An Improved Model for Evaluating Ecosystem Service Values Using Land Use/Cover and Vegetation Parameters

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(Received April 27, 2020; in final form July 15, 2020)

ABSTRACT

It is crucial to maintain the balance of economic development and ecosystem protection. The value of ecosystem services is an indicator to help people understand the importance of ecosystem protection. Traditional models estimate ecosystem service values only according to land use/cover data while ignoring vegetation status differences in the same land use/cover. This study uses the normalized difference vegetation index (NDVI), the leaf area index (LAI), and net primary productivity (NPP) as vegetation status data to describe the differences in the same land use/cover type. The principal component analysis (PCA) approach is used to reduce the correlations among the three types of vegetation status data. Then, the calculated vegetation status index after PCA is input into the estimation model. The case study in China shows that the improved model has two major advantages. First, it can clearly distinguish the differences in ecosystem service values even for the same land use/cover type. Second, it can clearly describe the transitional zones between different land use/cover types through continuous changes in ecosystem service values. This improved model can provide a more detailed description of the distribution characteristics of ecosystem service values in China and help policymakers balance economic development and ecosystem protection.

Key words: ecosystem service values, land use/cover data, vegetation status, principal component analysis (PCA)

Citation: Zhou, F.-C., X. Z. Han, S. H. Tang, et al., 2021: An improved model for evaluating ecosystem service values using land use/cover and vegetation parameters. J. Meteor. Res., 35(1), 148–156, doi: 10.1007/s13351-021-9199-x.

1. Introduction

Natural ecosystems offer materials, energy, and information for humans to live and develop, and human existence relies upon sensible use of the biotic and inorganic components of natural ecosystems (Feng et al., 2010; Douglas, 2015). By considering nature as a stock that provides a flow of services, ecosystem services link natural ecosystems to human welfare (Feng et al., 2010; Norgaard, 2010). Determining how humans depend on ecosystem services and the valuation of our dependence is a large issue (Daily, 1997). Costanza et al. (1997) gathered a large amount of information from ecologists, economists, policymakers, and the general public to build a synthesis approach to estimate the values of ecosystem services, aiming to make abundantly clear that ecosystem services account for an important portion of the total human welfare on this planet. To better assess the values of ecosystem services in a large region, Nelson et al. (2009) stressed the urgency and importance of understanding and mapping the spatial heterogeneity of ecosystem services, and Polasky et al. (2008) considered that spatially explicit ecosystem service information was needed to maximize conservation objectives. Therefore, remote sensing technology has served as a good solution because it can acquire spatially explicit images over the earth’s surface (Feng et al., 2010). Land use/cover data are usually used as a proxy measure of ecosystem ser-
vices because of their multiple linkages to carbon storage, biodiversity, soil degradation, watershed protection, and other types of services (Vitousek, 1994; Konarska et al., 2002; Zorrilla-Miras et al., 2014; Chen et al., 2019a, b). Land use/cover changes in terms of quantities and patterns, in addition to land use/cover structures and spatial configurations, tend to directly affect the structures of the principal ecological processes in a given area, thereby affecting the values of the ecosystem services in that area (Robinson et al., 2013; Serna-Chavez et al., 2014). Costanza et al. (1997) estimated global ecosystem service values based on an aggregated classification scheme with 16 primary land use/cover categories. Xie et al. (2008) developed an equivalent value per unit area of ecosystem services model in China by merging six primary land use/cover categories. Recently, Chen et al. (2019a) added “construction land” to the categories in Xie et al. (2008) and assessed the spatial association of ecosystem services with land use/cover data at the county level in China from 1995 to 2015.

In previous studies, one category of land use/cover only has one ecosystem service value. Consequently, the number of ecosystem service values is limited and discrete. In fact, these limited and discrete ecosystem service values cannot provide a precise evaluation of ecosystem service values because the real ecosystem varies continuously rather than discretely. Even in the same land use/cover type, ecosystem service values should be different because of different vegetation status. For example, 10-yr-old Betula luminifera and 25-yr-old poplar forests have great differences in their aboveground biomass, carbon storage capacity, and species richness, which are all important factors in evaluating ecosystem service values. To further show the differences in the same land use/cover, this study proposes an improved evaluation model by subdividing land use/cover categories based on vegetation status parameters and offers a case study in China. The study is organized as follows. Section 2 describes the remotely sensed data employed in this study. Section 3 describes the improved valuation model of ecosystem service values. The evaluation results and discussion are presented in Section 4. Conclusions are provided in Section 5.

2. Data

2.1 Land use/cover data

This study uses land use/cover data (LUCC) for China from 2018 provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn; Liu et al., 2010; Ning et al., 2018). This dataset was updated based on land use/cover data from 2015, with a spatial resolution of 1 km, and those data were updated based on land use/cover data from 2010, according to Landsat-8 remote sensing images, and generated by manual visual interpretation. This study uses the land use/cover classification model in Chen et al. (2019b) and classifies land use/cover into seven primary types: forestland, grassland, cultivated land, wetland, water, construction land, and unused land (Fig. 1).

2.2 Vegetation status data

As mentioned above, the disadvantage of traditional evaluation models is one value representing one land use/cover category. However, differences in plant heights, diameters at breast height, growing years, vegetation coverages, etc. can impact ecosystem service values. To better describe these differences, this study imports some vegetation status parameters to build a continuous coefficient to conduct a linear evaluation of ecosystem service values.

High landscape heterogeneity and species richness have long been recognized as significant factors of ecosystem service values. Both are related to patchiness in vegetation cover, which can be measured as variability in the normalized difference vegetation index (NDVI; Feng et al., 2010). Moreover, canopy vertical distribution information is essential for animal assemblages. For example, the three-dimensional structure of the canopy is an important driver of arthropod diversity in forests. Maximum tree height, density of the canopy layer, and forest gaps are associated with beetle assemblages (Hyer and Goetz, 2004). All of these characteristics can be associated with leaf area index (LAI). Carbon fixation by vegetation and its conversion to biomass provide the basis for crop and forest yields (Ozanne et al., 2003) and create the energetic foundation of nearly all communities on Earth as well as all of other ecosystem services (Feng et al., 2010). Net primary productivity (NPP) is a good indicator of the amount of carbon fixed by photosynthesis. Based on previous studies, in this study, the vegetation status parameters are NPP, LAI, and NDVI, which are all remotely sensed parameters that can be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS).

NPP is vital to human society because it not only provides essential materials, such as food, fiber, and wood, but also creates environments suitable for human inhabitation (Turner et al., 2005; Zhao et al., 2005; Plummer, 2006). NPP has received more attention in recent years because it is directly related to the global carbon
cycle and has clear economic attributes with the development of the global carbon trading market. This study uses the MODIS/Aqua NPP Yearly L4 Global 500 m Version 6 products (MYD17A3H) from 2018 from the NASA Earthdata website (https://search.earthdata.nasa.gov/search). Then, the spatial resolution of the yearly NPP product is upscaled to 1 km to be the same scale as that of the land use/cover data.

LAI is defined as the one-sided green leaf area per unit of ground area in broadleaf canopies and as one-half the total needle surface area per unit of ground area in coniferous canopies. LAI is a biophysical variable that can influence transpiration and photosynthesis at the plant canopy scale and carbon, water, and energy dynamics at the regional scale (Asner et al., 2003; Verbyla, 2005; Liu et al., 2007). This study uses the MODIS/Terra+Aqua LAI 8-Day L4 Global 500 m Version 6 product (MCD15A2H) from 2018 from the NASA Earthdata website (https://search.earthdata.nasa.gov/search). Then, the annual LAI product is derived from the average of all 8-day LAI products, and the spatial resolution of the annual LAI product is upscaled to 1 km to be the same scale as that of the land use/cover data.

NDVI is considered to be the most commonly used vegetation status parameter and can accurately describe the minute differences in vegetation status in the same land use/cover category. Although the above-mentioned three vegetation status parameters have different definitions, they have relatively high correlations because they are all related to the vegetation status. This study uses the MODIS/Aqua NDVI Monthly L3 Global 1 km Version 6 product (MYD13A3) from 2018 from the NASA Earthdata website (https://search.earthdata.nasa.gov/search). Then, the annual NDVI product is derived from the average of all monthly NDVI products.

3. Model
3.1 Principal component analysis (PCA) of vegetation status parameters

Vegetation status parameters are continuously varying and can accurately describe the minute differences in vegetation status in the same land use/cover category. Although the above-mentioned three vegetation status parameters have different definitions, they have relatively high correlations because they are all related to the vegetation status. The PCA approach is used in this study to reduce the correlations. PCA is an effective approach for compressing information in multidimensional data by calculating an orthogonal projection that maximizes the variance in the data (Iffraguerriri and Chang, 2000). In this study, the main objective of PCA is to find a lower-dimensional representation that can account for most of the variance in NPP, LAI, and NDVI. Before the PCA, all three vegetation status parameters should first be dimensionless and normalized with Eq. (1) to avoid the in-
fluences caused by an imbalance in units. Then, the comprehensive assessment result of the vegetation status can be calculated with Eq. (2) as follows:

$$NI_i = (I_i - I_{\text{min}}) / (I_{\text{max}} - I_{\text{min}}).$$  

(1)

$$VS = \text{PCA}(NI_{\text{NPP}}, NI_{\text{LAI}}, NI_{\text{NDVI}}).$$  

(2)

where $NI_i$ is the normalized vegetation status value in pixel $i$, $I_i$ is the original value in pixel $i$, $I_{\text{max}}$ is the original maximum value in all pixels, $I_{\text{min}}$ is the original minimum value in all pixels, $VS$ is the comprehensive assessment result of the vegetation status, and $NI_{\text{NPP}}$, $NI_{\text{LAI}}$, and $NI_{\text{NDVI}}$ are the normalized NPP, LAI, and NDVI values, respectively.

3.2 Improvement in the equivalent values of ecosystem services

An ecosystem service is a comprehensive multifunctional indicator that includes the supply, regulation, support, and cultural services provided by ecosystems (Millennium Ecosystem Assessment, 2005; Hu et al., 2015). Costanza et al. (1997) defined ecosystem service as the flows of materials, energy, and information from natural capital stocks that are combined with manufactured and human capital services to produce human welfare. Daily (1997) considered ecosystem services as the conditions and processes of natural ecosystems that fulfill human life. In Brauman and Daily (2008) and Douglas (2015), ecosystem services are the benefits that human beings derive from natural systems, including the provision, regulation, and cultural services that directly affect people and the supporting services needed to maintain other services. Based on the research of Costanza et al. (1997), Xie et al. (2008) provided a detailed look-up table (Table 1) of the equivalent values of ecosystem services based on land use/cover data in China from a survey of >700 ecologists. As seen in Table 1, the equivalent values of ecosystem services are evaluated for four primary ecosystem service types: supply services, regulation services, support services, and cultural services. Each primary ecosystem service type includes one or more subtypes. Different services have different weights: the largest score for supply services is 2.98, which is from the raw materials provided from forestland; the largest score for regulation services is 18.77, which is from the water regulation provided by aquatic areas; the largest score of support services is 4.51, which is from the biodiversity protection support provided by forestland; and the largest score for cultural services is 4.69, which is from the recreation and culture opportunities provided by wetlands. Obviously, regulation services have the highest weight, while supply services are not as important as the other services. Table 1 displays the relationships between land use/cover and human activities, natural resources, ecological protection, and climate change. Among these relationships, human activities appear to be more of a burden because the scores of cultivated land and construction land are both very low.

To overcome the disadvantage of “one ecosystem service value for one land use/cover category,” the improved equivalent values of ecosystem services will not be constant but will linearly change with changes in vegetation status. The original equivalent values of the ecosystem services in Table 1 are assumed to represent the average cases for each land use/cover type, which means that the higher vegetation status values will have higher equivalent values and the lower vegetation status values will have lower equivalent values even in the same land use/cover type. The improved equivalent ecosystem service value evaluation model should be expressed by Eq. (3) as follows:

$$EV_{\text{impr},i} = EV_{\text{original},i} \times \frac{VS_{\text{value}}}{VS_{\text{mean},i}}.$$  

(3)

where $EV_{\text{impr},i}$ is the improved equivalent value of an ecosystem service of land use/cover type $i$, $EV_{\text{original},i}$ is the original equivalent value of an ecosystem service of land use/cover type $i$ (based on Table 1), $VS_{\text{value}}$ is the vegetation status value, and $VS_{\text{mean},i}$ is the mean vegetation status value of land use/cover type $i$. Figure 2 illustrates the flowchart of the improved equivalent ecosystem service value evaluation model.

| Table 1. Equivalent value per unit area of ecosystem services in China (Xie et al., 2008) |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Type                | Subtype                  | Forestland | Grassland | Cultivated land | Wetland | Water area | Unused land | Construction land |
|--------------------|--------------------------|------------|-----------|------------------|----------|------------|-------------|------------------|
| Supply services    | Food                     | 0.33       | 0.43      | 1.00             | 0.36     | 0.53       | 0.02        | 0                |
|                    | Raw materials            | 2.98       | 0.36      | 0.39             | 0.24     | 0.35       | 0.04        | 0                |
| Regulation services| Gas regulation           | 4.32       | 1.50      | 0.72             | 2.41     | 0.51       | 0.06        | 0                |
|                    | Climate regulation       | 4.07       | 1.56      | 0.97             | 13.55    | 2.06       | 0.13        | 0                |
|                    | Water regulation         | 4.09       | 1.52      | 0.77             | 13.44    | 18.77      | 0.07        | 0                |
|                    | Waste treatment          | 4.02       | 2.24      | 1.47             | 1.99     | 0.41       | 0.17        | 0                |
| Support services   | Soil formation and retention | 4.02     | 2.24      | 1.47             | 1.99     | 0.41       | 0.17        | 0                |
|                    | Biodiversity protection  | 4.51       | 1.87      | 1.02             | 3.69     | 3.43       | 0.40        | 0                |
| Cultural services  | Recreation and culture   | 2.08       | 0.87      | 0.17             | 4.69     | 4.44       | 0.24        | 0                |
| Total              |                          | 28.12      | 11.67     | 7.90             | 54.77    | 45.35      | 1.39        | 0                |
4. Results and discussion

4.1 Results of the principal component analysis

Figure 3 shows the three normalized vegetation status parameter maps for China in 2018: Fig. 3a is the NPP map, Fig. 3b is the LAI map, and Fig. 3c is the NDVI map. As seen in Fig. 3a, the values in the NPP map in western China and Inner Mongolia areas are mostly lower than 0.1, and the values in the Greater Hinggan, the Lesser Hinggan, the Changbai mountain ranges, and southern China are relatively higher but still lower than those in the LAI map and the NDVI map. Compared to the values in the LAI map and the NDVI map, the values in the NPP map are generally lower because the original NPP (before normalization) data have a large range of values from 0 to over 2000 gC m\(^{-2}\), but most of the values are lower than 1000 gC m\(^{-2}\). As seen in Fig. 3b, the values in the LAI map in western China and Inner Mongolia areas are close to those in the NPP map because low vegetation cover areas and desert areas mainly exist there. However, the values in southern China in the LAI map have a clearer distinction compared to those in the NPP map because the LAI map clearly distinguishes the high and middle vegetation cover regions. Nevertheless, the NDVI map performs better in western China because it can clearly distinguish the low vegetation cover and desert regions.

Table 2 shows the eigenvalues of each principal component. The results demonstrate that the first two principal components contain over 96% of the vegetation status information, which means that these two components could reasonably be substituted for the original three vegetation status parameters. Equations (4) and (5) show that the first and second principal components contain most information from the LAI and NDVI maps.

\[
\text{PC}1 = 0.3541 \times \text{NINPP} + 0.6101 \times \text{NILAI} + 0.7088 \times \text{NINDVI};
\]

\[
\text{PC}2 = 0.0710 \times \text{NINPP} + 0.7733 \times \text{NILAI} - 0.6301 \times \text{NINDVI};
\]

Figure 4 is the comprehensive assessment result map of the vegetation status after the PCA, in which higher vegetation status values indicate a greater potential for ecosystem services, and lower vegetation status values indicate a lower potential for ecosystem services. As seen in Fig. 4, the low value regions are mainly distributed in Inner Mongolia, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, eastern coastal regions, Hainan, and Taiwan are clearly higher than those in other places, demonstrating the higher vegetation cover and greater potential of the ecosystem services in these areas. As seen in Fig. 3c, in comparison to the values in the other maps, the values in the NDVI map are generally higher while having less distinction in southeastern Tibet, southwestern Yunnan Province, the southeastern coastal regions, Hainan, and Taiwan. This is because NDVI tends to be saturated when biomass increases to a high value (Myneni et al., 1995; Hao et al., 2008), which is especially obvious in evergreen forest areas (Rahman et al., 2001). Overall, the LAI map performs better in the northeastern, central, and southern regions of China than in the other areas because the map clearly distinguishes the high and middle vegetation cover regions. Nevertheless, the NDVI map performs better in western China because it can clearly distinguish the low vegetation cover and desert regions.
and Xinjiang, where the vegetation status values are normally under 0.20 because many low vegetation coverage areas and deserts (such as the Taklimakan Desert and the Gurbantunggut Desert) exist due to the high altitudes and dry climates. Slightly higher value regions include the North China Plain, the Sichuan basin, the Yangtze River Delta (mainly in Shanghai and parts of Jiangsu, Anhui, and Zhejiang provinces), the Pearl River Delta in Guangdong Province, the middle reaches of the Yangtze River, and the Northeast China Plain (including southwestern Heilongjiang, the eastern part of Inner Mongolia, and the western parts of Jilin and Liaoning provinces), where the main grain production areas and urban agglomeration areas of China exist. One of the reasons for the lower vegetation status values in these regions is the tremendous pressure from socioeconomic development and urbanization (Chen et al., 2019b). High value regions are mainly located in high forest coverage areas, such as the Greater Hinggan, the Lesser Hinggan, and the Changbai mountain ranges in the northeast, and Fujian, Jiangxi, Guangxi, Zhejiang, Taiwan, Guangdong, Hunan, Hainan, Yunnan, and Guizhou, which are the areas with the highest forest coverage rates in China. Figure 4 displays the differences in not only different land use/cover types but also the same land use/cover type, such as the differences in the Northeast Plain and in the Middle–Lower Yangtze Plains, which are both mainly covered by cultivated land and different crop types, and the differences in the Greater Hinggan and Fujian Province, which both have high forest coverage areas but different forest types, growing years, canopy densities, etc.

4.2 Improved equivalent values of ecosystem services based on land use/cover and vegetation data

Based on Figs. 1, 4, we can quantitatively determine the vegetation status differences in the same land use/cover data. Figure 5 shows the vegetation status differences in cultivated land, forestland, grassland, wetland, and unused land. We can see that except for the water area and construction land, which are less affected by the vegetation status, the other five land use/cover types are all apparently affected by vegetation status. The upper and lower endpoints are the largest and smallest vegetation status values of each land use/cover type, respectively, and the rhombus points represent the mean values. As seen in Fig. 5, the largest and smallest vegetation status values in the five land use/cover types are 0.85 and 0.21 (cultivated land), 1.00 and 0.26 (forestland), 0.70 and 0.11 (grassland), 0.51 and 0.10 (wetland), and 0.48 and 0.08 (unused land), respectively. The largest

| Component | Initial eigenvalue | Variance (%) | Cumulative (%) |
|-----------|-------------------|--------------|----------------|
| 1         | 85.9954           | 85.9954      | 85.9954        |
| 2         | 10.0202           | 96.0156      |                |
| 3         | 3.9844            | 100.0000     |                |

Fig. 4. Comprehensive assessment result map of the vegetation status after the principal component analysis (PCA).
difference between the maximum and minimum is 0.74 in forestland, and the smallest difference is 0.40 in unused land. The large vegetation status differences in the same land use/cover type show that evaluating the ecosystem service values with one value in one land use/cover type is inadequate.

Figure 6 shows the improved equivalent value map of the ecosystem service values based on both the land use/cover type and the vegetation parameters calculated by Eq. (3). Figure 6a is the traditional equivalent value map of ecosystem services based only on the land use/cover type, while Fig. 6b is the improved equivalent value map of ecosystem services based on both the land use/cover type and the vegetation parameters. As seen in Fig. 6a, only seven values are shown because the land use/cover types are divided into seven primary types; however, the values in Fig. 6b continuously vary between 0 and 57 because the vegetation status values continuously vary. Comparison of Figs. 6a, b finds that there are two main advantages in the improved evaluation model. One advantage is that the equivalent values of the ecosystem services in Fujian, Jiangxi, Guangxi, Zhejiang, Taiwan, Guangdong, Hunan, Hainan, Yunnan, and Guizhou are apparently higher than those in the Greater Hinggan, the Lesser Hinggan, and the Changbai mountain ranges in the northeast, although both of these regions are covered by forests. As mentioned above, forests in the first group of areas have higher vegetation status values than those in the second group of areas, which leads to the differences in the equivalent values of the ecosystem services between the northeastern forestland and the southern forestland in China. The other difference lies in the transitional zones between different land use/cover types, such as the transitional zones between the grassland and forestland in eastern Inner Mongolia and the eastern Qinghai–Tibet Plateau. There is no transitional zone, but only a steep change in values in Fig. 6a; however, many smoothly changing transitional zones exist in Fig. 6b. As seen in Fig. 6b, the equivalent values of the ecosystem services gradually increase from unused land to grassland to forestland in the eastern Qinghai–Tibet Plateau. In particular, the equivalent values of ecosystem services in grasslands are different. Closer to unused land, the values of grassland are smaller; and closer to forestland, the values of grassland are larger, showing the natural spatial variation trend in the vegetation status and ecosystem services. Overall, the distribution trend in the equivalent values of ecosystem services in Fig. 6b appears similar to a combination of those in Figs. 1, 4, which shows the differences not only in different land use/cover types but also in the same land use/cover type. The clear distinction in the latter can better exhibit the distribution trend in the equivalent values of ecosystem services in some study areas that contain multiple climatic zones, geographic topographies, and a variety of forest and vegetation types.

Fig. 5. Vegetation status differences in cultivated land, forestland, grassland, wetland, and unused land.

Fig. 6. (a) Traditional equivalent value map of ecosystem services and (b) improved equivalent value map of ecosystem services.
5. Conclusions

Ecosystems offer the basic materials, energy, and information for human beings, and these materials, energy, and information can be converted into human welfare by ecosystem service values. The significance of ecosystem service values lies in helping people understand that ecosystem protection is as important as social and economic development. This is especially crucial in a vast number of developing countries where rapid industrialization and urbanization occur every day. Large land use/cover and vegetation status changes caused by industrialization and urbanization, even at small scales, may dramatically alter the costs or benefits of maintaining human welfare. Consequently, knowing the distribution characteristics of ecosystem service values and making reasonable development plans based on these values are very important for human welfare.

Traditional evaluation models of ecosystem service values are only based on land use/cover data and ignore the differences in the same land use/cover caused by different latitudes, altitudes, climatic conditions, growing years, etc. However, all of the above can strongly impact ecosystem service values. NDVI, LAI, and NPP data are used in this study to describe these influencing factors. They can show minute differences in the same land use/cover data, such as canopy vertical distribution information, three-dimensional structure of the canopy, density of the canopy layer, forest gaps, and the amount of carbon fixed by photosynthesis. This study improves the evaluation model of ecosystem service values by importing NPP, LAI, and NDVI data as vegetation status data to subdivide the land use/cover data. The PCA approach is used to reduce the correlations among the three different vegetation status. Through the comprehensive assessment result map of the vegetation status after PCA, obvious vegetation status differences in the same land use/cover data are shown, indicating that it is imperfect to assign only one ecosystem service value to one land use/cover data type. In the improved model, the original ecosystem service values from previous studies are assumed to represent the average cases of vegetation status, meaning that the higher vegetation status values will have higher ecosystem service values and the lower vegetation status values will have lower ecosystem service values even in the same land use/cover type. Compared with the traditional models, the improved model has two main advantages. First, it can clearly distinguish the differences in ecosystem services values in the same land use/cover type, such as the differences in northeastern forestland and southern forestland in China. Second, the improved model can clearly describe the transitional zones between different land use/cover types, such as the transitional zones between the grasslands and forestland in eastern Inner Mongolia and the eastern Qinghai–Tibet Plateau.

Today, China is undergoing tremendous changes. The eastern region is leading in development, while the China Western Development Strategy, the Northeastern Area Revitalization Plan, and the Rise of Central China Plan change the country every day (He et al., 2012; Li et al., 2016; Zhang and Xu, 2017). These changes affect the socioeconomic development and the environment. Although industrialization and urbanization over a long period change the land use/cover types in China, this does not mean that ecosystem service values must be lower. In China, green, low-carbon, and sustainable development, such as the policy of returning cultivated land to forest or grassland, can balance economic growth and environmental protection. At the same time, improvements in the vegetation status from advances in science and technology, environmental protection, and natural vegetation recovery can also promote ecosystem service values.

The improved evaluation model can provide a more detailed description of the distribution characteristics of ecosystem service values in China and help policymakers formulate more appropriate policies to balance economic development and environmental protection. There are still some improvements needed for this model that can be addressed in ongoing work, and one main aspect that we recommend is that more environmental status parameters should be involved in the model, not only the vegetation parameters but also atmospheric and water parameters.

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