

S1:

The valuation equivalence factor method provides the basis for this analysis, calculated as follows:

$$V_a = \frac{1}{7} \sum_{i=1}^n \frac{a_i p_i q_i}{A} \quad (i = 1, 2, \dots, n) \quad (1)$$

$$VE_{ij} = C_{ij} V_a \quad (i, j = 1, 2, \dots, n) \quad (2)$$

$$ESV = \sum A_k E_k \quad (3)$$

V_a is The economic value per unit area of crops in China, where I denotes the type of crop, and p_i indicates the current price of the i^{th} crop. q_j represents the yield of the j^{th} crop per unit area, while A_i refers to the total cultivation area for crop i , and A_{total} indicates the total cultivation area across four crop types. The ESV coefficient for the j^{th} ecosystem service function within the i^{th} ecosystem, C_{ij} measures the economic value of that service relative to one unit of farmland. V indicates the economic value per unit area of a specific crop. A_k denotes the area of the k^{th} land type, and E_k corresponds to the ESV for a unit area of that land type.

S2:

The LSTM (Long Short-Term Memory) model formulas for different components are as follows:

Input node:

$$g^{(t)} = \tanh(W_{gx}x^{(t)} + W_{gh}h^{(t-1)} + b_g)$$

Input gate:

$$i^{(t)} = \sigma(W_{ix}x^{(t)} + W_{ih}h^{(t-1)} + b_i)$$

Output gate:

$$o^{(t)} = \sigma(W_{ox}x^{(t)} + W_{oh}h^{(t-1)} + b_o)$$

Cell state:

$$s^{(t)} = g^{(t)} \odot i^{(t)} + (s^{(t-1)} \odot o^{(t)})$$

Hidden gate:

$$h^{(t)} = \tanh(s^{(t)}) \odot o^{(t)}$$

Output layer:

$$y^{(t)} = (W_{hy}h^{(t)} + b_y)$$

The LSTM (Long Short-Term Memory) model formulas describe the different components and how they function together. First, the input node output $g^{(t)}$ is calculated using the current time step input $x^{(t)}$ and the previous time step hidden state $h^{(t-1)}$ through the weight matrices W_{gx} and W_{gh} , along with the bias term b_g . The activation function used is \tanh , which constrains the output within the range of -1 to 1. The input gate $i^{(t)}$ output is computed using the input feature $x^{(t)}$ and the previous hidden state $h^{(t-1)}$ via the corresponding weight matrices W_{ix} and W_{ih} , and the bias term b_i . A Sigmoid activation function σ is applied, which produces an output between 0 and 1, determining the proportion of new information that flows into the cell state.

The output gate $o^{(t)}$ is calculated based on the weighted sum of the input features and the hidden state, along with the bias term b_o , using a Sigmoid activation function to control whether the cell state information flows into the hidden layer. The cell state $s^{(t)}$ is the core memory unit of the LSTM model, combining the output of the input node $g^{(t)}$ with the input gate $i^{(t)}$ to determine how much new

information is stored in the cell state. The current time step cell state also retains part of the previous time step state $s^{(t-1)}$, which is updated through the Hadamard product with the output gate $o^{(t)}$.

The hidden state $h^{(t)}$ is obtained by applying the \tanh function to the current cell state $s^{(t)}$, multiplied by the output gate $o^{(t)}$, which controls the flow of information from the cell state to the hidden state. Finally, in the output layer, the LSTM model generates the output $y^{(t)}$ by combining the hidden state $h^{(t)}$ with the weight matrix W_{hy} and the bias term b_y . This entire mechanism allows the LSTM to effectively retain long-term dependencies in sequential data, preventing the vanishing gradient problem, while dynamically updating and outputting information based on the current input.

S3:

Table S1. Unit Ecosystem Service Value Coefficients for the Qinghai-Tibet Plateau. Unit: USD/ha/year.

Ecosystem service	Farmland	Forest	Grassland	Water	Built-up land	Unused land
FD	277.54	27.75	83.26	27.75	2.78	2.78
WT	455.13	363.55	363.55	5045.32	-682.7	2.78
RM	27.75	721.55	13.88	2.78	0	0
CR	24.699	749.31	249.77	127.66	0	0
SR	405.18	1082.33	541.16	2.78	5.55	5.55
AQ	138.76	971.32	222.02	0.00	-671.6	0
RC	2.78	355.23	11.10	1204.44	2.78	2.78
BS	197.04	904.72	302.50	691.03	94.36	94.36
WS	166.51	888.07	222.02	5655.87	-2084.18	8.33
Total	1917.67	6063.82	2009.25	12757.61	-333.02	116.56

Note: FD: Food production; WT: Waste treatment; RM: Raw materials; CR: Climate regulation; SR: Soil retention; AQ: Air quality; RC: Recreation and culture; BS: Biodiversity services; WS: Water supply.

S4:

Dataset	Resolution/Meter	Data Source
Land use	1km	http://www.resdc.cn/
Annual mean temperature	1km	http://www.geodata.cn/
Elevation (DEM)	1km	http://www.gscloud.cn/
Luminous index	1km	http://www.resdc.cn/
Average annual decline	1km	http://www.geodata.cn/
GDP	1km	http://www.resdc.cn/
Population density	1km	http://www.resdc.cn/

Appendix E:

Table S2. 19 Climate Variables.

Code	Data name	Data sources
Bio1	Annual Mean Temperature/°C	WorldClim(https://worldclim)

Bio2	Mean Diurnal Range (Mean of monthly (max temp - min temp)) /°C	.org/data/worldclim21.html)
Bio3	Isothermality (BIO2/BIO7) (×100)	
Bio4	Temperature Seasonality (standard deviation ×100)	
Bio5	Max Temperature of Warmest Month/°C	
Bio6	Min Temperature of Coldest Month/°C	
Bio7	Temperature Annual Range (BIO5-BIO6)/°C	
Bio8	Mean Temperature of Wettest Quarter/°C	
Bio9	Mean Temperature of Driest Quarter/°C	
Bio10	Mean Temperature of Warmest Quarter/°C	
Bio11	Mean Temperature of Coldest Quarter/°C	
Bio12	Annual Precipitation/mm	
Bio13	Precipitation of Wettest Month/mm	
Bio14	Precipitation of Driest Month/mm	
Bio15	Precipitation Seasonality (Coefficient of Variation)/mm	
Bio16	Precipitation of Wettest Quarter/mm	
Bio17	Precipitation of Driest Quarter/mm	
Bio18	Precipitation of Warmest Quarter/mm	
Bio19	Precipitation of Coldest Quarter/mm	

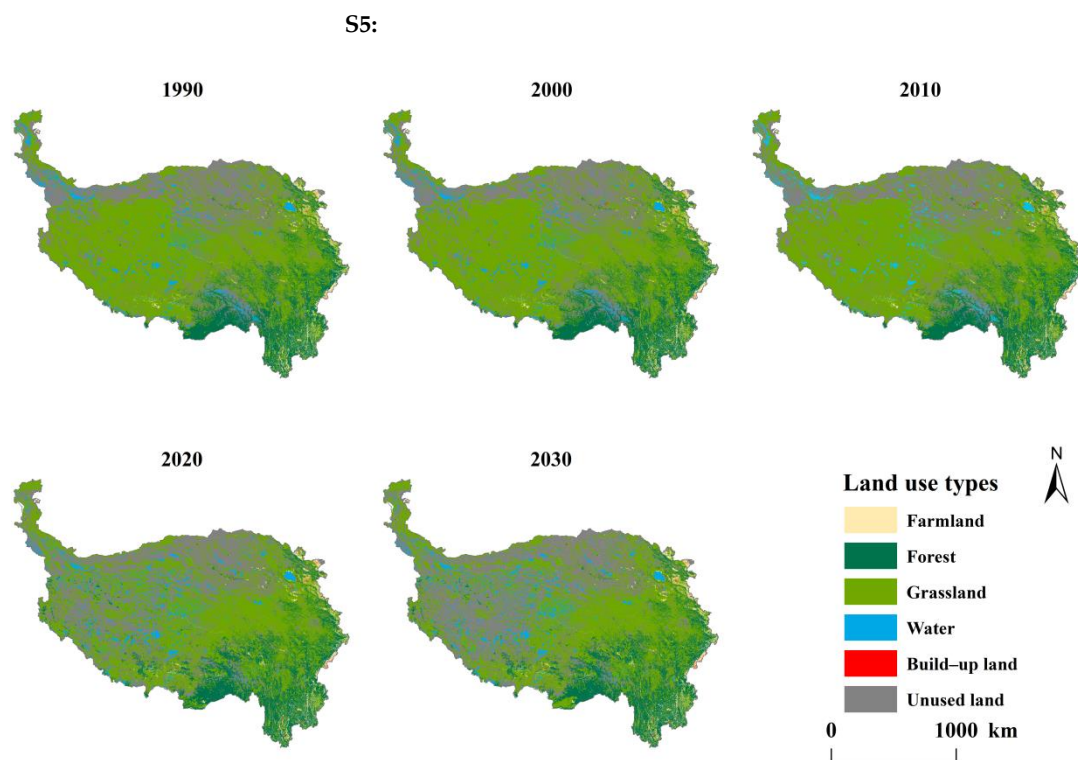


Figure S1: Spatial-temporal distribution of various types of land use on the Qinghai-Tibet Plateau from 1990 to 2030

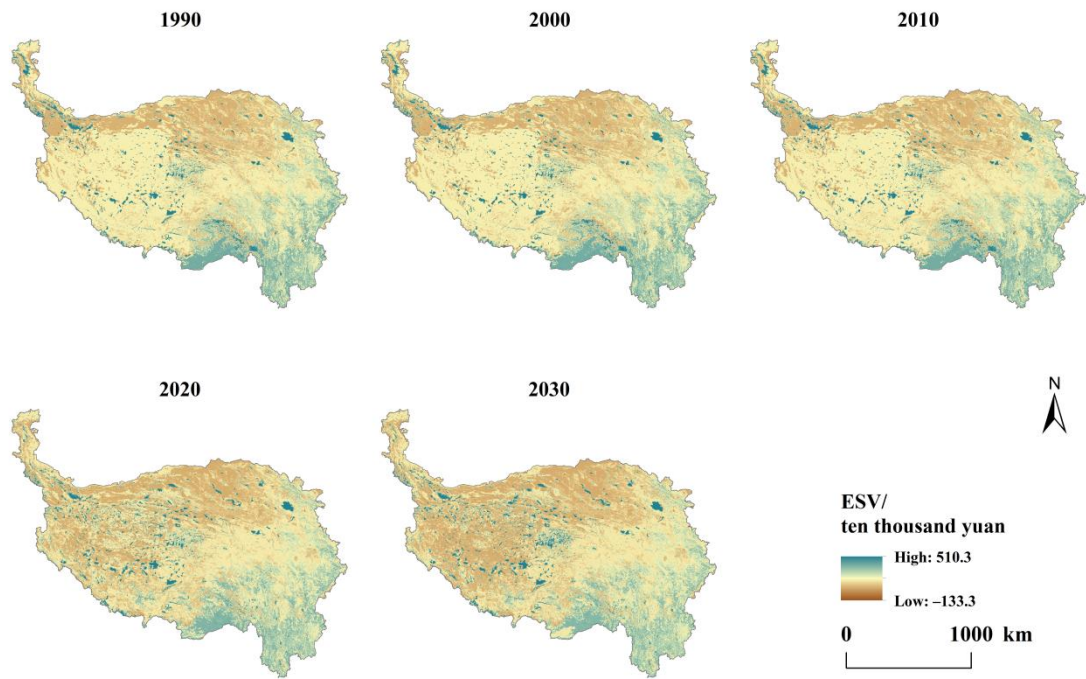


Figure S2: Spatial and temporal distribution of ESV from 1990 to 2030

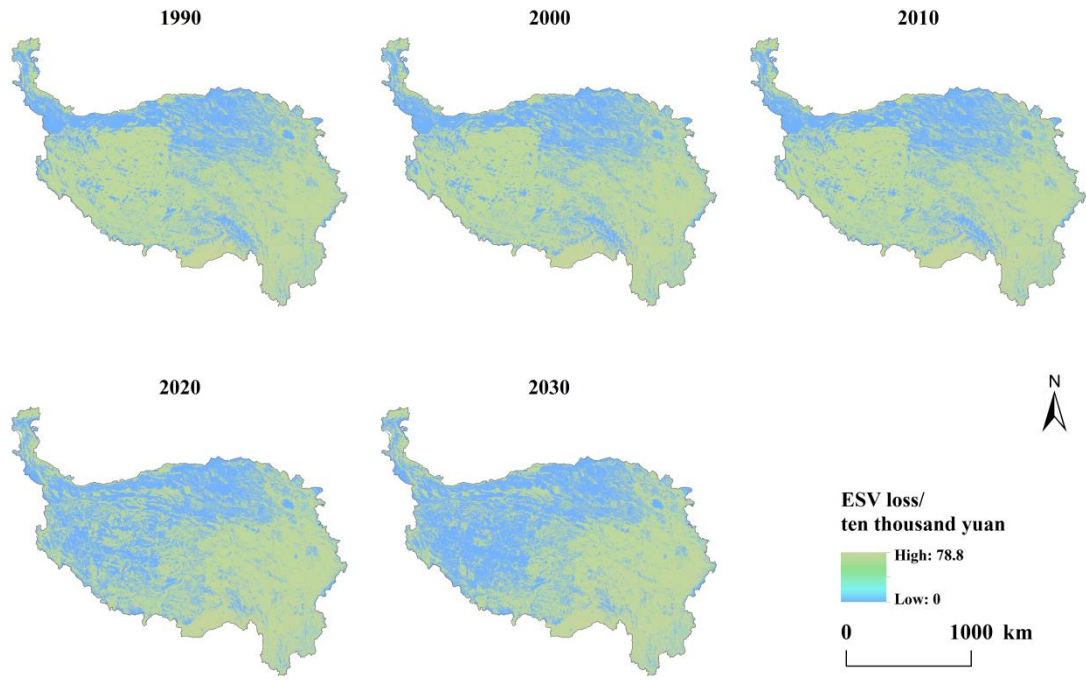


Figure S3: The spatial and temporal distribution of ESV losses from 1990 to 2030