting methods

According to China's National NR Physical Quantity Scale (China National Bureau of Statistics, 2002), NR asset account of Xi'an is divided into four secondary accounts: land resources, forest resources, water resources and mineral resources (Table 1).

Referring to the classification of NR liabilities by Yan et al (Yan et al., 2020) and the actual situation of NR in Xi'an, NR liability account is be established (Table 2). The main liabilities are the obligations of NR

Table 1
The physical quantity scale of natural resource assets in Xi'an.

Resource Type	Data resources
Land resources	In the Geographical Information Monitoring Cloud Platform, the "30 m" grid data of Shaanxi Province was obtained in 2010 and 2015. According to the city boundary of Xi'an, the ArcGIS software was used to extract the number of grids of different land use types, and the land use area data of Xi'an in 2010 and 2015 were obtained by the area conversion of each grid. Among them, "land use" is intended to include elements of land cover and land use.
Forest resources	Estimating the forest resources based on the forest area data of Xi'an, forest area, forest stock and age group composition data of Shaanxi Province based on the data of the *Eighth National Forest Resources Inventory* (2009–2013).
Water resources	*Xi'an Statistical Yearbook* of 2011 and 2016
Mineral resources	*Xi'an Mineral Resources Planning* (2006–2020)

Table 2
Natural resource liabilities monetary value accounting in Xi'an.

Resource Type		Data resources	Methods
Natural resource restoration obligation	Water pollution	*Xi'an Statistical Yearbook* in 2011–2016	Expense payment
	Air pollution	*Xi'an Statistical Yearbook* in 2011–2016	Expense payment
	Solid waste	*Xi'an Statistical Yearbook* in 2011–2016	Unit cost analysis model
Natural resource maintenance obligation	Maintenance of land resources	Reduction	Equivalent factor method
	Maintenance of forest resources	Reduction	Young forest: appraisal value from method of replacement cost Middle-aged forest, near-mature forest, mature forest, over-ripe forest: method of conversion current price
	Maintenance of water resources	*Xi'an Statistical Yearbook* in 2011–2016	Willingness to pay
	Maintenance of mineral resources	*Energy mineral resources consumption: Xi'an Statistical Yearbook* in 2011–2016	IPCC emission inventory method
		Other mineral resources exploitation: Xi'an Mineral Resources Planning (2006–2020)	The unit price of other mineral resources is obtained through the annual output of mineral resources and industrial output value of the *China Mining Yearbook* 2013.

restoration and maintenance. The NR restoration obligation is the obligation to address NR pollution. This obligation is divided into three subjects: water pollution discharge abatement, air pollution discharge abatement, and solid waste disposal and restoration. The maintenance obligation can be understood as the resource consumption and regeneration cost of NR depletion or degradation. This obligation is divided into maintenance of land, maintenance of forest resources, maintenance of water resources and maintenance of mineral resources.

2.3. Data processing for special accounts

2.3.1. Solid waste

Solid waste is composed mainly of industrial solid waste, household garbage and hazardous waste in Xi'an. The physical quantity of solid waste can be directly obtained from *Xi'an Statistical Yearbook*, but the monetary value of solid waste cannot. Therefore, this study adopts the unit cost analysis model, which means that the costs of solid waste disposal and restoration are obtained by multiplying the physical quantity of different types of solid waste with the corresponding unit treatment costs (Wu et al., 2018).

2.3.2. Forest resources

According to China's standard techniques for estimating forest economic values, the maintenance costs of forest resources are evaluated differently for different age groups (Wang et al., 2009). The maintenance costs of forest resources include the main felling cost, transportation cost, lumber yard cost, sales cost, management cost and other unforeseen expenses. The direct economic value of young forests is low. According to the cost input, the replacement cost method is used to calculate forest resource assets (Liu, 2018). Mature forests and over-ripe forests have complete market transaction values. The method of conversion to the current price can be used to estimate the value of forest resource assets. This method is also used to evaluate the value of middle-aged and near-mature forest resources due to the lack of calculation parameters necessary for the growth schedule of forest resources or harvesting tables.

2.3.3. Water resources

The main methods for calculating water resource value are the benefit value method, the opportunity cost method and the willingness-to-pay (WTP) method (Barton, 2002). The WTP is used to indirectly calculate the economic use value of water resources by subtracting the marginal cost of the water supply system from the consumer's WTP the water fee. This method is recommended by the World Bank and Asian Development Bank, and has many advantages, such as direct calculation and good applicability of the calculation results.

2.3.4. Energy mineral resources

Pan and Zhang (2011) performed carbon productivity research in various provinces across the country. The carbon dioxide emissions of energy mineral resource consumption, i.e., carbon dioxide equivalent emissions, were estimated by adopting the carbon emissions coefficient provided by the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

3. Case study

3.1. Study area

Xi'an is the capital of Shaanxi Province and one of China's 9 national central cities. It is currently the only one in Northwest China. It has a unique location advantage and is an important transportation hub in the west (Fig. 2). In 2019, Xi'an had a permanent resident population of 10.2 million, making it a key city with a net inflow of the western population. The Gross domestic product (GDP) of Shaanxi Province was 368.5 billion USD, and the GDP of Xi'an was 133.2 billion USD, accounting for 36.1% of the province's GDP and ranking first among cities in Northwest China. Xi'an's GDP grew by 7.0%, and its per capita GDP was 13 thousand USD (Xi'an Bureau of Statistics, 2019) Xi'an has a land area of 10,108 km^2, constituting 4.9% of the land area of Shaanxi Province (205,600 km^2), and 26.3% of the province's population (38.76 million persons). The built-up area of Xi'an increased from 231 km^2 in 2005 to 683.09 km^2 in 2017. The area of construction land has increased by 415.54 km^2 over the same period, accounting for 64.27% of Xi'an's existing construction land.

There are 6 rivers in Xi'an with a drainage area of more than 1,000 km^2 and 40 rivers with a drainage area of more than 50 km^2. The river network is dense. The total water resources included in the city's drainage basins are 2.347 billion m^3, but the per capita availability is 277 m^3. The spatial and temporal distribution of runoff is uneven. Among the 28 monitoring sections of 13 rivers in Xi'an, 21 monitoring sections meet the water quality standards when evaluated according to water environmental function zoning categories. The overall water pollution of Xi'an River declined in 2018, and the comprehensive pollution index decreased by 20.2% relative to the same period in the previous year. Xi'an's ambient air quality reached level 2 (good air quality) of the Ambient Air Quality Standard on 188 days, which is 51.5% of the total number of days in 2018. Although the urban green coverage rate in Xi'an has reached 36%, the per capita public green space is 8.6 m^2 compared with China's average of 36.65 m^2. The Guanzhong Plain urban agglomeration with Xi'an National Central City as its core is exerting the driving effect of cities and industries to form a metropolitan circle, but the status and influence of urban development do not match the current fragile ecosystem. The continuous industrial

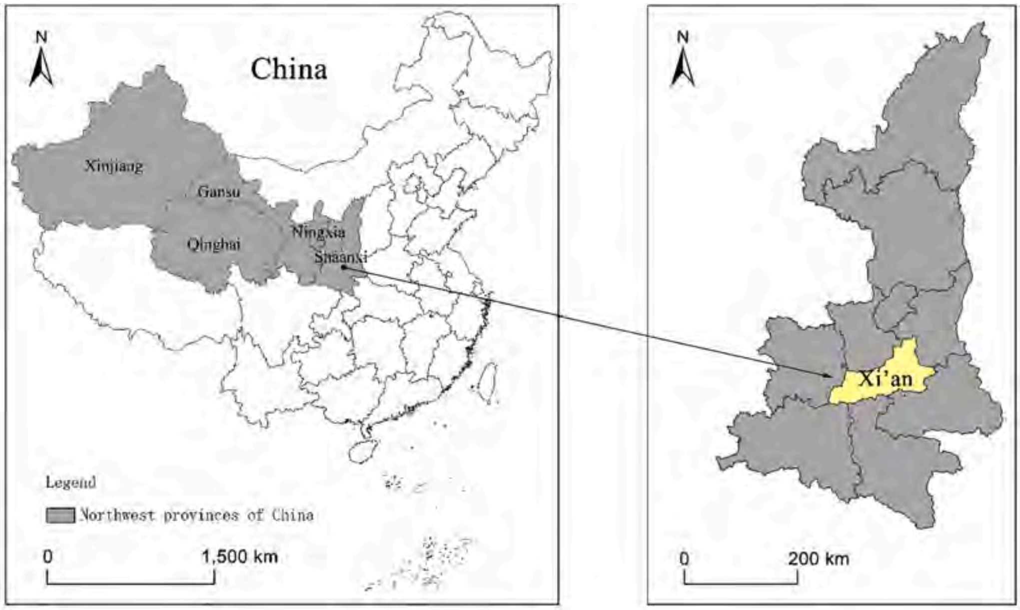

Fig. 2. Location of Xi'an in Shaanxi Province of China.

transformation and upgrading and the expanding population size have increased the demand for NR in Xi'an. The urban space has expanded rapidly, and problems such as declining air quality, water shortages and land designated for urban construction which has been depleted. The ecological carrying capacity associated with ecological restoration and construction in Xi'an has not fundamentally solved the problems of increased resource consumption and insufficient carrying capacity caused by population growth and industrial agglomeration. Urban

Table 3
Physical quantity and change in natural resource assets in Xi'an in 2010 and 2015.

Natural Resource Asset Account			2010	2015	Change value
Land resource asset (km^2)	Cultivated land		3,741.83	3,593.75	−148.08
	Forest land		3,069.46	3,064.12	−5.34
	Grassland		2,029.75	2,028.07	−1.68
	Water area		129.81	135.44	5.63
	Unused land		3.50	4.24	0.74
	Construction land		1,133.85	1,282.58	148.73
	Subtotal		10,108.20	10,108.20	–
Forest resource asset	Young forests	Area (ha)	87,909.33	87,756.40	−152.94
	Middle-aged forests	Volume (m^3)	4,079,540.51	4,072,443.25	−7,097.26
	Near-mature forests	Area (ha)	135,946.38	135,709.87	−236.51
		Volume (m^3)	6,308,758.70	6,297,783.23	−10,975.47
	Mature and over-ripe forests	Area (ha)	83,090.28	82,945.73	−144.55
		Volume (m^3)	3,855,906.48	3,849,198.28	−6,708.20
	Subtotal	Area (ha)	306,946	306,412	−534
		Volume (m^3)	14,244,205.7	14,219,424.8	−24,780.93
Water resource asset (10^6 m^3)	Total groundwater resources		14.70	11.37	−3.33
	Total groundwater resources		9.40	11.11	1.71
	Subtotal		24.10	22.48	−1.62
Mineral resource asset	Metal mineral resources Recoverable deposits	Gold (t)	20.25	–	
		Iron (t)	562,000	–	
		Copper (t)	48,046	–	
		Lead (t)	13,946	–	
		Zinc (t)	26,069	–	
		Silver (t)	20	–	
		Cadmium (t)	25,000	–	
		Selenium (t)	73,000	–	
	Non-metallic mineral resources Recoverable deposits	Chemical raw materials	Pyrite (thousand t)	157	–
		Building materials and others	Graphite (thousand t)	1,684	–
			Feldspar (thousand t)	1,179	–
			Limestone used in cement (thousand t)	57,720	–
			Limestone used in marble (thousand t)	7,960	–
			Kaolin (thousand t)	2,264	–
			Ceramsite clay (thousand t)	1,172	–
			Facing gabbro (thousand m^3)	80	–
			Facing marble (thousand m^3)	5,910	–

ecological security has become an increasingly prominent issue.

Xi'an is a historic city that is famous worldwide. It has 2 sites and 6 properties listed in *The World Heritage List*. It has not only historical and cultural sites spanning more than three thousand years of civilization, but also 23 national or public universities and 24 national scientific research institutes, ranking third among cities in China. In the accelerated process of urbanization, an increasing number of cultural sites have been incorporated into Xi'an urban planning and construction. The scale of universities and scientific research institutes has been expanding. The continuous expansion of scale has brought great land pressure caused by construction.

3.2. Physical quantity accounting of Xi'an's natural resource assets

Currently, there are two main types of NRBS. One is compiled from the perspective of accounting, with reference to the compilation style of a company's balance sheet, and is divided into resource assets and resource liabilities. The other is compiled following the SEEA-CF on the basis of end-of-term stock = initial stocks + stock changes. The second type of NRBS clearly and accurately shows changes in NR by subdividing the changing factors. According to the change factor or change reason matching entry in the SEEA, some data are estimated. For example, the market price inversion algorithm was used to evaluate the value of middle-aged and near-mature forest resources in Xi'an. The unit cost analysis model was used to estimate the cost of solid waste disposal and restoration. Therefore, in the early stage of urban NRBS compilation in Northwest, data published on government websites, such as the *Statistical Yearbook* of Shaanxi and Xi'an, and relatively simplified report forms such as "resource assets" and "resource liabilities" were used to calculate the utilization level and the physical quantity of NR assets in Xi'an (Table 3).

3.2.1. Land resource assets

The area of Xi'an is 10,108.20 km^2 (Table 3). Its geomorphology is divided into two parts: the Qinling Mountains and the Weihe Plain. The land resource accounting of Xi'an consists of six categories: cultivated land, forestland, grassland, water areas, unused land and construction land. Comparing the physical quantity data of land resources in 2010 and 2015, it reveals that areas of water, unused land and construction land increased in Xi'an, while areas of cultivated land, forestland and grassland decreased. Among the land use types, cultivated land had the largest reduction in area, from 3,741.83 km^2 in 2010 to 3,593.75 km^2 in 2015, which is a decrease of 3.96% (Fig. 3). Correspondingly, the construction land in Xi'an increased sharply, from 1,133.85 km^2 in 2010 to 1,282.58 km^2 in 2015, which is an increase of 13.12%. With the rapid development of the socio-economic and urbanization in Xi'an, in order to meet more commercial development needs, a large area of cultivated land has been converted into construction land, leading to the increasingly prominent problem of cultivated land occupation.

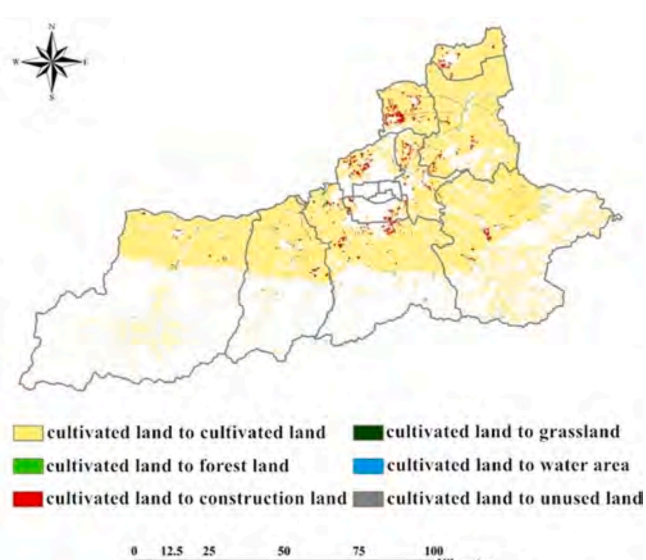

Fig. 3. Xi'an cultivated land conversion from 2010 to 2015.

3.2.2. Forest resource assets

Xi'an's forest coverage rate was 48.03% in 2016. However, forest resources are decreasing. The reduction reached 24,780.93 m^3 from 2010 to 2015 (Table 3). As an important ecological barrier, the northern foothills of the Qinling Mountains have concentrated the main forest resources in Xi'an. This barrier serves a multi-faceted function of biodiversity, water conservation, and soil conservation, affecting the resources and environment in Xi'an. The problem of illegal occupation of forestland, such as by quarrying, villa construction and land consolidation in the Qinling Mountains, has led directly to a decrease in the forested area of Xi'an.

3.2.3. Water resource assets

The river network in Xi'an is dense and has had the reputation of passing the "eight rivers around Chang'an" since ancient times. The Weihe River is the largest river slowing through Xi'an, with a length of 26 km and an average annual runoff of 4.69 billion m^3. Water resource assets accounting shows that the total amount of water resources in Xi'an in 2010 was 2.41 billion m^3, but in 2015, it fell to 2.25 billion m^3, a decrease of 6.72% (Table 3). Groundwater have reduced by 3.33 billion m^3. Surface water has increased by 1.71 billion m^3. Generally, there is a hydraulic connection between groundwater and surface water. Due to the destruction of urban vegetation, the ability of the surface to absorb water decreases, and soil and water conservation capacity weakens. Precipitation carries sediment to rivers, lakes and oceans and gradually leads to decrease in groundwater and increase in surface water.

3.2.4. Mineral resource assets

The asset value of metal mineral resources in Xi'an is 748,101.25 tons, and the maximum reserve of iron ore is 562,000 tons. At present, the development and utilization in Xi'an are focused on gold mines and non-metallic minerals such as building materials (Xi'an Natural Resources and Planning Bureau, 2013). The non-metallic mineral resources of Xi'an can be divided into chemical raw materials and construction materials. Pyrite is the main non-metallic mineral resource of chemical raw materials, with a reserve of 157 thousand tons and an asset value of 10.06 million USD. The value of construction materials and other non-metallic resource assets is 1.36 billion USD, accounting for 99.26% of the total value of non-metallic mineral resource assets, and these are the most important components of Xi'an's mineral resources.

3.3. Monetary value accounting of Xi'an's natural resource liability

To measure the depletion and degradation of NR in Xi'an, NR liability is divided into the obligations to restore and maintain NR.

3.3.1. Natural resource restoration obligation

Water pollution discharge abatement accounting mainly refers to sewage treatment costs generated during the consumption of water resources in Xi'an. Based on the source, water pollution emissions are divided into domestic sewage and industrial wastewater. The total discharge of wastewater in Xi'an from 2010 to 2015 was 2,780.45 million tons. Of this figure, the discharge of urban domestic sewage was 2,203.18 million tons (see Appendix Table B.1), accounting for 79.24% of the total emissions. The total amount of wastewater discharged showed a slight decline and then a rapid increase, reaching a peak of 645.52 million tons in 2015. Based on the composition of wastewater discharge in Xi'an (Fig. 4 and Table 4), the surge in emissions was due mainly to the increase in urban domestic sewage discharge. From 2013

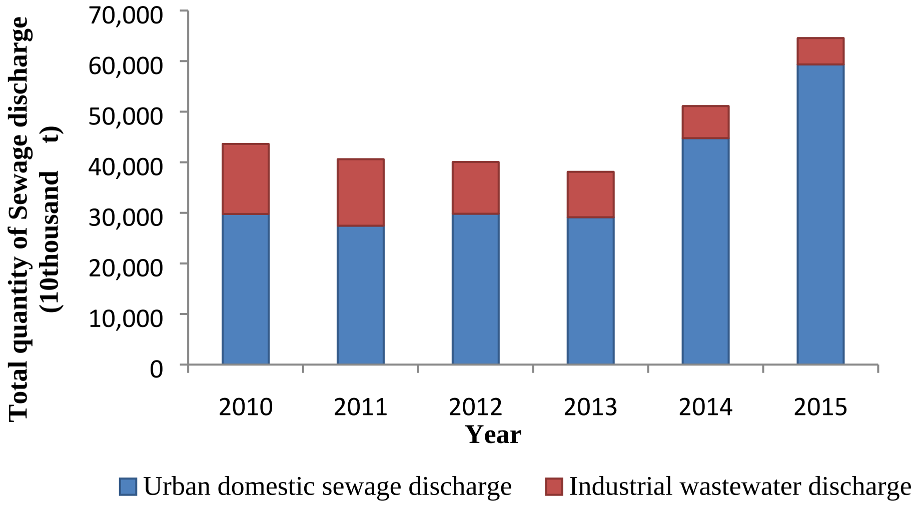

Fig. 4. Composition of total wastewater discharge in Xi'an from 2010 to 2015.

Table 4
Total quantity and restoration costs of sewage discharge in Xi'an from 2010 to 2015.

Classification	2010	2011	2012	2013	2014	2015	Total
Total quantity of Sewage discharge (million t)	436.22	406.06	400.47	381.08	511.10	645.52	2,780.45
Sewage discharge restoration costs (million USD)	35.91	71.50	68.66	158.41	80.84	137.90	553.22

to 2015, the urban domestic sewage discharge of Xi'an increased by 302.132 million tons, with a growth rate of 103.70%. The urban population of Xi'an increased from 4.09 million in 2013 to 5.46 million in 2015. The resulting increase in domestic water demand led to an increase in urban domestic sewage discharge. The cost of water pollution restoration in Xi'an was 553.22 million USD over 2010–2015 and fluctuated over the period. The water pollution discharge abatement costs in Xi'an in 2013 and 2015, 158.41 million USD and 137.90 million USD (see Appendix Table B.2), respectively, were significantly higher than those in other years. To strengthen the pollution control of the Weihe River and to solve the problem of insufficient sewage treatment capacity in Xi'an, four new sewage treatment plants were built, and plans were made to expand or begin operating seven sewage treatment plants along the Weihe River in 2013. Xi'an built and expanded 13 sewage treatment plants in 2015, adding a daily sewage treatment capacity of 1.065 million m^3. These measures achieved the complete collection and treatment of urban domestic sewage and industrial wastewater.

The total amount of air emissions from Xi'an in 2010–2015 was 952.83 thousand tons (domestic air emissions were 285 thousand tons, and industrial air emissions were 667.83 thousand tons). Sulfur dioxide accounted for the most significant air pollution. In 2012, Xi'an's air emissions began to decline after reaching a peak of 187 thousand tons (Fig. 5). Xi'an Environmental Protection Bureau began to implement *Coal-fired Boiler Dust and Sulfur Dioxide Emission Limit Standards*, which stipulated the maximum allowable emission concentration limits for coal-fired boiler soot and sulfur dioxide within the city in 2012. In the

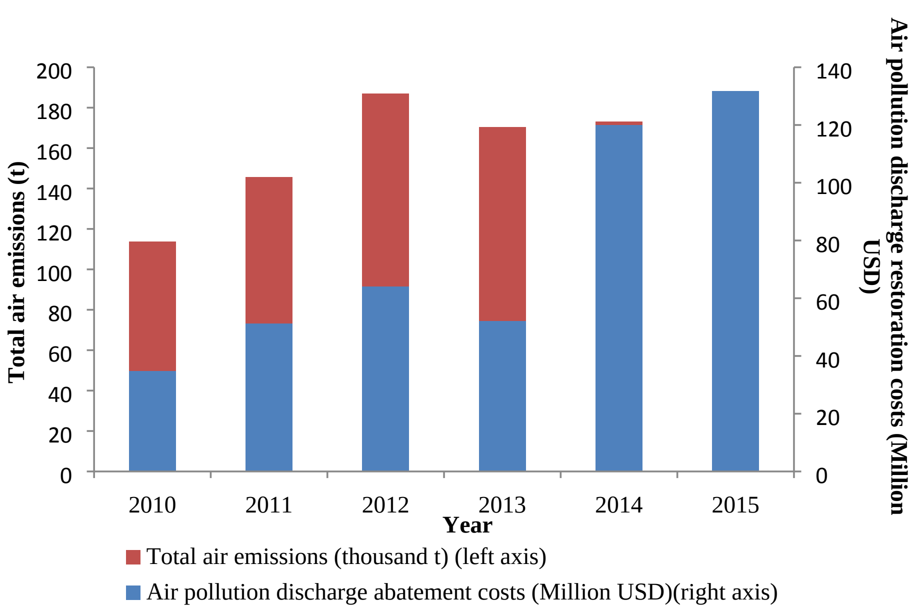

Fig. 5. Comparison of trends in total air emissions and air pollution discharge abatement costs in Xi'an from 2010 to 2015.

same year, Xi'an implemented 91 sulfur dioxide and nitrogen oxide emissions reduction projects and completed the demolition of 43 coal-fired boilers. Additionally, 70% of the non-electric boilers above the scale and 90% of the thermal power units in the city installed desulphurization facilities. Xi'an completed the demolition of 565 coal-fired boilers, and 27 thousand residential coal users switched to clean energy in 2013. The total air pollution discharge abatement expenditure in Xi'an from 2010 to 2015 was 453.51 million USD. A rapid increase in air pollution discharge abatement expenditure occurred in 2014, and the expenditure reached 131.62 million USD in 2015. In response to the *Implementation Plan for Pollution Control and Reduction of Xi'an* (2013), Environmental Protection Bureau accelerated the pace of organic waste gas treatment in industrial enterprises and gradually increased expenditure on air pollution discharge abatement. In 2014, industrial enterprises in Xi'an began the process of completion acceptance, project monitoring and performance evaluation of organic waste gas treatment projects, for which they received government subsidies. However, atmospheric governance cannot rely solely on short-term policies; rather, it focus on changes in urban emissions and dynamically adjust implementation plans.

The total amount of solid waste produced in Xi'an from 2010 to 2015 was 33,784.79 thousand tons (see Appendix Table B.15). The changes were relatively stable in 2011–2013 and increased rapidly in 2014–2015 (Fig. 6). Compared with water and air pollution discharge abatement, Xi'an's solid waste disposal policy system, cost input and information disclosure have seriously lagged. This lag has aggravated environmental pollution and caused potential risks. *Xi'an Statistical Yearbook* in 2011–2016 showed that investment in industrial solid waste cost management projects in Xi'an in 2010–2015 was 0.57 million USD. However, the estimated amount of solid waste disposal and restoration costs in Xi'an from 2010 to 2015 was 297.87 million USD (see Appendix Table B.1). This value was determined by calculating the greenhouse gas emissions from landfill treatment, which was beyond the scope of the statistical yearbook data.

3.3.2. Natural resource maintenance obligation

Areas of cultivated land, forestland and grassland in Xi'an decreased by 148.08 km^2, 5.34 km^2 and 1.68 km^2, respectively, from 2010 to 2015, accounting for 3.96%, 0.17% and 0.08%, respectively, of the total areas. The costs of this depletion were 21.67 million USD, 3.84 million USD and 0.51 million USD, respectively (see Appendix Table B.18).

Forest resources in Xi'an decreased by 534 ha, and the cost of consumption was 16.1 thousand USD in 2010–2015. Young forests and middle-aged forests accounted for the highest proportions of the overall decrease (28.64% and 28.95%, respectively), and overall, the forest resources are young. Because the restoration of vegetation requires a long growth cycle, the negative impact of forest atrophy on the decline in forest resource data is long-lasting. By ensuring stricter compliance with the approval process and carry out a reasonable resource compensation system, the government would better address the over-exploitation and deforestation of forest land.

The water sales volume in Xi'an was 2,489.29 million m^3, and the cost of water resource maintenance reached 790.73 million USD in 2010–2015 (see Appendix Table B.24). Despite a slight decline in 2011, the overall consumption of water resources in Xi'an showed an upward trend. This trend was related to increased socio-economic development, population expansion and increased water demand in Xi'an. On the other hand, the overall capacity of Xi'an water supply system improved in 2010–2015, and the supply met the urban water consumption needs in Xi'an. Therefore, Xi'an government could reasonably distribute production and living areas and continuously improve the NR infrastructure.

The energy mineral resources used in Xi'an consist mainly of coal, oil and natural gas. In terms of monetary value, the cost of energy mineral resource maintenance in 2010–2015 was 206.29 million USD, of which the energy consumption cost of industrial enterprises above the designated size was 190.02 million USD, accounting for 92.11% of the maintenance cost. The main types of energy consumed were raw coal and crude oil, with maintenance costs of 144.37 million USD and 40.82 million USD, respectively, accounting for 97.46% of the total cost of energy mineral resources (see Appendix Table B.30). Based on the trend of the physical quantity of energy mineral resource consumption, the consumption of kerosene, coke and crude oil in industrial enterprises above the designated size decreased sharply in 2010–2015 by 97.85%, 97.43% and 83.83%, respectively. The government aimed to achieve pollution control and smog reduction and implemented work to convert coal to gas and centralized heating in enterprises in built-up areas. Based on the experience of enterprise reform, the government gradually implemented measures to reduce the use of honeycomb coal to zero, change coal use to electricity use, and convert coal use to gas use through financial subsidies in urban areas.

Xi'an has clear regulations on the exploitation and utilization of mineral resources: advantageous minerals, minerals with outstanding potential value, and minerals that are more important for urban

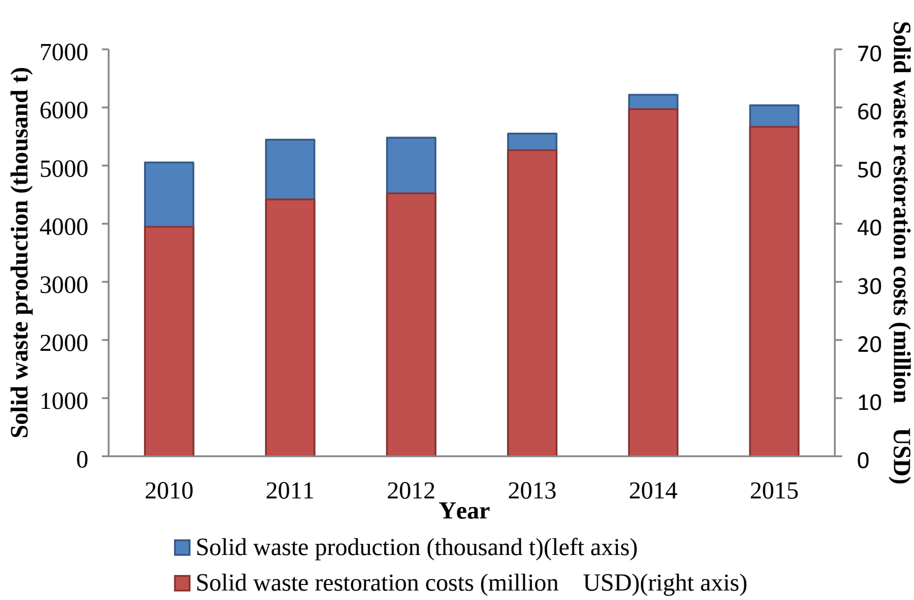

Fig. 6. Comparison of trends in solid waste production and restoration costs in Xi'an from 2010 to 2015.

construction, including gold, iron, zinc, silver, high-quality facing stone and limestone ore used for cement and other minerals, could be appropriately exploited. Xi'an has imposed restrictions on excessive mining and mining that causes serious damage and pollution to the ecological environment and strictly restricted national exports of superior minerals and strategic reserve minerals. In addition, it has strictly controlled the issuance of mining rights and the types of minerals mined. Mining of tungsten ore, poor iron ore, pyrite, low-quality cement limestone, low-quality graphite and other minerals, as well as farmland brick clay and sand and gravel resources within the specified range of river channels, is prohibited in Xi'an. From 2010 to 2015, the mining volume of other mineral resources in Xi'an was equivalent to 1.82 billion USD. Among them, the total annual mining volume of limestone ore used for cement reached 2 million tons in 2010 and 2.2 million tons in 2015, when it was valued at 1.52 billion USD. In principle, no new prospecting rights will be approved, and no new mining rights will be established within the northern part of the Qinling Mountains (Xi'an Municipal People's Government, 2016). To effectively protect the ecological environment of the northern part of the Qinling Mountains, Xi'an takes measures to classify and rectify existing mineral rights, strictly manage mineral rights and encourage the withdrawal of mineral rights (Xi'an Municipal People's Government, 2016).

4. Discussion

The study showed the physical quantity and value of NR assets in 2010 and 2015 and the changes in these assets in Xi'an. Moreover, the study conformed to the latest study direction of environmental accounting regarding how to scientifically account for NR as the core despite the challenges of compiling an NRBS (Lu et al., 2020). We established a new framework and method for NR accounting by drawing lessons from the SNA and SEEA. At present, NR accounting is divided into physical quantity accounting and monetary value accounting. It is easy to collect and account for physical quantity data, but the theoretical development and application of monetary value represent a bottleneck that has long been difficult to break through. The relevant research results are dependent on the micro-perspective of enterprises and government or the construction of detailed accounts of NR such as land resources, forest resources and water resources as well as the measurement of undeveloped and unproven energy resources associated with ecological functions. The NR assets that these studies focus on show only the city's resource stock and lack a systematic accounting practice for the value of NR. The problem of how to measure resource consumption and degradation from the perspective of accounting for NR liabilities truly reflects the impact of urban socio-economic activities on resources and the environment (Jia et al., 2019; Gonçalves et al., 2020). The public have started to invest in NC and account for it as an asset on an entity's balance sheet (Blignaut, 2019). Chinese domestic scholars have explored the preparation and application of China's NRBS from the perspective of governance and accounting attributes (Song et al., 2019). However, the lack of real data in developing cities makes it difficult to obtain assets and liabilities with accounting attributes. Thus far, whether these methods are suitable for Chinese cities in the NRBS exploration period of is still a crucial question. The contribution of this study is that based on physical quantity accounting, the monetary value method was used to calculate the NR liabilities of Xi'an in relation to NR restoration obligation and NR maintenance obligation accounts. The depletion and degradation of NR were measured to achieve a horizontal comparison of NR of different natures. Moreover, in processing special accounts, combined with the fragile characteristics of Xi'an's ecological environment and the data conditions of NR, more systematic accounting practice for NR values was created, and corresponding recommendations were proposed. To this end, we take Xi'an as a case to verify the feasibility of the framework and its reliability. This study will not only lay a scientific foundation for the assessment of urban NR management policies and implementation results in developing areas, but also have practical significance for promoting urban sustainable development.

The study evaluates the current situation of the management and utilization of NR in Xi'an and reflects the city's NR stock and consumption from the perspective of the calculation of NR assets and liabilities. From the perspective of the innovative environmental accounting knowledge system, the main logic and concept of compiling the NRBS is still based on the international standard SEEA-CF resource and environmental accounting statistical standards. But it is specifically based on the "Natural Resource Balance Sheet Test" promulgated and implemented by China. The Compilation Degree (Guidelines for Compilation) covers a wide range of contents. It connects resources, environmental and socio-economic activities around the urban ecosystem, laying a foundation for local governments to undertake environmental protection responsibilities. The study results confirm that the results of NR accounting have a positive effect on promoting the management and utilization of NR. The findings also explain why the dynamic monitoring and early warning of urban ecosystems through the preparation of NR balance sheets forms reasons for urban spatial development and ecological governance.

The preparation of China's NRBS is in its infancy. Hulunbuir in Inner Mongolia, Huzhou in Zhejiang, Loudi in Hunan, Chishui in Guizhou, and Yan'an in Shaanxi were selected as pilot cities for such preparation. However, the basis and methods for preparing these statements are still being explored. A standardized system has not yet been developed for NC accounting and valuation practices. The NBS is developing an NR asset and GEP accounting system in line with the SEEA-EEA and adapted to China's national conditions. By compiling China's national, provincial, and city-level environmental-economic accounts from top to bottom combined with the progress of the revision of the SEEA-EEA, knowledge on more effective NR management policies could be developed and implemented. Although important results are revealed by this study, there are also limitations. Firstly, due to the lack of direct data on forest resources in Xi'an, the physical quantity of forest resources was estimated based on forest area, forest accumulation and age group structure data of Shaanxi Province in the *Eighth National Forest Resources Inventory* (2009–2013). However, this alternative method will show changes only in forest resource assets affected by changes in forestland area. It does not reflect the dynamic change characteristics of tree size increasing with increases in tree age and the beginning of the harvesting period. Secondly, the impact of inflation on the price of NR has been ignored. Due to the short time span used in this study (only 5 years of data), the impact of inflation on resource prices was not significant. However, if a longer-term NRBS is developed, this impact must be considered. Thirdly, the data caliber is relatively great, and the data quality is relatively low, reducing the calculation accuracy. Overall, although accounting for NR can cover only resource changes, NR asset management may show greater effectiveness, and the universality of this framework still needs to be verified. Therefore, to determine how to prepare NRBS scientifically and reasonably, how to manage existing resources, how to use NR assets, how to promote the application of SEEA-EEA accounting standards in China, and how to implement NCAVES project research and other issues, the National Natural Resources Supervision Agency, Ministry of Ecology and Environment and other departments could implement accountability systems based on the results of NR asset accounting. This will be an important direction in the future.

5. Conclusion and recommendations

5.1. Conclusion

The compilation of NRBS could be based on the "recognition, measurement, recording, and reporting" practices of accounting (Zhou et al., 2018). The "first physical quantity, then value quantity" approach reflects the stock and quantity changes of NR (Feng et al., 2017). To measure the consumption and degradation of resources, diversified calculation methods could be adopted to form an operational accounting system.

Xi'an's physical resource utilization level shows that compared with 2010, the cultivated land area of Xi'an decreased by 148.08 km^2 in 2015 and was mainly converted into construction land. Construction land increased significantly, from 1133.85 km^2 in 2010 to 1282.58 km^2 in 2015, an increase rate of 13.12%. The occupation problem is prominent, forest resources are decreasing, soil and water conservation capacity is weakening, groundwater is decreasing, surface water is increasing, and total water resources have declined by 6.72%.

In addition, from the perspective of NR restoration obligations, first, urban domestic sewage discharge increased by 103.70% and water pollution discharge abatement costs surged. Second, the air pollution discharge abatement cost was 432.57 million USD. This cost was mainly associated with controlling the emissions of exhaust gas and sulfur dioxide from coal-fired boilers. Third, the investment in the industrial solid waste cost control project in Xi'an was 0.57 million USD, which was insufficient to cover the solid waste disposal cost. Increasing investment in solid waste cost control projects would ensure the effective implementation of environmental protection policies. From the perspective of NR maintenance obligations, the main energy consumption enterprises were industrial enterprises above a designated size. The main types of consumption included raw coal and crude oil consumption. The energy reform and treatment work achieved initial success. Furthermore, the limestone used in cement accounted for 83.49% of the value of other mineral resources, and there is possibility of obtaining new reserves.

Accounting can identify gaps, ensure consistency over time, ensure consistency between physical and monetary measures, provide links between physical and economic measures, etc. Through NR accounting, the accounting approach adds analytical capacity to basic statistics. It can more accurately reflect the differences in different types of NR over different periods and achieve the effect of fixed ratio measurement.

5.2. Recommendations

5.2.1. Use NRBS to serve the formulation of urban land space planning

Accounting for NR and the intensity of their use through NR accounting would contribute to the optimization of land use planning decisions. It is necessary not only to improve the control of NR factors such as land, forests, water and minerals, but also to focus on overloaded areas, especially critically overloaded areas. An NRBS can reflect the stock and quantity changes of NR in the form of data and quantitatively measure the depletion and degradation of resources. At the same time, an NRBS can provide data support for urban land space planning. Then, such planning can not only meet the requirements of resource and ecological carrying capacity, but also effectively implement regional differentiated management according to the intensification and slowdown of resource and environmental consumption. The ecological compensation mechanism encourages the development of green industries that are in line with the main desired functions.

5.2.2. Resource and environment dynamic monitoring and predicting

We use long-term time series data to build an NR asset and liability information platform with timely feedback on NR assets and liability information. We can use this information to judge the rationality of NR maintenance and environmental restoration costs, analyse the factors driving changes in NR assets, monitor the ecological carrying capacity and issue warnings about capacity problems, and enhance the transparency of NR changes. The evaluation results can be included in the leadership performance evaluation system to implement public supervision.

5.2.3. Auditing departing leaders for eco-environmental responsibility

The conflict between short leadership terms and the ecological environment assessment cycle must be solved, and the one-sided pursuit of short-term benefits during leadership tenure, which leads to resource and environmental problems, must be prevented. The corresponding responsibility and rights of leaders are clearly defined through the NRBS. The need for such audits and the audit accountability of leaders are stipulated by the Chinese government in the "*Lifetime Accountability System for Ecological Environmental Damage Responsibility*".

Declaration of Competing Interest

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

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Appendix A. Supplementary data

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