Supporting Information

S1 GEP Accounting Methods

In this study, we calculate GEP based on the IPBES ecosystem service classification that includes material services, regulating services, and non-material services (1). In material ecosystem services, we include agricultural crops, animal husbandry, fishery, forestry, and nursery production in Qinghai, along with material services from water supply originating in Qinghai. In regulating services, we include soil retention, sandstorm prevention, flood mitigation, air purification, water purification, and carbon sequestration. In non-material services, we include ecotourism. We chose to include these ecosystem services both because they are important and we had available data and methods to estimate their value.

S1.1 Material Services

A. Biophysical quantities

Material ecosystem services include the various products produced in Qinghai Province for which ecosystems contribute in a significant way to their output. Information on annual production of material services is obtained from a variety of economic accounting systems including the Qinghai Provincial Bureau of Statistics (2-3).

Water supply

Qinghai Province is the headwaters of three major rivers: the Yellow River, the Yangtze River, and the Mekong River. Water originating in Qinghai is used in Qinghai and in many downstream provinces in the Yellow, Yangtze, and Mekong river basins, along with provinces in several other river basins in Southwestern China. Water resources from Qinghai are used for agricultural, hydropower, and industrial production, and for domestic use.

Water resources use includes: 1) the water supply for industrial use and domestic use in Qinghai Province (m^3), labeled Q_{QI} and Q_{QD}, which comes from the *Qinghai Water Resources Bulletin* (4-5); and 2) the water supply for use downstream in the Yangtze River (W_{QYA}, m^3) and the Yellow River (W_{QYE}, m^3), which comes from the *Qinghai Water Resources Bulletin* (4-5). The amount of hydropower production includes: 1) hydropower production in Qinghai Province, Q_{QHP} which comes from Q*inghai Statistical Yearbook* (2-3); and 2) the hydropower production in all downstream dams, Q_{DHP}.

When we calculate the water resource from Qinghai used in downstream provinces, we first calculate the fraction of surface water in each downstream province that originates in Qinghai. Denote downstream provinces by i, $i = 1, 2, \ldots N$. The amount of water that originates in Qinghai flowing into province i is denoted W_{iQ} (m^3). We adjust the amount of water flowing out of Qinghai in the Yangtze River, W_{QYA}, or the Yellow River, W_{QYE} (m^3; 4-5), by losses as water flows downstream (6, 7):

$$\text{Yangtze River: } W_{iQ} = W_{QYA} \times (1 - 0.005\%)^{l_i}$$

$$\text{Yellow River: } W_{iQ} = W_{QYE} \times (1 - 0.01\%)^{l_i}$$

where l_i (km) is the length of the river between where the river leaves Qinghai Province and where the river enters into province *i*.

The fraction of surface water in province *i* that originates in Qinghai is defined as $F_{iQ} = \frac{W_{iQ}}{W_{iT}}$. W_{iT} is the total amount of surface water in province *i* is reported by provincial water resource agencies (m^3; 8-41).

The water resources from Qinghai used by industry in downstream province *i* are $Q_{iI} = F_{iQ}W_{iI}$, where W_{iI} is the amount of water used by industry in province *i* (m^3; 8-41).

The amount of water from Qinghai in domestic use is defined similarly. The water resources from Qinghai in domestic use in downstream province *i* is $Q_{iD} = F_{iQ}W_{iD}$, where W_{iD} is the amount of water in domestic use in province *i* (m^3; 8-41).

We include the value of water used for irrigation downstream in the Yellow River Basin, but not for the Yangtze River Basin or other river basins. Crops in the Yangtze Basin and other river basins downstream from Qinghai are mostly grown without irrigation as there is adequate rainfall. Irrigation, however, is common the Yellow River Basin. The amount of agricultural crops grown with irrigation using water resources from Qinghai in province *i*, Q_{iA} (t), is calculated as

$$Q_{iA} = F_{iQ}W_{iA}E_{iI}E_{CU}$$

where W_{iA} is the amount of water used in irrigation in province *i* in the Yellow River Basin (m^3; 12-15, 22-25, 28-29, 34-37), E_{iI} is the irrigation efficiency of province *i* in the Yellow River Basin (%; 12-15, 22-25, 28-29, 34-37), and E_{CU} is the crop water use efficiency (t/m^3; 42).

For downstream hydropower production, we calculate the fraction of hydropower electricity generated at each dam downstream from Qinghai attributable to water resources from Qinghai. Let F_{jQ} be the fraction of water at downstream dam *j*, *j* = 1, 2, …, *J*, that originates in Qinghai: $F_{jQ} = \frac{W_{jQ}}{W_{jT}}$, where W_{jQ} is the amount of water from Qinghai flowing through dam *j* (m^3) and W_{jT} is the total amount of water flowing through dam *j* (m^3; 43-50). W_{jQ} for dams along the Yangtze or Yellow Rivers is calculated by taking the amount of water flowing out of Qinghai in the Yangtze River, W_{QYA}, or the Yellow River, W_{QYE} (m^3; 4-5), adjusted by losses as water flows downstream (6, 7):

$$\text{Yangtze River: } W_{jQ} = W_{QYA} \times (1 - 0.005\%)^{l_j}$$

$$\text{Yellow River: } W_{jQ} = W_{QYE} \times (1 - 0.01\%)^{l_j}$$

where l_j (km) is the length of river between dam *j* and Qinghai Province.

Downstream hydropower production at dam *j* attributable to water resources from Qinghai, measured in kwh, is $Q_{jHP} = F_{jQ}E_j$, where E_j is the amount of hydropower electricity produced at dam *j* (kwh; 43-50). We then aggregated hydropower production across all downstream dams: $Q_{DHP} = \sum_{j=1}^{J} Q_{jHP}$.

B. Accounting value

The annual value of material services (Yuan) for agricultural products, animal husbandry products, fishery products, forest products, and nursery products are reported in the *Qinghai Statistical Yearbook* (2-3). We adjust the value of agricultural products and animal husbandry products to include only the portion of value due to inputs from nature, netting out the portion of value due to labor and other human made inputs. For agricultural crops we used a value of 38.55% for the proportion of value attributable to nature (51). For animal husbandry we used 36.5% for the proportion of value attributable to nature (52).

We calculate the accounting value of water resources from Qinghai used in industry, domestic use, irrigation for agricultural crops, and hydropower production, as follows. We calculate the accounting value of water supply for industrial use by *multiplying the amount of industrial water by the market price of* industrial water:

$$V_I = Q_{QI}P_{QI} + \sum_{i=1}^{N} Q_{iI}\, P_{iI}$$

where P_{QI} is the *market price of* industrial water in Qinghai (Yuan/m^3), and P_{iI} is the *market price of* industrial water of province i (Yuan/m^3). Market prices of industrial water come from the E20 Environment Platform (http://www.h2o-china.com/price/) (53).

We calculate the accounting value of water supply for domestic use by *multiplying the amount of domestic water by the market price of* domestic water:

$$V_D = Q_{QD}P_{QD} + \sum_{i=1}^{N} Q_{iD}\, P_{iD}$$

where P_{QD} is the *market price of* domestic water in Qinghai (Yuan/m^3), and P_{iD} is the *market price of* domestic water of province i (Yuan/m^3). Market prices of domestic water come from the E20 Environment Platform (http://www.h2o-china.com/price/) (53).

For the accounting value of hydropower, we multiply the amount of electric power generation attributable to water resources from Qinghai by the market price of electricity:

$$\mathrm{V_H} = (Q_{QHP} + Q_{DHP}) \times P_E$$

where P_E is the residential electricity price (Yuan/kWh, 54). This method will tend to overestimate the value of this ecosystem service because we do not deduct the value of the other human produced inputs including the dams and machinery necessary to convert hydropower into electricity.

For agriculture, we calculate the *accounting value* of crop production downstream from irrigation made possible by using water resources from Qinghai as follows. We calculate the revenue from crop production net

$$V_\mathrm{A} = \sum_{i=1}^{N} Q_{iA}P_A\, F_A$$

where P_A is the crop price (Yuan/ton), and F_A is the fraction of crop value attributable to nature.

For F_A, we use the same proportions here as we did for Qinghai agricultural crops (38.55%). For crop price we use the price of wheat, which is the most common crop in the Yellow River Basin. The price of wheat comes from National Development and Reform Commission (http://jgs.ndrc.gov.cn/zcfg/201410/t20141016_629600.html). For F_A, we use the same proportions here as we did for Qinghai agricultural crops.

Table S1. **Material services in Qinghai province.** Quantity units: (t) tons, (m^3) cubic meters, (np) number of plants, (kwh) kilowatt hours.

Functional category	Group indicator	Individual product quantity indicators
Agricultural products	Grains	wheat (t), highland barley (t), etc.
	Beans	broad beans (t), peas (t), etc.
	Potato	potato (t)
	Oil	rapeseed (t), flax seed (t), etc.
	Hemp	hemp (t)
	Sugar	beets (t)
	Tobacco	tobacco (t)
	Herbs	traditional Chinese medicine herbs (t)
	Vegetable	Broccoli (t), cabbage (t), etc.
	Melon	melon (t)
	Fruit	apple (t), pears (t), grapes (t), etc.
Animal husbandry products	Meat	beef (t), lamb (t), pork (t), etc.
	Dairy	milk (t)
	Animal fur	wool (t), cashmere (t), plush (t), camel hair (t), horse mane (t), etc.
	Other animal husbandry products	eggs (t), honey (t), etc.
Fishery products	Breed aquatic	breed aquatic (t)
Forest products	Timber	timber (m^3)
	Other forest products	Chinese prickly ash (t), walnuts (t), etc.
Nursery products	Nursery products	flowering plants and seedlings (np)
Water supply	Water resources	Water supply for domestic, industrial and agricultural use in Qinghai and downstream provinces (m^3)
	Hydropower production	hydropower production (kwh)

C. Additional issues, extensions, and omissions

We include the entire value of material output in ecosystem services from fishery, forestry, and nursery production even though the application of human labor, machinery and other human produced inputs contributes to their production. For these services, we overestimate the value of the ecosystem services. We lacked systematic data on costs for human labor, machinery, and other human created inputs for these sectors. The production in these sectors is relatively small.

We adjusted the value of agricultural crop production and animal husbandry to include only the proportion of value attributable to nature. Our estimates of value of material services understate the contribution of nature to the extent that we have not included all material services. For example, we did not include the value of water supply downstream in the Mekong River Basin, much of which occurs in Southeast Asian countries outside of China.

S1.2 Soil retention

A. Biophysical quantity

Soil erosion removes topsoil and nutrients, leading to reductions in the fertility of lands. Sediment that reaches streams and rivers contributes to reductions in downstream water quality. Sediment fills in hydropower reservoirs and leads to the decreased hydropower output.

The ecosystem service of soil retention refers to the soil retained by ecosystems, which prevents sediments from entering water bodies and causing damages. We measure soil retention as the difference between soil erosion without vegetation cover and soil erosion under the current land cover pattern and soil erosion control practices (e.g. terraced fields). Soil retention was calculated using the Universal Soil Loss Equation (USLE; 55) and InVEST model (56), and the model can be expressed as:

$$Q_{sr/h} = R \times K \times LS \times (1 - C \times P)$$

where $Q_{sr/h}$ represents the soil retention capacity ($t \cdot ha^{-1} \cdot y^{-1}$), R is the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot a^{-1}$) determined using kinetic energy of raindrops and intensity of rainfall (in hectare-millimeters per hour) over one year, K is erodibility of the soil or the amount of soil lost through erosion per unit area following rainfall of a given intensity ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$), LS is the topographic factor representing the effect of the length of slope, C is the vegetation cover factor, and P is the practice factors of soil erosion control (e.g., terraced fields).

Rainfall erosivity (R) reflects the potential for rainfall and runoff to cause soil erosion (57). In this study, we adopted the Daily Rainfall Erosivity Model (58), for which only conventional rainfall data (daily precipitation) is needed. We use rainfall data from 603 weather stations.

$$\bar{R} = \sum_{k=1}^{24} \bar{R}_k$$

$$\bar{R}_k = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=0}^{m} (\alpha \times P_{i,j,k}^{1.7265})$$

where $\bar{R}$ is the average annual rainfall erosivity, $\bar{R}_k$ is the average rainfall erosivity for the kth half month, k is 24 half months in a year (k=1, 2, …, 24), i is the number of years in accordance with rainfall data (i=1, 2, …, n), j is the number of erosive rainfall days in the *k*th half month of the *i*th year (j=0, 1, …, m), $P_{i,j,k}$ is the daily precipitation (mm) on the *j*th erosive rainfall day in the *k*th half month of the *i*th year, and α is a parameter that is assigned a value of 0.3937 for the warm season (May-September) and 0.3101 for the cold seasons (October-April).

Soil erodibility (K) reflects the sensitivity of soil particles to erosive forces and it is an internal factor affecting soil erosion that is closely related to soil attributes (57). The Erosion/Productivity Impact Calculator (EPIC) was employed to calculate *K* for soil clay, silt, sand, and organic carbon content (59-60). This study conducted by Zhang et al. (60) was used for subsequent revisions.

The topographic factor (LS) reflects the effects of terrain (slope length and gradient) on soil erosion (61). We integrated the relevant research on gentle and steep slopes, and performed calculations using different slope segments (62-64), making a correction for slopes of >28.81°. The slope length was computed with reference to the ArcInfo AML code (61), which was implemented in the ArcInfo Workstation (ArcGIS 9.3).

The vegetation cover factor (C) describes the effect of vegetation on soil erosion, and is related to vegetation structure and cover. Parameter values were assigned to the vegetation cover factor according to previous studies (65-67), where different ecosystem types and vegetation coverage were considered for forests, shrubs and grasslands (64). For farmlands (except paddy lands), the model established by Liu et al. (66) was applied. For wetlands (including paddy lands, a type of farmland), cities, and bare lands (e.g., deserts, lichens), we used the following values 0, 0.01, and 0.7, which were derived from parameters using in Nonpoint Source Pollution and Erosion Comparison Tool (65). The input data of ecosystem classification images and vegetation cover in 2000 and 2015 were used to calculate the C factor.

The practice factors of soil erosion control (p) describes the effect of artificial erosion control practices on soil erosion, refers to the ratio of soil erosion amount when specific erosion control practices are adopted and corresponding erosion amount when no measures are taken for slope tillage (55). If there no artificial practices, P=1 (68).

We sum the per hectare amount of sediment, $Q_{sr/h}$, over the number of hectares in a watershed to generate a measure of soil retention by watershed, Q_{sr} (t).

B. Accounting value

The accounting value of soil retention includes the reduced dredging cost in hydropower reservoirs and reduced non-point source pollution treatment costs:

$$V_{sr}=V_{sd}+V_{dpd}$$

where V_{sr} is the *accounting value* of soil retention provided by the ecosystem (Yuan/year), V_{sd} is the reduced cost of dredging (Yuan/year), V_{dpd} is the reduced cost of non-point source pollution treatment (Yuan/year).

We measure the value of reduced reservoir dredging cost as

$$V_{sd}=\lambda \times (Q_{sr}/\rho) \times c$$

where λ is the sediment deposition coefficient (69), ρ is the soil bulk density (t/m^3), c is the cost of reservoir dredging per unit (Yuan/m^3).

If pollutants from soil erosion exceed the water environmental carrying capacity, we take the water environmental carrying capacity as the actual water purification capacity. Then the *accounting value* can be calculated as follows:

$$V_{dpd} = \sum_{i=1}^{2} Q_{sr} \times c_i \times t_i \times d_i \times p_i$$

where c_i is the content of N and P in sediment, t_i is the transfer rate of erosive sediment transfer to river (70), d_i is the diffusion rate and refers contribution rate of soil retention to nitrogen and phosphorus in water (71), and p_i is the cost to treat waste water of nitrogen and phosphorus (Yuan/t) (72-73).

If the pollutants from soil erosion don't exceed the water environmental carrying capacity, we consider that the emitted pollutants from industry and domestic are all purified by ecosystems. The amount of purified N and P by ecosystems is the amount of emitted pollutants.

C. Additional issues, extensions, and omissions

We did not include the loss of topsoil and nutrients leading to reduced soil fertility in the accounting value of the ecosystem service of soil retention for two reasons. First, we currently lack the evidence base on which to build the relationship between soil erosion, soil fertility, and crop productivity for Qinghai. Second, we already include the value of current agricultural crop production, which depends on current fertility. Reductions in soil fertility will affect future crop production (and future GEP) so that reductions in soil fertility should be reflected in ecosystem assets accounting once information is available.

We did not include losses from local landslides. Though local landslides are observable in the remote sensing data (30m x 30m), we do not have information about their impacts or the value of the impacts.

S1.3 Sandstorm prevention

A. Biophysical quantity

Sandstorm prevention (wind erosion control service) refers to the sand retained in an ecosystem for one year. We measure sandstorm prevention as the difference between wind erosion without vegetation cover and wind erosion under the current land cover pattern. We used the Revised Wind Erosion Equation (RWEQ) model (74) to estimate the sandstorm prevention service. The RWEQ combines empirical and process modeling and has been extensively tested under broad field conditions. To simulate sand/soil loss at a regional scale over varying vegetation cover and patterns, we rewrote the RWEQ into the dynamic modeling language of PC Raster (75). PC Raster is an environmental modeling language embedded in a Geographical Information System, providing spatial and temporal functions that can be used to construct regional models.

The RWEQ model estimates sand/soil loss (S_L; kg·m^{-2}) as a function of several factors: weather (WF), soil erodibility (EF), soil crust (SCF), surface roughness (K'), and vegetation cover (C), which permit estimation of the potential maximum transport capacity without vegetation cover by wind (Q_{pmax}) as follows:

$$Q_{pmax} = 109.8[WF \times EF \times SCF \times K']$$

$$S_p = 150.71 \cdot (\mathrm{WF} \times \mathrm{EF} \times \mathrm{SCF} \times \mathrm{K}')^{-0.3711}$$

$$S_{pL} = \frac{2 \cdot z}{{S_p}^2} Q_{pmax} e^{-(z/S_p)^2}$$

We estimate the wind erosion amount under the current land pattern as follows：

$$Q_{max} = 109.8[WF \times EF \times SCF \times K' \times C]$$

$$\mathrm{S} = 150.71 \cdot (\mathrm{WF} \times \mathrm{EF} \times \mathrm{SCF} \times \mathrm{K}' \times \mathrm{C})^{-0.3711}$$

$$S_{La} = \frac{2 \cdot z}{S^2} Q_{max} e^{-(z/S)^2}$$

To calculate the sand storm prevention (wind erosion control) service for a given location, Q_{sp} ($kg \cdot m^{-2}$), we calculate the difference in RWEQ model with no vegetation (S_{Lp}) versus with vegetation (S_{La}).

$$Q_{sp} = S_{Lp} - S_{La}$$

where S_{Lp} ($kg \cdot m^{-2}$) is the potential soil loss caused by wind erosion, S_{La} ($kg \cdot m^{-2}$) is the soil loss caused by wind erosion, Q_{pmax} ($kg \cdot m^{-1}$) is the potential maximum transport capacity, Q_{max} ($kg \cdot m^{-1}$) is the maximum transport capacity, S_p(m) is the potential field length, *S* (m) is the critical field length, *z* (m) is the distance from the upwind edge of the field.

Weather Factor (WF) represents the influence of climate conditions on wind erosion. *WF* is partitioned according to the preponderance and positive parallel ratio values from the weather file (76-77). *WF* is determined by dividing the total wind value for each period by 500 and multiplying by the number of days in the period (78-79).

$$WF = Wf \times \frac{\rho}{g} \times SW \times SD$$

$$Wf = u_2(u_2 - u_1)^2 \times N_d$$

where *Wf* [$(m/s)^3$] is the wind factor, ρ (kg/m^3) is air density, *g* (m/s^2) is gravitational acceleration, *SW* is soil factor, *SD* is snow cover factor, u_1 is wind velocity of sand movement, we used 5 m/s, u_2 (m/s) is monthly average wind velocity from meteorological station, N_d is number of days with wind velocity greater than 5m/s.

Soil Erodible Factor (EF). The erodible fraction is that fraction of the surface 25mm of sand/soil that is smaller than 0.84mm in diameter as determined by a standard compact rotary sieve (80). From a soil sieving data base (Scientific data center of cold region and arid region, http://westdc.westgis.ac.cn/), the highest value for *EF* during a year for each site was correlated with basic soil physical and chemical properties (81).

$$\mathrm{EF} = \frac{29.09 + 0.31sa + 0.17si + 0.33(sa/cl) - 2.59OM - 0.95CaCO_3}{100}$$

where *sa* (%) is coarse sand content of soil, *si* (%) is silty sand content of soil, *cl* (%) is clay particles content of soil, *OM* (%) is organic matter content of soil, C_aCO_3 (%) is $CaCO_3$ content, we used 0 in this research.

Soil Crusting Factor (SCF). When raindrops impact the soil surface, there is a redistribution of soil particles and a formation of surface crust. The resulting soil surface can be extremely hard or very fragile and may decrease or increase wind erosion potential (82). The *SCF* equation was developed using laboratory wind tunnel tests on resistance of soil aggregates and crusts to windblown sand (83).

$$\mathrm{SCF} = \frac{1}{1 + 0.0066(cl)^2 + 0.021(OM)^2}$$

where *cl* (%) is clay particles content of soil, *OM* (%) is organic matter content of soil.

Surface Roughness Factor (K'). The original RWEQ was designed to calculate wind erosion loss at a field scale. Tillage operations modify the soil surface roughness and flatten and bury crop residues. When scaled up to a region, we replaced soil ridge roughness with roughness caused by topography, and was calculated by the Smith-Carson equation.

$$\mathrm{K}' = e^{(1.86K_r - 2.41K_r^{0.934} - 0.127C_{rr})}$$

$$K_r = 0.2\frac{(\Delta H)^2}{L}$$

where C_{rr} (cm) is random roughness factor, we didn't consider it in this research; K_r (cm) is topographic roughness factor; L is relief parameter; ΔH is elevation difference within distance of L.

Vegetation Factor (C). The vegetation quantity on the ground surface has a significant impact on sand/soil erosion by wind. To quantify the effect of vegetation, the fraction of the ground surface covered with non-erodible plant material (flat residues), the plant silhouette from standing plant residues (standing residues), and growing crop canopies (crop canopy) are used in RWEQ (84).

$$\mathrm{C} = e^{-0.0483(SC)}$$

where *SC* (%) is vegetation fraction.

B. Accounting value

The sandstorm prevention service provides benefits through reduction in the health costs of populations living in downwind areas. The *accounting value* of sandstorm prevention service is equal to the reduction in health costs from reduced exposure to wind borne sand and dust (V_{SP}, Yuan/year), which is found by comparing the difference between the potential exposure to wind borne sand and dust assuming there is no vegetation (V_p), and the actual exposure to wind borne sand and dust (V_a):

$$V_{SP} = V_p - V_a = M \times C \times \left(P_p n_p - P_a n_a\right)$$

where P_p is the potential affected population, P_a is the actual affected population, M is the percentage of the affected population that will become ill due to exposure to dust and sand, C is the health cost per person who becomes ill (Yuan/per capita), n_p is the potential days of exposure to wind borne sand and dust per year with no vegetation cover, and n_a is the actual days of exposure to wind borne sand and dust per year (85).

The exposed population is based on the prevailing wind direction and the exposure distance to sand and dust. We include population up to 70 km downwind from a sand and dust source as being affected by sand and dust, which is calculated based on results from Li et al. (85). Prevailing winds are from the west. We used population distribution based on a 1km x 1km resolution population raster from the Resource and Environment Data Cloud Platform (http://www.resdc.cn/Default.aspx). Vegetation covers the eastern part of Qinghai so that sand and dust originating in Qinghai does not affect downwind provinces. However, the potential affected population (P_p) extends beyond Qinghai because if vegetation cover is removed throughout Qinghai there will be exposed populations in downwind provinces. The percentage of the affected population that will become sick due to exposure to sand and dust (M) comes from Peng et al. (86). The health cost per person who becomes ill comes from Wang et al. (87). The actual days of exposure to wind borne sand and dust per year comes from Li et al. (85). We calculate the potential days of exposure to sand and dust per year (n_p) based on the days of exposure to sand and dust per year within the desert area of Qinghai Province (85).

C. Additional issues, extensions, and omissions

We did not account for variable wind direction or differences due to interception by landscape features introduced by variable topography.

S1.4 Flood mitigation

A. Biophysical quantity

Heavy rainfall events resulting in flooding causes major economic losses. Natural vegetation, wetlands, lakes, and reservoirs, can store water and affect the timing and magnitude of water runoff and water flows, acting as sponges, intercepting storm rainfall and absorbing water through root systems and storage capacity (88). Flood mitigation can be defined as the storage capacity of natural vegetation, wetlands, natural lakes and reservoirs, which can be used to absorb or spread out the excess water flows during flooding.

The flood mitigated service provided by ecosystems includes: (*i*) runoff retention by vegetation and (*ii*) runoff retention by wetlands, (*iii*) runoff retention by lakes, and (*iv*) runoff retention by reservoirs:

$$C_{fm} = C_{vc} + C_{wc} + C_{lc} + C_{rc}$$

where C_{fm} is the total storage of flood water (m^3), C_{vc} is the storage of flood water from natural vegetation (m^3), C_{wc} is the storage of flood water by wetlands (m^3), C_{lc} is the storage of flood water by lakes (m^3), C_{rc} is the storage of flood water by reservoirs (m^3).

For natural vegetation (forest, shrub and grassland): Flood mitigation from vegetation was calculated based on the difference between runoff with no vegetation and runoff with vegetation in the wet season (m^3). We use the monthly water yield model of InVEST (56) to identify the monthly water yield with current land covers and with no vegetation.

For wetlands: Flood storage provided by wetlands was calculated as follows:

$$C_{wc} = A \times D$$

where *A* is the wetland area (m^2), and *D* is the average depth of the wetland (m).

For lakes: Flood storage for lakes was constructed based on the relationship between available storage capacity and lake area (89-90), since the latter is closely related to storage capacity and is much easier to acquire. For lakes in Qinghai, we used the following relationship:

$$Ln(C_{lc})=0.680\ Ln(A)+5.653$$

where *A* is the lake area (90).

For reservoirs: Flood storage for reservoirs was constructed based on the relationship between flood control storage capacity and total storage capacity (91), which is available for most reservoirs in China:

$$C_{rc} = 0.35 \times C_t$$

where C_t is the total storage capacity of the reservoir (m^3).

B. Accounting value

We calculated the accounting value of flood mitigation by using the average cost of downstream flooding in the wet season along the Yangtze River where flooding is a serious problem. We did not calculate flood mitigation benefits for either the Mekong or Yellow River Basins as flooding is less of a concern in these Basins. The accounting value of the flood mitigation service (V_{fm}; Yuan/year) is

$$V_{fm} = C_{fm} \times C_{fd}$$

where C_{fm} is flood control storage capacity of ecosystems (m^3), C_{fd} is the average cost of downstream flooding disaster in wet season (Yuan/ m^3) based on the relationships between runoff in the main stream of the Yangtze River in wet season and cost of flooding disaster during 2006-2015. We built a statistical model relating the amount of damage caused by flooding per year and the amount of flood water using 10 years of data in Yangtze River Basin. We found that the flood damage increased by 469.2 million Yuan for each billion m^3 of increased flood water, Damage (Yuan) = - 959.6 + 0.4692*Flood water (m^3), R^2=0.44.

C. Additional issues, extensions, and omissions

Hydrological processes (e.g., water retention in ecosystems) are difficult to accurately measure. Other than for reduced flooding, we did not attempt to measure the value of changing the timing of flows of water downstream. We assumed that increased water storage in Qinghai is associated with flood water at downstream locations. There are complicated issues of timing of flows from different places within the Yangtze River Basin so that increased flows from some portions of the basin are more damaging than others, which we did not attempt to model. In addition, we did not assess non-linear effects of flood water on damage. We also did not calculate flood mitigation benefits for the Yellow or Mekong Rivers.

S1.5 Air purification

A. Biophysical quantity

Vegetation contributes to air purification by absorbing or filtering air pollutants and thereby reducing exposure to harmful air pollution. Sulphur dioxide, nitrogen oxides, and industrial sources of particulate matter are the three main air pollutants in China. Each vegetation type i ($i = 1, 2, \ldots, I$) has a capacity to absorb or filter each air pollutant type j (j = SO_2, NO_x, PM) given by QA_{ij} ($kg \cdot ha^{-1} \cdot y^{-1}$), see Table S3. The annual amount of air purification for pollutant j at location l ($l = 1, 2, \ldots, L$) is given by

$$QA_{jl} = Min\left[X_{jl}, \sum_{i=1}^{I} A_{il}\, QA_{ij}\right]$$

where X_{jl} is the total emission amount of air pollutant j at location l ($kg \cdot ha^{-1} \cdot y^{-1}$), and A_{il} is the area of vegetation type i at location l (ha). The total amount of air purification for pollutant j from vegetation in a region is given by

$$QA_j = \sum_{l=1}^{L} QA_{jl}.$$

Table S3. Air filtration capacity of different vegetation types

Ecosystem	Air pollutants	Filtration capacity ($t \cdot km^{-2} \cdot a^{-1}$)	References
Forest	SO_2	24.6	(92-96)
	NO_x	0.57	(93, 95)
	PM	3831.7	(92, 96-98)
Shrub	SO_2	8.4	(99-100)
	NO_x	0.19	(93)
	PM	162.4	(93)
Grassland	SO_2	0.09	(95)
	NO_x	0.06	(95)
	PM	12	(101)

B. Accounting value

In China, the National Development Reform Commission (NDRC) assesses a charge for emissions of various air pollutants. These charges are set on a provincial level. We use the charges for Qinghai Province as the accounting price for air pollutants. The value of reducing SO_2, NO_x, and PM, given by C_{SO_2}, C_{NO_x}, C_{PM}, respectively (Yuan/t), comes from National Development and Reform Commission (72-73). The value of air filtration (Yuan/year) is given by

$$V_{AP} = QA_{SO_2} \times C_{SO_2} + QA_{NO_x} \times C_{NO_x} + QA_{PM} \times C_{PM}$$

Table S4. Treatment cost of different air pollution

Types of air pollution	Treatment cost in 2000 (Yuan/t)	Treatment cost in 2015 (Yuan/t)
SO_2	630	1260
NO_x	630	1260
PM	150	150

C. Additional issues, extensions, and omissions

Ideally we would use avoided health damages from air pollution rather than cost of reducing pollution but we lack detailed epidemiological models linking health outcomes with exposure to air pollution. As the value of air purification in Qinghai is low using cost instead of reduced health damages does not affect GEP very much. In other places such as parts of eastern and central China with much higher pollution loads, it is more important to try to assemble the necessary data to use reduced health damages.

S1.6 Water purification

A. Biophysical quantity

Wetlands, lakes, and rivers can provide a valuable water purification service by absorbing and filtering water pollution. We selected three indicators to account for the amount of pollutants purified by wetlands, including the amount of chemical oxygen demand (COD), ammonia nitrogen (NH-N), total phosphorus (TP). Each ecosystem type i (i = 1, 2,…, I) has a capacity to absorb or filter each water pollutant type j (j = COD, NH-N, TP) given by QW_{ij} measured in kg per hectare per year. The annual amount of water purification for pollutant j at location l (l = 1, 2,…, L) is given by

$$QW_{jl} = Min\left[W_{jl}, \sum_{i=1}^{I} A_{il}\, QW_{ij}\right]$$

where W_{jl} is the total emission amount of water pollutant j at location l measured in kg per hectare per year, and A_{il} is the area in hectares of ecosystem type i at location l. The total amount of water purification for pollutant j from ecosystems in a region is given by

$$QW_j = \sum_{l=1}^{L} QW_{jl}.$$

B. Accounting value

We use water treatment costs for removing COD, ammonia nitrogen and total phosphorus to assess the *accounting value* of the water purification service. The treatment cost of reducing COD, NH-N, and TP is given by C_{COD}, C_{NH-N}, C_{TP}, respectively (Yuan/t). The treatment costs of reducing COD, ammonia nitrogen and TP come from National Development and Reform Commission (72-73). The value of water filtration (Yuan/year) is given by:

$$V_{WP} = QW_{COD} \times C_{COD} + QW_{NH-N} \times C_{NH-N} + QW_{TP} \times C_{TP}.$$

Table S5. Treatment cost of different water pollution

Types of air pollution	Treatment cost in 2000 (Yuan/t)	Treatment cost in 2015 (Yuan/t)
COD	700	1400
NH-N	875	1750
TP	2800	2800

C. Additional issues, extensions, and omissions

There exists a large gap between where ecological modeling stops (e.g., amount of nutrients in water supply) and where valuation would typically begin (e.g., human health impacts measured in disability adjusted life years). Here we used treatment costs rather than health or other impact costs. In the future, if additional integrated modeling is available we could use relationships between nutrient concentrations in water, exposure to people, and health and other losses associated with exposure to low quality water.

S1.7 Carbon sequestration

A. Biophysical quantity

Carbon sequestration in ecosystems is the process of capture and long-term storage of atmospheric carbon dioxide (CO_2). Carbon sequestration refers to the increase in carbon in terrestrial ecosystems, which slows the current rate of increase of atmospheric CO_2 (102), while storage refers to the carbon remaining in terrestrial ecosystems, possibly over the long term (103-104). Carbon storage represents not only the result of carbon sequestration (104), but also indicates the importance of restoration or avoidance of deforestation (105). We examined the dynamics of biomass carbon storage in Qinghai's forest, grassland, and wetland ecosystems, and estimated the average annual carbon sequestration of Qinghai's terrestrial ecosystems. Since the grassland vegetation will wither every year, its fixed carbon will be returned to the atmosphere or into the soil. Therefore, regardless of the carbon sequestration of the grassland vegetation, only the soil carbon sequestration of the grassland is considered. The biomass carbon storage of different types of ecosystem (Q_{tCO_2}) was obtained with the following formula:

$$Q_{tCO_2} = M_{CO_2}/M_c \times (F_{cs} + G_{cs} + W_{cs})$$

$$F_{CS} = R_{FCS} \times S_F$$

$$G_{CS} = R_{GSCS} \times S_G$$

$$W_{CS} = \sum_{i=1}^{n} R_{iWCS} \times S_{iw}$$

where Q_{tCO_2} is the amount of carbon sequestration in terrestrial ecosystems (tCO_2/y), F_{cs} is annual carbon sequestration of forests and shrubs (tC/y), G_{cs} is annual carbon sequestration of grasslands (tC/y), W_{cs} is annual carbon sequestration of wetlands (tC/y), M_{CO_2}/M_c (44/12) is transformation coefficient of molecular weight from CO_2 to C, R_{FCS} is the carbon sequestration rate of forests and shrubs ($tC \cdot ha^{-1} \cdot a^{-1}$), S_F is area of forests and shrubs (ha), R_{GSCS} is the carbon sequestration rate of grasslands soil ($tC \cdot ha^{-1} \cdot a^{-1}$), S_G is the area of grasslands (ha), R_{iWCS} is the carbon sequestration rate of wetland i ($gC \cdot m^{-2} \cdot a^{-1}$), S_{iw} is the area of wetland i; i is the type of wetland, i=1, 2, …, *n*, *n* is the types number of wetlands.

Table S6. Annual carbon sequestration rate of different ecosystems

Ecosystem types	Carbon sequestration rate of ecosystems ($tC \cdot ha^{-1} \cdot a^{-1}$)		References
	2000	2015	
Forests and shrubs	0.2	0.92	(106-107)
Grasslands	0.03	0.03	(108)
Wetlands-lake	12.57	12.57	(109)
Wetlands-swamp	67.11	67.11	(109)

B. Accounting value

The *accounting value* of carbon sequestration can be assessed by multiplying the amount of carbon sequestered (tCO_2/y) by a carbon price, P_c (Yuan/tCO_2). There are several different approaches for establishing a carbon price: (i) setting price equal to the cost of sequestering carbon via afforestation or reductions in industrial emissions; (ii) using a market price for trade of carbon permits on carbon exchanges; and (iii) setting price equal to the social cost of carbon that measures the present value of damage measured in dollar terms associated with the emission of a unit of CO_2 to the atmosphere (110). We choose to use the cost of afforestation (111) because Chinese carbon trade market are in a preliminary stage of development, while artificial afforestation is a main measure for ecosystem restoration and protection, and China is the country with the most afforestation in the world. Afforestation should be done in places that do not negatively impinge on other ecosystem services, such as in dry regions where tree planting may reduce water availability (112-113). The accounting value of carbon sequestration, V_{cs} (Yuan/year) is given by

$$V_{cs} = Q_{CO2} \times C_c$$

where Q_{CO2} is amount of sequestrated carbon by ecosystems (tCO_2/y), C_c is afforestation cost (Yuan/tCO_2).

C. Additional issues, extensions, and omissions

We did not include greenhouse gas emissions from fires due to low frequency of fire in Qinghai. We also did not include greenhouse gas emissions other than carbon.

S1.8 Non-material services

Non-material ecosystem services refer to a wide range of benefits provided by natural landscapes including tourism and recreation values, mental and physical health values of being in nature, and aesthetic, spiritual and cultural values. While these benefits can be large and of great importance to people they are often quite difficult to accurately measure in monetary terms. Currently, we lack the evidence base to support inclusion of values for many non-material services. Here we include only the value of ecotourism in Qinghai using information on the number of tourist visits and on-site surveys of visitors to top ecotourism sites. There are rich ecotourism resources and many famous scenic locations in Qinghai Province. We choose three famous scenic locations (Beishan Forest Park, Kanbula National Forest Park, and Qinghai Lake) and conducted questionnaire surveys at these locations.

A. Biophysical quantity

We collect the number of tourists in 2000 and 2015 in Qinghai Province according to the statistics data of Qinghai Province.

B. Accounting value

We used surveys to gather information on the expenditure per trip to scenic locations in Qinghai. We conducted onsite questionnaire surveys at Beishan Forest Park, Cambra Forest Park and Qinghai Lake. The useable survey sample size was 462 respondents. The questionnaire was divided into two sections, including (*i*) personal information (gender, age, education, occupation, income, residence address, etc.), and (*ii*) travel information (visiting places, travel time, transportation fee, admission fee, accommodation, etc.). We used the travel information to calculate the travel expenditure. For travel expenditure we took the following cost elements into account: 1) entrance fees, tour costs and other expenses at the recreation site, 2) travel expenses such as tickets, fuel, tolls, etc., 3) accommodation costs, 4) the cost of time spent by the visitor to travel to the site. We use the salary of the visitor to calculate the time cost of the visitor. Recent travel cost analyses relying on real payments data (114) suggest that such an assumption may be more defensible than the low proportions of wage rate suggested by early studies (e.g. 115).

We used a zonal consumer cost model, which is the simplest implementation of the expenditure method (EM). We collected information on the number of visits to each site from different distances (zones) and the cost of round trips from each of these zones to the sites. Then, we calculated the travel cost and time cost for travel from different zones.

The implementation of a zonal consumer cost model comprises the following main steps:

(i) Definition of geographical zones where visitors to the site come from. Each of these zones should be defined in a way that the travel cost to the recreation area in question will be more or less the same.

(ii) Data collection concerning the number of visitors to the site in question from each defined zone and estimation of the visitation rates from each zone.

(iii) Calculation of the average consumer cost of the round trip from each zone to the recreation site, which includes direct travel cost and time cost, which comes from the questionnaire.

The total ecotourism expenditure is then calculated based on the average expenditure per tourist and tourist number in each zone. We used the proportion of tourists from each zone from the survey and scaled this up to the total number of tourists in each zone using information about the total number of tourists in Qinghai.

Table S7. Ecotourism monetary value in Qinghai (2015)

Travel cost (Billion Yuan)	Time cost (Billion Yuan)	Total visitor cost (Billion Yuan)
18.1	3.5	21.6

The expenditure approach used conforms with recent natural capital accounting exercises such as those carried out for the UK (116). However, we fully acknowledge that expenditures may not correlate well with the welfare benefits provided by outdoor recreational assets. For example, individuals who value such assets highly may move house to be near them, thereby reducing their travel expenditures in a manner that does not reflect the values they hold for recreational experiences. Economic benefit-cost analyses seek to assess these underlying values, however, such analyses lack the ready tractability and comparability with GDP that our GEP measure provides.

C. Additional issues, extensions, and omissions

We included the entire value of ecotourism in non-material services even though human labor and infrastructure investments also contributes to its production. We do not differentiate the natural contributions of tourism from other investments (e.g., human labor, infrastructure) due to lack of data.

S2 GEP application in China

Table S8. Purposes of using GEP by central government agencies (and their corresponding

agencies at the provincial, city, and county levels)

Government agencies	Purposes
National Development and Reform Committee	Composite (integrated, overall) Effectiveness of eco-compensation programs (evaluate all national eco-compensation and conservation programs together)
Ministry of Ecology and Environment	Performance of EFCA counties Overall performance of conservation (all national and local efforts together). Evaluation of local government performance (counties that do not consider GDP ~1000 counties in EFCA counties; effectiveness of conservation for all counties, cities and provinces)
Ministry of Finance	Evaluating effectiveness of ecological financial transfer payment
State Forestry and Grassland Administration	Assessing the ecological benefits of forests, wetlands, wildlife
Ministry of Agriculture	GEP of agricultural systems (croplands, pasture, lakes with focus on fisheries)
Standardization Administration	Guidance for GEP accounting
Ministry of Housing, Urban and Rural Construction	Assessing ecosystem services of urban greenspace
Ministry of Natural Resources of the PRC	Ecological space (natural ecosystems)
Ministry of water resources	Assessing water ecosystems (rivers, lakes, wetlands; focus on water resources)

Table S9. GEP Projects supported by the government agencies

Project name	Project goals	Supporting Agencies	Duration (years)
Accounting methods and pilot study of ecological asset and eco-compensation	Establish technical guidelines and pilot study for EA and GEP accounting to evaluate effectiveness, efficiency and equity of eco-compensation programs at provincial, city, and county levels	Ministry of Science and Technology	2016-2020
PRC GEP Accounting for Eco-Compensation	Establish technical guidelines and implementation for GEP accounting to evaluate overall effectiveness of eco-compensation programs at provincial, city, and county levels	National Development and Reform Committee/ Asian Development Bank	2016-2017
Comprehensive evaluation methods of and policies for counties in key ecological function zones	Develop GEP-based indices for evaluating government performance of counties in key ecological function zones; suggest policies for implementation	National Development and Reform Committee	2015-2016
GEP accounting guidelines and pilot studies	Construct GEP accounting guidelines; Implement pilot studies in different eco-geographical regions	Ministry of Ecology and Environment	2014-2015
GEP accounting and training programs	Carry out national GEP accounting, and train technical experts at provincial, city, and county levels	Ministry of Ecology and Environment	2016
GEP accounting methods and case studies	Develop GEP accounting frameworks and methods Test the frameworks and methods in different regions	Chinese Academy of Sciences	2013-2015
GEP accounting of Hinggan League in Inner Mongolia	Implement GEP and ecosystem assets accounting in six counties of Hinggan League and apply the GEP in performance of counties	Inner Mongolia – Hinggan League	2014-2016
GEP accounting of Erdos and applications	Conduct GEP accounting and ecosystem assets and apply the GEP in effectiveness of conservation and restoration	Inner Mongolia – Erdos City	2014-2015
GEP accounting in Tonghua City, Jilin Province	Carry out ecological asset and GEP accounting and use the GEP in evaluating conservation effectiveness	Jilin – Tonghua City	2015-2016
GEP accounting in Yantian District, Shenzheng	Implement GEP and ecosystem assets accounting and evaluate the ecological benefits in urban areas of Yantian District	Shenzheng – Yantian District	2014-2015
GEP accounting in Xishui County,	Carry out GEP and ecosystem assets accounting and use the GEP in evaluating conservation	Guizhou – Xishui County	2016

Guizhou Province	effectiveness		
GEP accounting in Shunde District, Guangdong Province	Implement GEP and ecological asset accounting and evaluate conservation performance of township governments in Shunde city	Guangdong – Shunde District	2016-2017
GEP accounting in Shenzhen City, Guangdong Province	Conduct GEP and ecosystem asset accounting and apply them in urban management and city sustainability	Guangdong-Shenzhen	2019-2020
GEP accounting in Lishui City, Zhejiang Province	Conduct GEP and ecosystem asset accounting and apply them in effectiveness of conservation and green development	Zhejiang-Lishui city	2018-2019
GEP accounting in Fuzhou City, Jiangxi Province	Conduct GEP and ecosystem asset accounting and apply them in effectiveness of conservation and green development	JIangxi-Fuzhou city	2019-2020

S3 Eco-compensation in Qinghai Province

Table S-10 Eco-compensation programs in Qinghai 2010-2015[a]

Eco-compensation program	Compensation payments (billion Yuan)
Sloping Land Conversion Program (SLCP)	4.234
Compensation for Ecological Benefits of Public Welfare Forest (EBPWF)	3.649
Natural Forest Conservation Program (NFCP)	1.798
Three-North Shelter Forest Program (TNSFP)	0.557
Wetland Ecological Compensation Program (WECP)	0.218
Grassland Ecological Protection Subsidy Policy (GEPSP)	9.736
Return Grazing Land to Grassland (RGLG)	2.871
Ecological Financial Transfer for Key Ecological Function Areas (EFTKEFA)	9.721
Ecosystem Restoration of Qinghai Lake Basin Program (ERQBP)[1]	0.450
Sanjiangyuan Ecosystem Protection and Restoration Project (SEPRP)[2]	12.584
Qilianshan Ecosystem Protection and Ecological Construction (QEPRP)[3]	0.300
Total (billion Yuan)	45.819

Note: [a] All schemes and budgets run from 2010-2015 except: [1] 2010-2012, [2] 2011-2015, [3] 2014-2015.

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