ESTIMATION OF ECOLOGICAL ASSET VALUES IN SHANGRI-LA BASED ON REMOTELY SENSED DATA

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Abstract. Ecological assets are an important material base of the national economy and sustainable social development. Shangri-La, China is an important area of forest and farmland that has been returned to forest, but the ecological environment is fragile. It is urgent to start to an ecological asset values estimation study. Choosing remote sensing data, meteorological data, surface observations and statistics as the data sources. The results show: (1) From the perspective of ecological assets, adjusting climate and water conservation contribute the most.(2) In the context of single ecological asset value per unit area, the sequence from highest to lowest is the following, water conservation > adjusting climate > soil and water conservation > production of organic matter > nutrient circulation > cultural entertainment.(3) From the perspective of the type of ecological system, forest and shrub grassland contribute the most. (4) From the value of ecological assets per unit area of each ecosystem type, agricultural land > forest > shrub grassland > waters > wetland > artificial land > permanent snow glacier > unutilized land. It is particularly significant for people to make reasonable decisions when exploiting and utilizing natural resources which can be aided by an ecological asset values estimation study.

Keywords: *ecological environment, ecosystem services, CASA model, soil and water conservation, net primary productivity*

Introduction

Ecosystem not only provides humans with the necessary raw materials for life and production, but also the products and services it provides are also important assets that humans rely on for survival and development (Luo, 2008). In the 1970s, scholars such as Holdern (1974) and Westman (1977) began to study global ecosystem services, and the concept of ecological asset value evaluation also came into being. In recent years, China and foreign countries have begun to calculate the value of ecological assets from the perspective of different regional scales (Xu et al., 2012; Chen et al., 2012; Xing, 2020) and different ecosystem types (Han et al., 2000; Yu, 2005). Such as Daily et al. (2009) analyzed the role played by the integration of ecosystem services into decision-making, Richmond et al. (2007) analyzed the contribution of ecological assets to GDP and used this contribution to calculate the empirical price of ecosystem services, Gadaud and Rambolinaza (2010) conduct research on methods and technologies of ecological

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asset evaluation, and evaluate the compensation value of fire risk willingness in the Landes area of France, Byeori et al. (2017) use keywords to analyze recent developments in ecological asset research and guide the research direction of future ecosystem asset analysis in Korea. In general, in terms of research content, most foreign countries have made systematic and in-depth estimates for several of the ecosystem services (Daily, 1997; Gómez et al., 2013; Delphin et al., 2016); in China, the main focus is on exploring the concept of ecological assets, constructing an index system for ecological assets, and accounting for the value of ecological assets (Gao et al., 2007; Sun et al., 2008). In terms of research methods, foreign estimation methods mainly include InVEST model, ESR model, ARIES model and SoLVES model (Polasky et al., 2011; Bagstad et al., 2013), Most of these models only account for a single or a few items of ecological service value, and some models are currently only suitable for value evaluation in a very small number of areas. The evaluation methods studied in China mainly include two types. One is to use the unit area value method to estimate ecological assets, for example, Xie et al. (2008) have optimized the value system based on Costanza et al. (1997) and established a value standard system suitable for domestic ecological asset evaluation, and then there have been many related research cases (Ouyang et al., 2013; Liu et al., 2013; Chen, 2021), The disadvantage of this method is that it cannot reflect the temporal and spatial differences of different ecosystems and regions. The other is to obtain different ecological parameters through the establishment of measurement models, and to estimate the value of ecological assets by remote sensing. For example, Zhu et al. (2007) and others have used remote sensing technology to establish an ecological asset calculation model to dynamically assess China's terrestrial ecological assets, but the accuracy of this method is heavily dependent on the established measurement model and the acquired ecological parameters. In general, most of the current studies underestimate the total value of ecological assets and only account for the value of ecosystem services. Although the value of natural resources is included in the very few studies, the results cannot fully reflect the value of natural resources and are related to ecosystems. Some information overlaps in service value accounting (Zhang et al., 2004; Hou et al., 2015; Sun et al., 2017; Wang, 2019). In addition, most of the current researches only carry out static or dynamic estimation of the total amount of ecological assets, and the research scope is limited to the indicator system and accounting methods, and lacks management strategies and suggestions for regional economic and social development and ecological asset conditions.

At the same time, scholars in China and abroad have explored and studied the estimation of ecological assets from various perspectives. However, due to the enormous difficulties in the determination of cost assessment methods and data acquisition, no scholars have been able to complete the resource and environmental accounting in a comprehensive way. For Shangri-La, due to limited data, it is impossible to estimate the value of natural resources, such as mineral resources, biological resources, mobile resources, environmental resources and land resources. In fact, there is a certain relationship between the value of natural resources and the value of ecological services. That is, part of the natural resources is calculated when assessing the value of the ecological services resource value. Therefore, the ecological asset valuation in this study estimated only six values of ecosystem services.

It is of special significance to select Shangri-La in Diqing Prefecture of Northwest Yunnan as the research area to carry out remote sensing estimation of ecological assets. First, Yunnan Province is a high-value area with dense ecological assets in China, while

Northwest Yunnan is the main forest area in Yunnan Province and has high forest coverage. Before the implementation of relevant forestland protection policies in Shangri-La, the main financial revenue of the area came from forestry production. In 1999, Yunnan Province launched the Natural Forest Conservation Project and the Project of Converting Farmland to Forestry and Grassland, and the ecological environment of Yunnan Province has changed accordingly. Second, the study site is located in the middle and upper reaches of the Hengduan Mountains and international rivers, and its ecosystem is fragile. The changes in terrestrial ecosystem assets (especially its forest ecosystem) can reflect global changes to a certain extent. In addition, the study area is located in the hinterland of a World Natural Heritage Site with three parallel rivers in Yunnan Province, which is one of the 20 biodiversity hotspots designated by the WWF. Finally, there is a lack of research on remote sensing measurements of medium-scale ecological assets in Yunnan Province (Liu et al., 2007; Chen et al., 2007; Shi et al., 2009). Therefore, the remote sensing estimation of the ecological assets in Shangri-La and the timely and accurate grasp of the ecological assets in the Northwest Yunnan Converted Farmland to Forest Area can provide a scientific basis for the construction and protection of the ecological environment in the study area, as well as the relevant government decisions.

Materials and Methods

Location and description of the study area

Shangri-La is located in the northwestern part of Yunnan Province, China, which is in the eastern part of Diqing Tibetan Autonomous Prefecture, between 26˚52' ~ 28˚52' N and 99˚22' ~ 100˚19' E. It is the location of the "Tea-Horse Ancient Road". Shangri-La is adjacent to Daocheng County and Muli County in Sichuan Province in the east, Lijiang city in Yunnan Province in the south, Lijiang city in Yunnan Province across the river, Deqin County in Diqing Tibetan Autonomous Prefecture and Weixi County in the west, and Derong County and Xiangcheng County in Sichuan Province in the north. The shape of Shangri-La is narrow at both ends and wide in the middle. The widest distance between the east and west is approximately 88 km, and the distance between the north and south is approximately 218 km. Therefore, the shape of Shangri-La is similar to a narrow willow-shaped zone (*Fig. 1*). The total land area of the county is approximately 11613 km^2, which is the largest county-level city in Yunnan Province (Wang et al., 2004; Yang, 2009). A total of 11 townships are divided into 4 towns and 7 townships. The 4 towns are Jiantang town, Xiaozhongdian town, Jinjiang town and Hutiaoxia town; the seven townships are Nixi township, Dongwang township, Gezan township, Shangjiang township, Sanba Naxi Nationality township and Wujingxiang township.

Shangri-La is located in the north and south of China. The topography is high in the northwest and low in the southeast. The highest point is Balagozhong, with an elevation of 5545 m. The lowest point is Luojihan, with an elevation of 1503 m. The difference between the highest and lowest elevations is 4042 m, and the average elevation of the county is 3459 m (*Fig. 2a*), the data was captured on the geospatial data cloud platform (http://www.gscloud.cn). Shangri-La is rich in biological and mineral resources. There are 4 seasons in the mountains and 10 miles in different days. It has a three-dimensional climate pattern and a variety of soil types (*Fig. 2b*). The map of soil types was obtained from 1:200,000 Diqing Soil Distribution Map by geometric correction and vectorization.

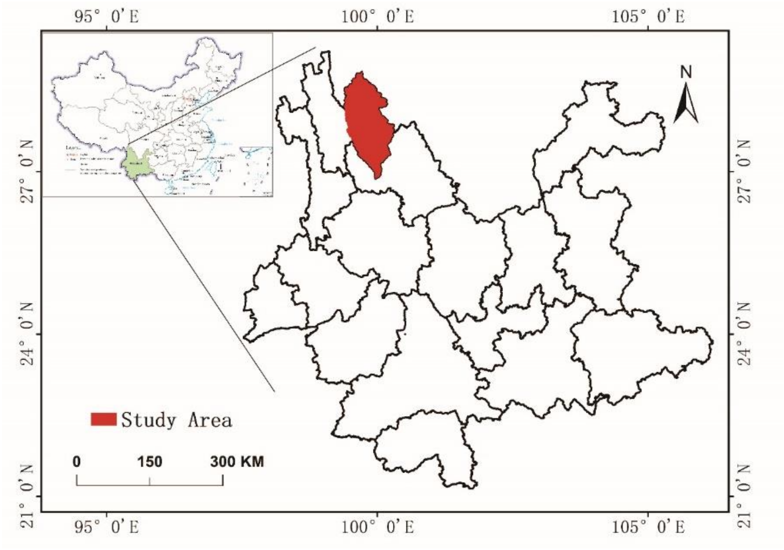

Figure 1. *Research Location Map*

Note: the map is based on the standard map with drawing review No. GS (2019) 1825 downloaded from the standard map service website of the State Bureau of surveying, mapping, and geographic information of China (http://bzdt.ch,mnr.gov.cn), and the base map is not modified.

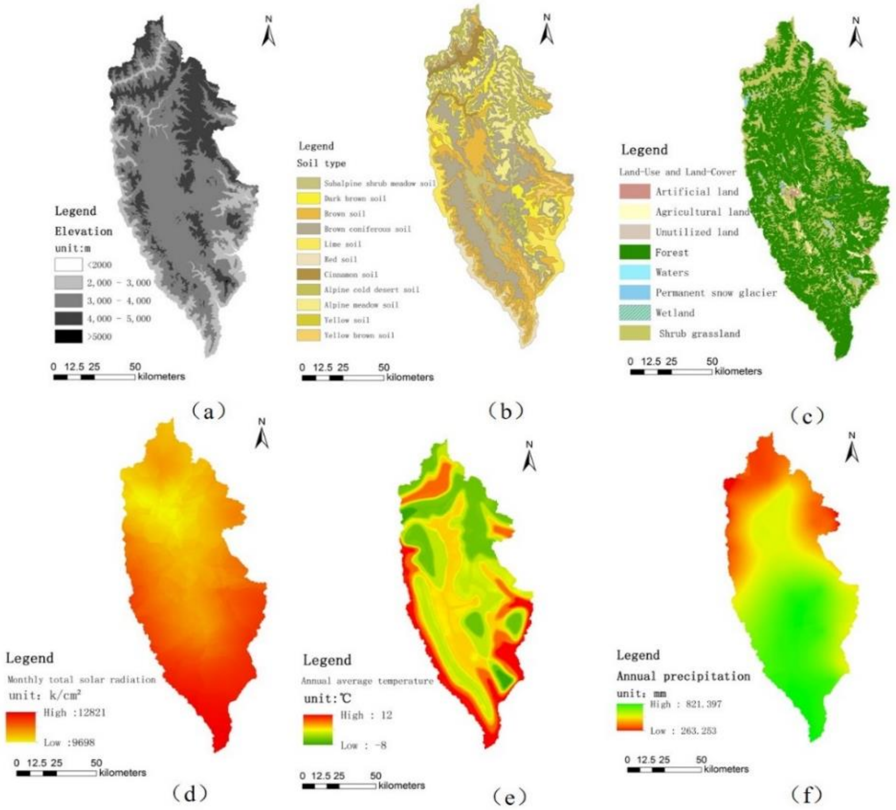

Figure 2. *Related images of the study area:(a) Elevation Distribution;(b) Soil Types;(c) Land Use and Land Cover;(d) Monthly Solar Total Radiation Interpolation Chart;(e) Annual Average Temperature;(f) Annual Precipitation*

Data sources

Remote sensing image data: The remote sensing data include Terra MODIS (Moderate Resolution Imaging Spectroradiometer, MODIS) MOD09A1 data. Representative MOD09A1 data from July 2013 with a spatial resolution of 500 m × 500 m were selected from the geospatial data cloud, and the Landsat TM (Thematic Mapper, TM) remote sensing images were selected. The date of acquisition was November 12, 2013. The resolution from the geospatial data cloud was 30 m × 30 m. The reason why to choose the images in November is that the image quality in November is the best, however, in June to August is the rainy season in the study area with heavy cloud cover and poor image quality. The MODIS image data and Landsat TM image data were geometrically corrected and tailored. To better analyze and apply the data quantitatively, the MODIS data were resampled to 397 × 946 and then resampled as necessary.

DEM (Digital Elevation Model, DEM): A 1:50,000 DEM with UTM (Universal Transverse Mercator, UTM) projection mode was used.

Meteorological data: The meteorological data included the monthly precipitation, the monthly average temperature and the total monthly solar radiation, and the data were obtained from the Zhongdian County Climate Data. From Zhong Dian County Agricultural Climate Division (Zhongdian County Agricultural Zoning Committee, 1986),we obtain the contour map of the annual average temperature and the annual precipitation contour map of Shangri-La. Finally, in the case of the DEM, the meteorological element raster dataset with the same pixel size, the NDVI (Normalized Difference Vegetation Index, NDVI) data (250 m × 250 m) and the same projection mode was obtained by kriging interpolation. NDVI is derived from MODIS data using the difference between the near-infrared and red bands and the ratio of the sum of the two bands.

$$NDVI = (NIR - R) / (NIR + R) \tag{Eq.1}$$

In the formula, *NIR* is the band of near-infrared, *R* is the band of red.

Other geographic base map data: The 1:200,000 soil type maps of Diqing Tibetan Autonomous Prefecture were scanned, digitized and projected, and the land use classification map of Shangri-La in 2013 was projected by UTM. To facilitate the spatial analysis of relevant data, we unified the coordinate system and projection method of all the above data. The coordinate system was WGS-84; the projection mode was UTM; the Zone was 47; and the spatial unit of measure was meters.

Classification of land use by remote sensing

Landsat TM images were used to classify the three-level classification system into the first-level classification system by means of manual interaction and visual interpretation. The classification system refers to (*Table 1*). The image interpretation results were verified by field survey sample data and GPS points (Wang and Li, 2004; Wang et al., 2004; Jiang, 2004), with an accuracy of 81.09%, which met the research requirements. The field survey was conducted in all towns and villages of Shangri-La in 2013, including approximately 525 samples of various land use and land cover types like woodland, shrub grassland, water area, agricultural land, artificial land, unused land, wetland and so on.

The main land use classification types in the study area were construction land, traffic land, cultivated land, garden land, natural forest, shrub forest, grassland, inland swamp, river, lake, reservoir, bare land and permanent snow glacier. And, most of the forest in Shangri-La are natural forests. According to the research needs, the ecosystem types in the study area were classified into 8 categories: forest, shrub grassland, waters, agricultural land, artificial land, unutilized land, wetland and permanent snow glacier (Chen et al., 2001; Du et al., 2004) (*Fig. 2c*).

Table 1. *Land Use/ Land Cover Classification System*

Class I	Class II	ClassIII
Artificial land	Land used for building	Urban land use
		Rural residential areas
	Traffic land	Highway land
		Airport land
Agricultural land	Cultivated land	Paddy field
		Dry land
	Garden plot	Orchard
Forest	Natural forests	Deciduous forest
		Evergreen forest
Shrub grassland	Shrub grassland	Shrub wood
		Grassland
Wetland	Inland wetland	Inland marsh
Waters	Inland waters	River
		Lake
		Reservoir
Unutilized land	Bare land	Bare land
		Bare rock
	Sand	River flat
Permanent snow glacier	Permanent snow glacier	Permanent snow glacier

Models and methods

The values of ecological assets are not fixed. Generally, the values will change with time. The total value of ecological services and natural resources provided by all ecosystem types in a region constitutes the total value of the ecological assets. This value will change with changes in ecosystem area and quality.

$$V = \sum V_C \tag{Eq.2}$$

$$V_c = \sum\sum R_{ij} * V_{C_i} * S_{ij} \tag{Eq.3}$$

In the formula, *i* is the performance of the ecosystem service value of ecosystem type i in ecosystem type *C*, Vc_i is the unit area value of the ecosystem service value of ecosystem type i in ecosystem type *C*; *j* is the total number of pixels in ecosystem type *C*; S_{ij} is the spatial resolution, and R_{ij} represents the adjustment coefficient.

Estimation of adjustment coefficient

According to previous research results (Pan et al., 2004), vegetation coverage and NPP (Net Primary Productivity, NPP) are generally used to represent the quality of ecosystems.

$$R_{ij}=[\left(\frac{NPP_j}{NPP_{mean}}+\frac{f_j}{f_{mean}}\right)/2] \qquad \text{(Eq.4)}$$

In the formula, NPP_{mean} is the average NPP of the ecosystem, f_{mean} is the average vegetation coverage, NPP_j is the NPP of the *j* pixel, and f_j is the vegetation coverage of the j pixel (Pan, 2004).

Estimation of NPP

NPP refers to the amount of organic matter accumulated by green plants per unit time and area. It is the total amount of organic matter produced by plant photosynthesis minus the remaining part after autotrophic respiration. Traditional NPP measurement methods are easily restricted by natural conditions, and the development of remote sensing technology provides data support for the dynamic estimation of NPP. Among the existing NPP estimation models, the CASA (Carnegie Ames Stanford Approach, CASA) model has attracted attention due to its advantages of fewer parameters and simple calculation process, and has been widely used in global and regional NPP estimation.

Eight different types of ecosystem NPPs, including agricultural land, forest, shrub grassland, wetland, artificial land, waters, unutilized land and permanent snow glacier, were estimated using the experience of previous CASA models. The CASA model is mainly based on remote sensing data, which are driven by vegetation types, soil and soil distribution and meteorological data. This model is a type of light energy utilization model. The NPP value of the model is calculated according to the photosynthetic active radiation, temperature and water stress coefficients and the maximum light energy conversion rate (Potter et al., 1997).

$$NPP(x,y)=APAR(x,y)*\varepsilon(x,y) \qquad \text{(Eq.5)}$$

Estimation of APAR

Green plants rely on solar radiation energy for photosynthesis. Plants synthesize part of the radiation energy into their own organic matter. PAR (Photosynthetically Active Radiation, PAR) refers to the energy used by vegetation. Its wavelength range is 380-710 nm of visible light. The total amount of solar radiation produced by vegetation and its physiological and ecological characteristics determine the amount of PAR absorbed by vegetation.

$$APAR(x,t)=SOL(x,t)*fPAR(x,t)*0.5 \qquad \text{(Eq.6)}$$

In the formula, *SOL (x, t)* is the total solar radiation at x in the month of image t. These data are interpolated by the kriging spatial interpolation method for many years in Shangri-La (*Fig. 2d*). fPAR (x, t) indicates the proportion of PAR absorbed by plants. Different vegetation types and seasonal changes will make this value change. A coefficient of 0.5 refers to the ratio of the amount of PAR used by plants to the total amount of solar radiation.

In the model, *fPAR* is the NDVI and vegetation type, and its maximum value is not more than 0.95.

$$fPAR(x,t) = \min[\frac{SR - SR_{\min}}{SR_{\max} - SR_{\min}}, 0.95] \quad \text{(Eq.7)}$$

In the formula, *SR (x, t)* is obtained from the *NDVI (x, t).*

$$SR(x,t) = [\frac{1 + NDVI(x,t)}{1 - NDVI(x,t)}] \quad \text{(Eq.8)}$$

Estimation of light utilization rate

The utilization rate of light energy is the basis and an important parameter for estimating NPP. Generally, the efficiency of photosynthetic radiation absorbed by plants in the transformation to organic carbon is called the utilization rate of light energy. Normally, the utilization rate of plant light energy is large. However, research shows that the utilization rate of light energy is affected by many external conditions. First, it is affected by temperature, and second, it is affected by precipitation.

$$\varepsilon(x,t) = T_{\varepsilon 1}(x,t) * T_{\varepsilon 2}(x,t) * W_{\varepsilon}(x,t) * \varepsilon^{*} \quad \text{(Eq.9)}$$

In the formula, $W_{\varepsilon}(x,t)$ is the influence coefficient of the water stress factor, which refers to the influence of the water factor on the NPP. $T_{\varepsilon 1}(x,t)$ indicates the extent to which the utilization rate is limited when the temperature is high. $T_{\varepsilon 2}(x,t)$ refers to the extent to which the utilization rate is limited when the temperature is low, and ε^* refers to the maximum light utilization rate that can be achieved under ideal conditions.

$$T_{\varepsilon 1}(x,t) = 0.8 + 0.02 * T_{opt}(x) - 0.0005 * [T_{opt}(x)]^2 \quad \text{(Eq.10)}$$

In the formula, $T_{opt}(x)$ refers to the monthly mean temperature of the study area at the highest NDVI value. According to the statistics of the NDVI values of Shangri-La in different months of 2013, it is found that the Shangri-La NDVI reached the highest value in July. Through the statistical analysis of the Zhongdian Climate Data, the average temperature of Shangri-La in July is 13℃.

$T_{\varepsilon 2}(x,t)$ refers to the process in which the utilization rate of light energy of plants decreases, that is, when the temperature of the environment increases or decreases slowly and transitions away from the most suitable temperature for vegetation. Its principle is that when the temperature of vegetation is not the most suitable, plant respiration will become stronger, which will naturally lead to an increase in energy consumption, a decrease in photosynthesis and a consequent decrease in the utilization rate of light.

$$T_{\varepsilon 2}(x,t) = \frac{1.184}{\{1 + \exp[0.2 * T_{opt}(x) - 10 - T(x,t)]\}} * \frac{1}{\{1 + \exp[0.3 * (-T_{opt}(x) - 10 + T(x,t))]\}} \quad \text{(Eq.11)}$$

In the formula, *T(x,t)* denotes the temperature at pixel *X* of the *t* month. In this paper, the annual mean temperature of Shangri-La (*Fig. 2e*) and the monthly mean temperature of Shangri-La for many years were used to obtain monthly temperature interpolation maps through spatial interpolation.

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$W_{\varepsilon}(x,t)$ is the effect of vegetation available water on the change of energy utilization. When the corresponding effective water changes in the environment, the value will change accordingly. Its value is from 0.5 (drought) to 1 (humidity).

$$W_{\varepsilon}(x,t) = 0.5 + 0.5 * E(x,t) / E_p(x,t) \tag{Eq.12}$$

In the formula,$E(x,t)$ is the actual regional evapotranspiration, and $E_p(x,t)$ is the potential regional evapotranspiration.

$$E(x,t) = \frac{\{P(x,t) * R_n(x,t) * [P(x,t)^2 + R_n(x,t)^2 + P(x,t) * R_n(x,t)]\}}{\{[P(x,t) + R_n(x,t)] * [P(x,t)^2 + R_n(x,t)^2]\}} \tag{Eq.13}$$

In the formula, $P(x,t)$ is the precipitation (mm) of pixel x in month t. Based on the annual precipitation value of Shangri-La (*Fig. 2f*) and the monthly average precipitation for many years in Shangri-La, the monthly precipitation interpolation maps are obtained by spatial interpolation (Pan et al., 2014) $R_n(x,t)$ is the net solar radiation.

$$R_n = [E_{p0}(x,t) * P(x,t)]^{0.5} * \{0.369 + 0.589 * [\frac{E_{p0}(x,t)}{P(x,t)}]^{0.5}\} \tag{Eq.14}$$

In the formula, $E_{p0}(x,t)$ can be derived from the Thornthwaite vegetation-climate relationship model (Zhang et al., 1997), which refers to local potential evapotranspiration (mm). The monthly mean is used for the calculation.

$$E_p(x,t) = [E(x,t) + E_{p0}(x,t)] / 2 \tag{Eq.15}$$

Referring to the simulation value of light utilization in the Zhu et al. (2004) model, the value of light utilization factor ε* in this study is shown in *Table 2*.

Table 2. *Value of Light Utilization of Different Ecological Types (unit gCMJ)*

Veg. types Month	**Forest**	**Agr. land**	**Water**	**Art. land**	**Unutilized land**	**Shrub grassland**	**Wet.**	**Per. snow glacier**
1	0.438	0.268	0.219	0.157	0.168	0.259	0.322	0.219
2	0.365	0.213	0.177	0.124	0.184	0.259	0.306	0.177
3	0.440	0.253	0.228	0.134	0.217	0.280	0.332	0.228
4	0.558	0.292	0.252	0.188	0.218	0.276	0.336	0.252
5	0.681	0.404	0.355	0.221	0.234	0.322	0.328	0.355
6	0,714	0.471	0.383	0.254	0.251	0.400	0.425	0.383
7	0.672	0.473	0.378	0.246	0.239	0.421	0.467	0.378
8	0.696	0.459	0.365	0.242	0.220	0.398	0.410	0.365
9	0.737	0.455	0.386	0.244	0.238	0.374	0.392	0.386
10	0.659	0.352	0.326	0.203	0.202	0.254	0.298	0.326
11	0.565	0.308	0.267	0.199	0.217	0.285	0.341	0.267
12	0.422	0.252	0.216	0.136	0.214	0.266	0.327	0.216
Average value	0.579	0.350	0.296	0.196	0.217	0.316	0.357	0.296

Note: **Veg.**: Vegetation; **Agr.**: Agricultural; **Art.**: Artificial; **Wet.**: Wetland; **Per.**: Permanent

Results and Discussion

Estimated results of ecological assets in Shangri-La

Remote sensing estimation of different types of ecological assets produces different values because of different ecosystem types and ecosystem service functions. For example, forestland is more comprehensive in terms of ecosystem service functions, while urban and unused land are obviously insufficient. And, water conservation mainly means storage the water bodies in local for biological use; water and soil conservation mainly mean the prevention and control of soil erosion and the rational development and utilization of water and soil resources. *Table 3* shows the corresponding relationship between ecosystem types and ecosystem service functions.

Table 3. *Ecosystem Type and Ecological Service Function Relationship Table*

	Water con.	Soil and water con.	Adjusting climate	Nutrient circulation	Pro. of org. matter	Cultural Ent.
Forest	+	+	+	+	+	+
Agricultural land	+	+	+	+	+	-
Waters	+	-	+	-	+	+
Artificial land	+	-	+	+	+	+
Unutilized land	+	+	+	+	+	-
Shrub grassland	+	+	+	+	+	+
Wetland	+	-	+	-	+	+
Permanent snow glaciers	+	-	+	+	+	+

Note: "+" means that the ecosystem has the value of ecological services, while "-" means that it is not or difficult to measure. **con.**: conservation; **Reg.**: Regulating; **Pro.**: Production; **org.**: organic; **Ent.**: Entertainment

Spatial distribution of eco-asset value per unit area

According to the abovementioned relevant models, the value of ecological assets per unit area of the study area can be calculated (*Fig. 3*, *Table 4*). From the analysis, it can be seen that the highest value of water conservation per unit area of Shangri-La in 2013 is in the water ecosystem, followed by woodland, and the lowest value of water conservation is attributed to unused land. In general, the values of water conservation per unit area of Shangri-La are mostly the same. Among the 8 ecosystem types in Shangri-La, water area, artificial land, wetland and permanent snow glacier have no soil and water conservation value, and the highest value of soil and water conservation per unit area is attributed to agricultural land because the income of agricultural land per square kilometer in the selected model is more than that of woodland. Furthermore, the highest value of regulating climate per unit area is attributed to woodland, followed by shrub and grassland, and the lowest is attributed to water area and permanent snow glacier because the latter two have lower primary productivity values. The highest nutrient cycling value per unit area is in shrub grassland because shrub grassland has a higher N, P, K distribution rate than does woodland, followed by artificial land because the nutrient cycling value of artificial land mainly refers to green grassland and grassland. The value is also affected by shrub and grassland. The lowest cyclic value of nutrients per unit area is in water area and permanent snow glacier because their net primary productivity values are low; the highest value of organic matter per unit area is in woodland, followed by shrub and grassland, and the lowest value is in permanent snow glacier. The recreational values are the same except for agricultural land and unused land, which is consistent with the model in this paper. Thus, there was a flaw in type selection.

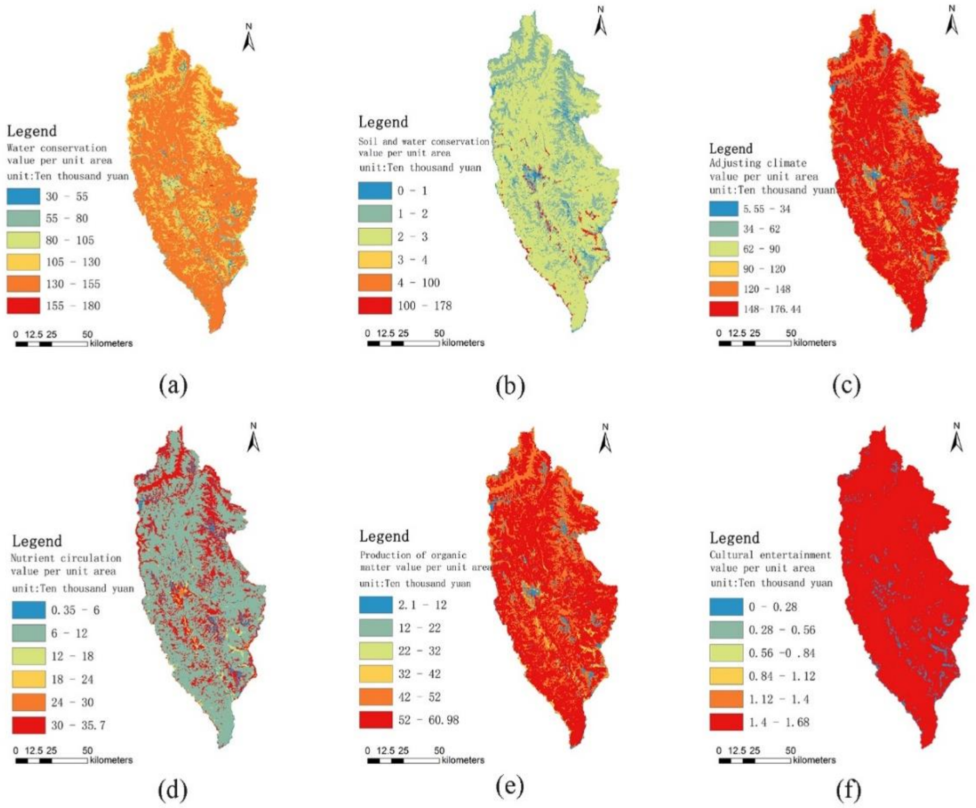

Figure 3. *Value of ecological assets per unit area:(a) Water conservation;(b) Soil and water conservation;(c) Adjusting climate;(d) Nutrient circulation;(e) Production of organic matter;(f) Cultural entertainment*

Table 4. *Value of ecological assets per unit area of various types of ecosystems*

	Forest	**Agr. land**	**Unuti. land**	**Waters**	**Art. land**	**Wet.**	**Shrub gra.**	**Per. snow glacier**	**Total value**
Water con.	136.000	58.000	30.000	180.000	94.000	120.960	118.440	113.400	850.800
Soil and water con.	2.970	178.000	1.800	0.000	0.000	0.000	1.010	0.000	183.780
Adj. climate	176.440	105.000	18.940	5.550	10.500	38.300	130.440	5.940	491.110
Nutrient cir.	11.180	14.420	3.700	0.350	28.560	2.200	35.700	0.350	96.460
Pro. of org. matter	60.980	36.000	6.550	2.270	3.630	13.240	48.620	2.100	173.390
Cultural ent.	1.680	0.000	0.000	1.680	1.680	1.680	1.680	1.680	10.080
Total value	389.250	391.420	60.990	189.850	138.370	176.380	335.890	123.470	1805.620

Note: **Agr.**: Agricultural; **Unuti.**: Unutilized; **Art.**: Artificial; **Wet.**: Wetland; **gra.**: grassland; **Per.**: Permanent; **con.**: conservation; **Adj.**: Adjusting; **cir.**: circulation; **Pro.**: Production; **org.**: organic; **ent.**: entertainment

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From the total value of ecological assets per unit area of each ecological type, the order from high to low is agricultural land, forestland, shrub grassland, water area, wetland, artificial land, permanent snow glacier and unused land. The reason why agricultural land ranks higher than forestland and shrub grassland is that the average income of agricultural land per unit area was relatively high. In addition, the general trend is reasonable.

Spatial distribution of total value of ecological assets in ecosystems

Similarly, using the above model, we can calculate the total value distribution maps of 6 ecological assets in Shangri-La in 2013, including water conservation, nutrient cycling, soil and water conservation, organic matter production, climate regulation and recreational value (*Fig. 4*, *Table 5*). The maps and tables show that the highest value of water conservation in the ecosystems of Shangri-La is forestland, accounting for approximately 73% of the total value of water conservation in the whole county, followed by shrub and grassland, accounting for approximately 24%, and other land use types, accounting for a smaller proportion. In the total value of soil and water conservation, agricultural land accounts for a higher value, followed by forestland; in the value of regulating climate, it is still forestland and grassland. The proportion of shrubs and grasslands is larger; among the total value of nutrient cycling, the proportion of shrubs and grasslands and woodlands is the largest, and the smallest is the water ecosystem. The value of organic matter production and recreational value is still dominated by woodlands and shrubs and grasslands. The order of the six values from high to low is adjusting climate value, conserving water source value, producing organic matter value, nutrient cycling value, soil and water conservation value and recreational value. It can be seen that forestland and shrub grassland occupy an important position in the ecological environment, and among all the values of ecological assets, the values of water conservation and climate regulation are particularly important.

Accuracy evaluation and analysis

After estimating the value of an ecosystem's ecological assets, it is necessary to analyze the accuracy of the evaluation results, which repeats the whole estimation process. That is, the process starts over, from the data sources used in this estimation, to the data processing, to the selection and calculation of parameters in the estimation; finally, the use of methods for the estimation and the acquisition of the estimation results must be done. Then, accuracy analysis is carried out.

First, from the point of view of data source acquisition, the TM and MODIS remote sensing data used in this paper were downloaded from authoritative data acquisition website geospatial data clouds, while the meteorological data and related statistical data were extracted from a number of relevant institutions and professions in Shangri-La, and some data processing was also completed through professional software. Although errors are inevitable in these processes, these errors are also within the scope of acceptance.

In addition, in the process of estimating parameters, the parameters in this paper are either calculated based on Shangri-La data or refer to previous research results; moreover, when calculating the NPP and soil conservation of the Shangri-La ecosystems, the parameters involved in estimating the value of individual ecological assets and the statistical parameters involved are calculated based on field data. The accuracy is beyond doubt, and the parameters that refer to the previous research results are also the national average, which may lead to errors in the final results; however, these errors are not very large.

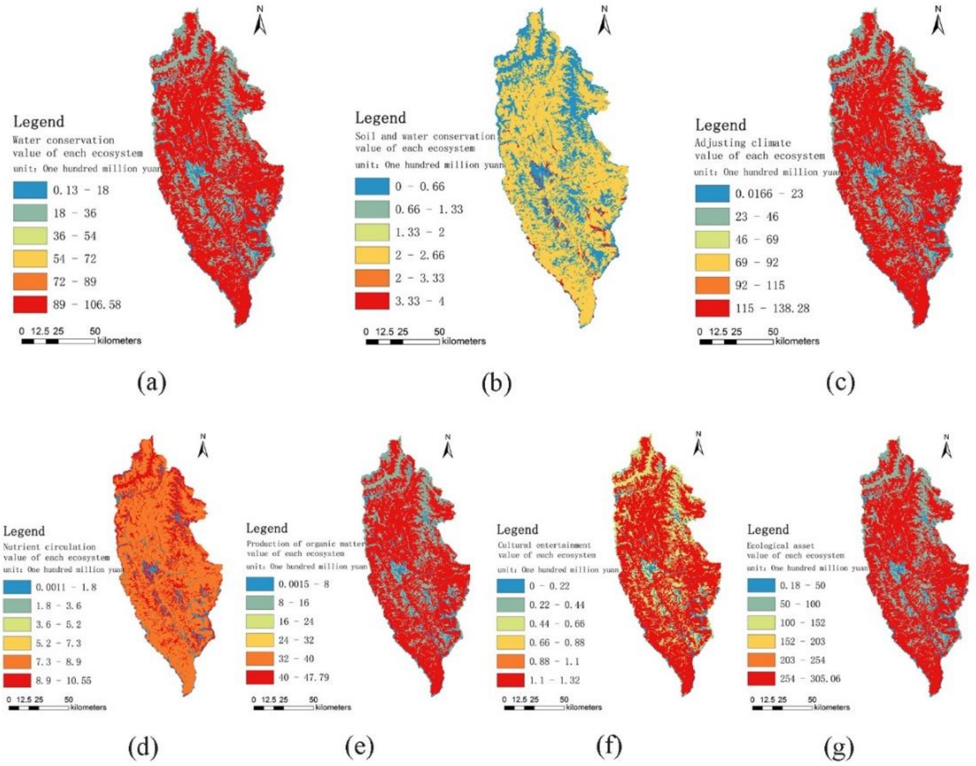

***Figure 4.** The value of each ecological asset in each ecosystem: (a) Water conservation; (b) Soil and water conservation; (c) Adjusting climate; (d) Nutrient circulation; (e) Production of organic matter; (f) Cultural entertainment; (g) Total ecological asset value*

***Table 5.** The Value of Ecological Assets of Ecosystem (unit:100 million yuan)*

	Forest	Agr. land	Unuti. land	Waters	Art. land	Wet.	Shrub gra.	Per. snow glacier	Total value
Water con.	106.580	1.310	0.590	0.540	0.140	0.133	35.000	1.292	145.585
Soil and water con.	2.330	4.000	0.035	0.000	0.000	0.000	0.299	0.000	6.664
Adj. climate	138.280	2.370	0.368	0.017	0.050	0.042	38.540	0.068	179.735
Nutrient cir.	8.760	0.330	0.072	0.001	0.040	0.002	10.550	0.004	19.760
Pro. of org. matter	47.790	0.820	0.127	0.007	0.017	0.002	14.370	0.023	63.156
Cultural ent.	1.320	0.000	0.000	0.005	0.007	0.002	0.496	0.019	1.849
Total value	305.060	8.830	1.192	0.570	0.255	0.181	99.255	1.407	416.749

Note: **Agr.**: Agricultural; **Unuti.**: Unutilized; **Art.**: Artificial; **Wet.**: Wetland; **gra.**: grassland; **Per.**: Permanent; **con.**: conservation; **Adj.**: Adjusting; **cir.**: circulation; **Pro.**: Production; **org.**: organic; **ent.**: entertainment

At the same time, because many basic data and statistics are difficult to obtain, it is difficult to measure the value of ecosystem services in the estimation of the value of ecological assets, such as the scientific research value of ecosystems. However, this paper uses the value of cultural entertainment to supplement these values so that the final results are not too low.

Finally, compare the estimation results of Shangri-La ecological asset value through similar research conducted by domestic and foreign scholars. Costanza et al. (1997) estimated that the average value of the services provided by the global ecosystem is about 33 trillion dollars per year; Pimentel (1997) conducted research on global biodiversity and estimated the value of global ecosystem services to be approximately 2.928×1012 dollars; Yu et al. (2006) estimated the total value of ecological assets in Huzhou city, the final result was 20.333 billion yuan; Li (2008) studied Songnen Plain obtained 65.968 billion yuan in total value of ecological assets; Sun (2008) studied in the Yangtze River Delta obtained 17.637 billion yuan in total value; at the same time, Zhang (2004) estimated ecological assets, obtained a result of 39.13 billion yuan in Inner Mongolia. Xie (2010) estimated the total value of Fuzhou's ecological assets, and the total amount he calculated was 23.7 billion yuan. Through the above research, it is found that the total amount of regional ecological assets is positively correlated with area, ecosystem conditions, and geographic conditions, that is, the larger the area, the better the ecosystem conditions, the superior the geographical environment, and the greater the total amount of ecological assets. Comparing the above research results with the estimated result of Shangri-La ecological assets of 41.675 billion yuan, we found that they are consistent in spatial distribution and quantitative trends.

Conclusion

It was found that the models of remote sensing estimation of ecological assets (total regional ecological asset value model and single ecological asset value evaluation model) and the NPP estimation model (CASA) were suitable for Shangri-La. And, the total value of ecological assets in Shangri-La was 41.675 billion yuan, and the total value of ecological assets per unit area was 18.5562 million yuan, among the data, the sequence of the value of various ecological assets in Shangri-La is the following: adjusting climate is 17.97 billion yuan, water conservation is 14.5 billion yuan, production of organic matter is 6.3 billion yuan, nutrient circulation is 1.97 billion yuan, soil and water conservation is 660 million yuan, cultural entertainment is 180 million yuan; the sequence of the value of each ecosystem type is the following: forest is 30.5 billion yuan, shrub grassland is 9.925 billion yuan, agricultural land is 883 million yuan, permanent snow glaciers is 141 million yuan, unutilized land is 119 million yuan, waters is 57 million yuan, artificial land is 25 million yuan, wetland is, and, from the perspective of the proportion of the total value of forest and shrub grassland, vegetation plays an important role in the value of ecological assets; the sequence of the value of single ecological asset value per unit area in Shangri-La is the following: water conservation is 8.508 million yuan, adjusting climate is 4.911 million yuan, soil and water conservation is 1.8378 million yuan, production of organic matter is 1,733,900 yuan, nutrient circulation is 964,600 yuan, cultural entertainment is 100.8 million yuan; the sequence of the value of each ecosystem type per unit area is the following: agricultural land is 3.114 million yuan, forest is 3.895 million yuan, shrub grassland is 3.3589 million yuan, waters is 1.8985 million yuan, wetland is 1.763 million yuan, artificial land is 1.3839 million yuan, permanent snow glaciers is 1.2347 million yuan, unutilized land is 609,000 yuan.

Inevitably, there are some aspects that need to be improved or strengthened in the estimation process. First of all, Shangri-La is a typical mountain and valley area, it is difficult to obtain detailed data of meteorological data and soil data. Although through interpolation analysis, the accuracy still needs to be improved. At the same time, the selection of ecological asset evaluation index is not perfect, only six indexes were selected, including water conservation, adjusting climate, soil and water conservation, production of organic matter, nutrient circulation and cultural entertainment, but there are more indexes than six (Costanza et al., 1997; Daily, 1997), resulting in a certain difference between the estimated value of ecological assets and the actual value. And, the natural resources do not been separately estimate, in particular, the ecosystem is a dynamic system, so ecological assets are also dynamic, but if the value of ecological assets needs to be dynamically monitored and evaluated (Sun et al., 2017; Wang, 2019; Xing, 2020), it is necessary to ensure that the data is fast and timely, due to the limitations of research materials and technical means, this study did not compare the value of ecological assets on a temporal and spatial scale.

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