Supplementary Materials

1. Ecosystem service quantification methods

1.1. Habitat Quality

The InVEST quantifies habitat quality based on LULC and threats to biodiversity：

$$Q_i = H_i \cdot \left[1 - \frac{(D_i)^{2.5}}{(D_i)^{2.5} + k^{2.5}}\right] \quad (S1)$$

where Q_i is the habitat quality of raster *i*; D_i is the degree of habitat degradation risk of raster *i*. H_i refers to the habitat suitability of raster *i,* which is determined by LULC. *k* is the half-saturation constant, which was set as the default value of 0.05 for InVEST. Parameter H_i was set based on Sun et al. (2019) in Table S1.

Table S1. Habitat suitability of different LULC types and the degree of sensitivity of different LULC to different habitat threat factors

LULC types	Habitat suitability score	Threat factors						
		Garden management	National road	Provincial road	Expressway	Railway	Cultivated land	Built up area
Barren	0	0	0	0	0	0	0	0
Water Bodies	0.9	0.2	0.4	0.4	0.3	0.3	0.5	0.4
Urban and Built-up Lands	0	0	0	0	0	0	0	0
Dense Forests	0.95	0.7	0.8	0.8	0.8	0.7	0.6	0.4
Open Forests	0.5	0.7	0.8	0.8	0.8	0.7	0.6	0.4
Forest/Cropland Mosaics	0.4	0	0.5	0.7	0.5	0.5	0	0.8
Natural Herbaceous	0.7	0.7	0.8	0.8	0.8	0.7	0.8	0.6
Herbaceous Croplands	0.3	0.5	0.5	0.5	0.5	0.75	0	0.8
Shrublands	0.6	0.7	0.8	0.8	0.8	0.7	0.6	0.65

$$D_{ij} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{W_r}{\sum_{r=1}^{R} W_r} \right) \cdot I_{riy} \cdot r_y \cdot S_{jr} \quad (S2)$$

$$I_{riy} = \begin{cases} 1 - \dfrac{d_{iy}}{d_{rmax}}, if\ linear \\ e^{\frac{-2.99}{d_{rmax}} \cdot d_{iy}}, if\ exponential \end{cases} \quad (S3)$$

Where D_{ij} is threat level, Y_r is the grid cells. R is threat types. W_r is the threat intensity, determined by Chen et al. (2021) in Table S2. I_{rxy} is the extent to which LULC is affected by the variation of r-type threats with distance (Equation S3); S_{jr} is the sensitivity to threat factors, as determined by Chen et al. (2021) in Table S1. d_{rmax} is the maximum threat distance of the r-type threat factor. d_{rmax} and the spatial decay type of different threats ($linear/exponential$) were determined based on Chen et al. (2021) in Table S2

Table S2 Threat intensity weights, longest threat distance, and distance decay type of threat factors

Threat factor	Longest threat distance (km)	Weight	Spatial decay type
Garden management	1	0.4	exponential
National road	2	0.7	linear
Provincial road	1	0.6	linear
Expressway	1.5	0.6	linear
Railway	2	0.7	linear
Cultivated land	4	0.6	linear
Construction land	8	0.4	exponential

1.2. Water Yield

InVEST model calculates water yield by using LULC data, soil type, and rainfall data in the following equation S4:

$$Y_i = \left\{ [1 + (R_i)^{\omega_i}]^{\frac{1}{\omega_i}} - R_i \right\} \cdot P_i \quad (S4)$$

where Y_i is the water yield; P_i refers to the mean annual precipitation; ω_i is

the plant available water coefficient of raster *i* (Donohue et al. 2012), which can be calculated in Equation (S5); R_i is the Budyko dryness index of raster *i* (Budyko 1974), which can be calculated in Equation (S6).

$$\omega_i = Z \cdot \frac{Min(Rest.layer.depth,\ root.depth) \cdot PAWC}{P_i} + 1.25 \qquad (S5)$$

$$R_i = \frac{k_i \cdot ET_{0i}}{P_i} \qquad (S6)$$

where $Rest.layer.depth$ is the root-limiting depth; $root.depth$ is the root depth for different vegetation types, depending on the LULC data, and is determined in this study by referring to the guidelines of Allen et al. (1998) in Table S3; AWC_i is the amount of water available for plants in the soil of grid *i* (mm); *Z* is a hydrogeological parameter between 1 and 30, which was used in this study as default value in InVEST; k_i is the vegetation evapotranspiration coefficient (Kc) for grid *i*, determined by LULC, with reference to González-García et al. (2020) (Table S3). ET_{0i} is the reference evapotranspiration of raster *i*.

Table S3. Biophysical parameters in the InVEST Water Yield model.

LULC types	Root_depth (mm)	The evapotranspiration coefficient (Kc)
Barren	0	0.001
Water Bodies	0	1
Urban and Built-up Lands	0	0.001
Dense Forests	1285	1
Open Forests	1285	0.9
Forest/Cropland Mosaics	942.5	0.8
Natural Herbaceous	850	0.6
Herbaceous Croplands	600	0.7
Shrublands	660	0.9

1.3. Soil Retention

The InVEST model estimates sediment retention based primarily on topography, climate, soil, and LULC by using Equation (S7) (Zhou et al. 2019):

$$SS = R \cdot K \cdot LS \cdot (1 - C \cdot P) \quad (S7)$$

$$R = \sum_{i=1}^{12} \left[1.735 \cdot 10^{\left(1.5\lg\frac{{P_i}^2}{P} - 0.8188\right)} \right] \cdot 17.02 \quad (S8)$$

where SS denotes soil retention (t/yr); K is soil erodibility; LS is slope factor; C is a land cover management factor, which was set as the values recommended by InVEST; P is a support practice factor, which does not apply to the study area, and is ignored in this study; R is rainfall erodibility, which is estimated by referring to the study of Wischmeier and Smith (1978), see equation (S8); P is precipitation; P_i is the precipitation of month *i* (mm/month).

1.4. Urban Cooling

InVEST model calculates urban cooling by using the following equation (Zawadzka et al. 2021)**:**

$$HMI_i = \begin{cases} CC_i & ,if\ CC_i \geq CC_{Parki}\ or\ GA_i < 2ha \\ CC_{Parki} & ,otherwise \end{cases} \quad (S9)$$

Where: $\mathrm{HM_i}$– *heat mitigation index,* $\mathrm{CC_i}$ – *cooling capacity*, $\mathrm{CC_{park_i}}$ – cooling capacity, $\mathrm{GA_i}$ –the area of green space (ha) within the cooling distance d_{cool} for grid *i*. The default value of 250m of InVEST is used as the cooling distance in this study.

$$CC_i = 0.6 \cdot S_i + 0.2 \cdot A_i + 0.2 \cdot \frac{ET_{0i} \cdot k_i}{ET_{max}} \quad (S10)$$

$$CC_{Parki} = \sum_n g_n \cdot CC_i \cdot e^{\frac{-d(n,j)}{d_{cool}}} \quad (S11)$$

Where, S_i is shade, set to 1 for trees larger than 2 m, see Table S4. A_i is the albedo, this study set this parameter based on Taha et al. (1988), Stewart and Oke (2012); ET_{max} is the maximum value of ET_0; ET_{0i} and k_i are defined in the same

way as in Equation (S6), and the value of k_i is shown in Table S3.; $d(n,j)$ is the distance between raster *n* and *j* located within the cooling distance; g_n is the value of *n* raster within the cooling distance , the value is 1 if it is a green field, otherwise it is 0.

Table S4. Biophysical parameters in the InVEST Urban Cooling model.

LULC types	Shade	Green area	Albedo
Barren	0	0	0.275
Water Bodies	0	0	0.06
Urban and Built-up Lands	0	0	0.1675
Dense Forests	1	1	0.15
Open Forests	1	1	0.2
Forest/Cropland Mosaics	1	1	0.2
Natural Herbaceous	0	0	0.2
Herbaceous Croplands	0	0	0.2
Shrublands	0	1	0.225

1.5. Flood Risk Mitigation

The InVEST model is mainly based on LULC information and rainfall during storms to calculate flood risk mitigation:

$$RT_i = \begin{cases} \left[P - \dfrac{\left(P - 0.2 \cdot S_{max_i}\right)^2}{P + 0.8 \cdot S_{max,i}}\right] \cdot PA \cdot 10^{-3} & ,if\ p > \lambda \cdot S_{max,i} \\ P \cdot PA \cdot 10^{-3} & ,otherwise \end{cases} \quad (S12)$$

$$S_{max,i} = \frac{25400}{CN_i} - 254 \quad (S13)$$

where RT_i is the runoff retention of raster i; P is the storm depth; S_{max_i} is the curve function to calculate the potential retention of raster *i*; PA is the area per unit raster (m^2); CN_i is the empirical parameter on raster i that depends on the hydrological soil and LULC (NRCS 2004). According to the study of Zhong et al. (2022), we set this parameter in Table S5.

Table S5. Biophysical parameters in the InVEST Flood Risk Mitigation model.

LULC types	CN_A	CN_B	CN_C	CN_D
Barren	77	86	91	94
Urban and Built-up Lands	93.5	95	96	96.5
Dense Forests	36	60	73	79
Open Forests	36	60	73	79
Forest/Cropland Mosaics	48	67.75	78.25	83.5
Natural Herbaceous	49	69	79	84
Herbaceous Croplands	65	76	84	88
Shrublands	36	60	73	79

1.6. Air Purification

Air purification refers to the ability of vegetation to filter air pollution provided by green space (Nowak et al. 2013), which is mainly based on leaf surface area (LAI), and wind speed for estimating.

$$I = F \cdot A \cdot T \cdot (1 - R) \cdot 10^{-9} \quad (S14)$$

$$F = V_d \cdot C \quad (S15)$$

where I is the annual deposition of $PM2.5$ (kg/yr), A is the leaf surface area (m^2), T is the assessment period (hr), R is the resuspension rate (%), F is the removal flux, V_d is the deposition rate (m/hr), and C is the PM2.5 concentration (ug/m^3). R and V_d are referenced to Nowak et al. (2013), which were obtained by wind speed conversion.

1.7. Carbon Sequestration

We calculated ecosystem carbon sequestration based on the conversion coefficient between NPP and CO_2:

$$Q_{tco2} = NPP \cdot a \quad (S16)$$

Where, Q_{tco2} is the greenhouse gas uptake by vegetation (t/km²); a is the conversion factor to convert NPP to greenhouse gas uptake, and 1.63 was taken as the value of a with reference to Jiang et al. (2021).

1.8. Water Retention

The InVEST model calculates water retention based on annual precipitation, annual runoff coefficient, and evapotranspiration data by using the following Equation：

$$V_{REi} = 0.001 \cdot [P_i \cdot (1 - RC_i) - ET_{0i} \cdot k_i] \cdot pixesl.area \quad (S17)$$

Where V_{REi} is retained water volume (m³ /yr); P_i is the rainfal (mm/yr); RC_i is the runoff coefficient of raster i, which is determined in this study with reference to Hamel et al. (2021), see Table S6.; $pixesl.area$ is the area of the raster (m²); ET_{0i} and k_i are consistent with the meaning of Equation (S10) have the same meaning, and the product of the two represents evapotranspiration.

Table S6：The runoff coefficient of different LULC types.

LULC types	CN_A	CN_B	CN_C	CN_D
Barren	0.002	0.202	0.189	0.349
Urban and Built-up Lands	0.758	0.766	0.773	0.787
Dense Forests	0.001	0.078	0.146	0.277
Open Forests	0.001	0.078	0.146	0.277
Forest/Cropland Mosaics	0.002	0.083	0.154	0.291
Natural Herbaceous	0.002	0.087	0.161	0.304
Herbaceous Croplands	0.002	0.087	0.161	0.304
Shrublands	0.002	0.087	0.161	0.304

1.9. Nitrogen Retention and Phosphorus Retention

The InVEST calculates water purification based primarily on LULC, DEM, and runoff data by using the following Equations：

$$NR_i = M_i - M_i \cdot (1 - eff_i') \cdot \left(1 + e^{\frac{IC_0 - IC_i}{k}}\right)^{-1} \quad (S18)$$

$$IC_i = \log_{10}\left(\frac{\bar{S}_i\sqrt{A_i}}{\sum_i d_i \cdot S_i^{-1}}\right) \quad (S19)$$

$$IC_0 = \frac{IC_{max} + IC_{min}}{2} \quad (S20)$$

NR_i is the retention of pollutants on grid i (kg/yr); M_i is the output of pollutants on grid i (kg/yr); eff_i' is the maximum retention efficiency of grid i; k is the calibration parameter, and the recommended value 2 of InVEST is used in this study; IC_i is the connectivity index, see Equation (S19); $\bar{S}_i$ is the average slope, estimated from DEM data; A_i is the area (m²) of the upslope area of grid i, obtained from DEM data; d_i is the flow path length (m) of grid i along the steepest downslope direction, obtained from DEM data; IC_{max} and IC_{min} are the maximum and minimum values of IC, respectively.

$$eff_i' = \begin{cases} eff_{LULCi} \cdot \left(1 - e^{\frac{-5 \cdot l_{idown}}{l_{LULCi}}}\right) & ,if\ down_i\ is\ a\ stream\ pixel \\ eff_{downi}' \cdot e^{\frac{-5 \cdot l_{idown}}{l_{LULCi}}} + eff_{LULCi} \cdot \left(1 - e^{\frac{-5 \cdot l_{idown}}{l_{LULCi}}}\right), if\ eff_{LULCi} > eff_{downi}' \\ eff_{downi}' & ,otherwise \end{cases} \quad (S21)$$

where eff_{LULCi} is the maximum pollutant retention rate of the LULC of raster i, which is determined in this study with reference to the studies of Wu et al. (2019), Zhao and Li (2022), see Table S7; l_{idown} is the Euclidean distance of raster i to its downslope area, which is estimated by DEM; l_{LULCi} is the distance, and the default value of 150m from InVEST was used in this study.

Table S7： InVEST model NDR module attributes table

LULC types	load_n	eff_n	load_p	eff_p
Barren	4	0.05	0.001	0.05
Water Bodies	9.05	0.05	0.65	0.05
Urban and Built-up Lands	1.8	0.8	0.011	0.8
Dense Forests	3.57	0.8	0.25	0.8
Open Forests	3.55	0.525	0.7555	0.525
Forest/Cropland Mosaics	5.33	0.4	0.33	0.4
Natural Herbaceous	23.61	0.25	1.895	0.25
Herbaceous Croplands	3.57	0.8	0.25	0.8
Shrublands	9.05	0.05	0.65	0.05

1.10. Outdoor Recreation

In calculating outdoor recreation services, we considered the following three aspects: natural elements, nature conservation, and water elements (Paracchini et al. 2014). In this study, factors that are accessible and relevant to YRD were selected to describe each of the above components of outdoor recreation. The selected factors can be found in Zhong et al. (2022). We assumed that the opportunity for water bodies to provide outdoor activities decreases with increasing distance from water, so a distance decay function was used to determine the fraction of the water element factor.

2. Ecosystem service demand quantification methods

2.1. Habitat Quality

Habitat quality demand refers to that human needs to conserve biodiversity (including genes, species, populations, and habitats) in areas of interest (Natural Capital Project 2022). In this study, it is considered that areas with higher habitat quality and higher risk of habitat degradation (the extent to which habitats are affected by human activities) need protection; conversely, areas with lower habitat quality and lower risk of habitat degradation are in lower need of protection. Therefore, this study

considered the above two factors to assess the habitat quality needs. Habitat quality and risk of habitat degradation were normalized by the Max-Min method and a Cross Matrix (Table S8) was calculated to assess the habitat quality demand, with an equal interval method.

Table S8. Habitat quality and habitat risk degradation cross matrix

		Habitat quality Q_{xj}					
Degree of risk of habitat degradation D_{xj}		<0.17	0.17-0.33	0.33-0.5	0.5-0.67	0.67-0.83	>.83
	<0.17	0	0	0	0	0	0
	0.17-0.33	0	0.2	0.2	0.4	0.4	0.6
	0.33-0.5	0	0.2	0.4	0.4	0.6	0.8
	0.5-0.67	0	0.4	0.4	0.6	0.6	0.8
	0.67-0.83	0	0.4	0.6	0.6	0.8	0.8
	>.83	0	0.6	0.8	0.8	0.8	1

2.2. Crop Production

This study used the product of population density and daily per capita food consumption to quantify food production need (Zhong et al. 2022):

$$GC_i = P_i \cdot PC_y \quad (S22)$$

Where GC_i is food consumption (kg/yr); P_i is the number of population in raster i (persons); PC_y is the annual per capita food consumption in year y (kg/yr).

2.3. Water Yield

The amount of water consumption per year was calculated from the per capita water consumption and population density in China, which includes agricultural, industrial, urban public, residential, and ecological recharge (González-García et al. 2020):

$$YC_i = P_i \cdot YC_y \quad (S23)$$

Where YC_i is water consumption (m^3 /yr), P_i is the number of population in

grid i (persons), and PC_y is water consumption in year y (m^3/yr).

2.4. Soil Retention

Soil retention demand refers to the amount of ecological restoration that humans need to do after soil erosion occurs, i.e. the actual amount of erosion of the soil (Villamagna et al. 2013). We calculate soil retention demand by following the methods proposed by Licheng et al. (2019)：

$$SD = R \cdot K \cdot LS \cdot C \cdot P \quad (S24)$$

where SD denotes the amount of soil to be maintained in the area of interest (t/yr) and the meaning and origin of the parameter are the same as in Equation (S7).

2.5. Water Retention

In this study, the runoff volume in the bare soil case was used as the demand for water retention, and the estimation method of InVEST was as follows：

$$V_{RUi} = 0.001 \cdot P_i \cdot RC_i \cdot pixel.area \quad (S25)$$

Where V_{RUi} is the annual runoff volume of grid i (m^3/yr) in the case of bare soil, and the meaning of other factors is the same as the meaning of Equation (S17).

2.6. Nitrogen Retention and Phosphorus Retention

This study uses the output of pollutants as the demand for water purification：

$$M_i = load_i \cdot \frac{RP_i}{RP_{av}} \quad (S26)$$

where M_i is the output of pollutants on grid i (kg/yr); $load_i$ is the output of LULC pollutants on grid i (kg/yr), which is determined in this study with reference to the studies of Wu et al. (2019), Zhao and Li (2022). RP_i is the quickflow index of

grid i. obtained by normalizing the runoff volume estimated by the water production model, and RP_{av} is the mean value of the quickflow index.

2.7. Outdoor Recreation

Outdoor recreation demand is obtained through a cross-analysis matrix of accessibility to outdoor activity facilities (areas with outdoor recreation supply greater than 0.45) and population density (Zhong et al. 2022).

Table S9. Outdoor Activity Service Demand Cross Matrix

		Accessibility					
Population Density		<0.3	0.3-0.6	0.6-0.9	0.9-1.2	1.2-1.5	>1.5
	<5	0	0	0	0	0	0
	5-50	0	0.2	0.2	0.4	0.4	0.6
	50-100	0	0.2	0.4	0.4	0.6	0.8
	100-200	0	0.4	0.4	0.6	0.6	0.8
	200-400	0	0.4	0.6	0.6	0.8	0.8
	>400	0	0.6	0.8	0.8	0.8	1

References：

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