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Postprint: A Study on Gross Ecosystem Product Accounting in Garzê Tibetan Autonomous Prefecture

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Abstract

Ganzi Tibetan Autonomous Prefecture (hereinafter referred to as Ganzi Prefecture) boasts favorable ecological conditions yet lags economically. Assessing the ecosystem service functions and their values in Ganzi Prefecture holds significance for the sustainable socioeconomic development of the region. By accounting for the Gross Ecosystem Product (GEP) of Ganzi Prefecture, including the valuation of provisioning services, regulating services, and cultural services, this study aims to reveal the direct contributions of Ganzi Prefecture' s ecosystems to human well-being through intuitive economic data. The accounting results demonstrate that in 2010, the Gross Ecosystem Product (GEP) of Ganzi Prefecture totaled 754.559 billion yuan, with a per capita value of 711,800 yuan, approximately 61 times the region' s Gross Domestic Product (GDP) and per capita GDP in the same year. Among these, regulating services held the greatest value at 684.228 billion yuan, accounting for 90.68% of the total GEP; the values of provisioning services and cultural services were 63.264 billion yuan and 7.067 billion yuan, respectively, representing 8.38% and 0.94% of the GEP. The study concludes that the value of ecosystem service functions in Ganzi Prefecture is substantial, and that protecting the ecosystems of Ganzi Prefecture equates to safeguarding human well-being. These results can provide an important basis for ecosystem management, ecological conservation, and ecological compensation in Ganzi Prefecture.

Full Text

Preamble

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Gross Ecosystem Product Accounting for the Garzê Tibetan Autonomous Prefecture

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Abstract

Garzê Tibetan Autonomous Prefecture (hereinafter referred to as Garzê) is located along the upper reaches of the Yangtze River. Its unique geographical location contributes to the prefecture' s complex and diverse landscapes and rich biodiversity. Garzê possesses abundant hydropower resources, comprising thousands of rivers that can be divided into three major systems: the Jinsha River, Yalong River, and Dadu River. Owing to its important ecological location, Garzê provides numerous ecosystem functions, such as water retention, soil conservation, flood mitigation, and biodiversity protection. Although Garzê' s ecological condition is excellent, the prefecture' s economy has lagged behind that of the rest of the country, and many of the important ecosystem products and services it provides have not been fully recognized or adequately quantified. Therefore, assessing Garzê' s ecosystem services is both essential and urgent and will contribute to the sustainable development of the prefecture' s society and economy.

In this study, Garzê' s ecosystem services were divided into three categories (ecosystem provisioning, regulating, and cultural services), and Garzê' s gross ecosystem product (GEP) was evaluated using market value, replacement cost, and travel cost methods, among others, in order to assess the direct contribution of Garzê' s ecosystem to beneficiaries. Our results indicated that the GEP of Garzê was 754.559 billion Yuan in 2010 and that the per capita GEP was 711,800 Yuan, which is about 61 times the prefecture' s gross domestic product (GDP) and per capita GDP of the same year. Among the ecosystem services, the total value of ecosystem-regulating services was the largest, at 684.228 billion Yuan and accounting for 90.68% of the prefecture' s GEP. The total value of ecosystem provisioning services and cultural services was 63.264 billion Yuan and 7.067 billion Yuan, respectively, accounting for 8.38% and 0.94% of the prefecture' s GEP.

In terms of service types, water retention, climate regulation, and carbon sequestration-oxygen release were the core services, with a total value of 84.38% of the prefecture' s GEP, thus confirming Garzê' s high plant cover and function as a significant water retention area of the upper reaches of the Yangtze River. In terms of ecosystem types, the values of the ecosystems were ranked as follows: Grassland > Forest > Shrub > Wetland > Farmland > Bare land > Glaciers

and snowfield > Town. The total value of Grassland, Forest, Shrub, and Wetland was 98.87% of the prefecture' s GEP. This indicated that these four ecosystems are the main source of ecological products and services; contribute vast economic value to human society; and therefore deserve relatively more attention than other ecosystem types.

Our study suggests that Garzê' s ecosystem services are highly valuable and that protecting the prefecture' s ecosystem will also protect human welfare. The findings of the study can be applied to administrative policymaking and environmental protection, and it will provide a scientific basis for the management, protection, and compensation of the region' s ecosystems.

Keywords: Garzê; ecosystem service; Gross Ecosystem Product (GEP)

1. Study Area Overview

Garzê Tibetan Autonomous Prefecture is located in western Sichuan Province (98°22 –102°29 E, 27°58 –34°20 N) on the eastern Qinghai-Tibet Plateau, forming a transitional zone between the Qinghai-Tibet Plateau and the Sichuan Basin and Yunnan-Guizhou Plateau. With an average elevation of 3,500 m, it features typical low-latitude, high-altitude landforms, covering an area of 152,600 km² (31.5% of Sichuan' s total area), making it the largest prefecture-level administrative region in the province. Garzê is an ethnic minority autonomous prefecture predominantly inhabited by Tibetans.

The climate belongs to the mountain cold temperate humid and semi-humid type, with an average annual precipitation of 330.6–902.6 mm, evaporation of about 1,735.8 mm, relative humidity of 46%–74%, annual sunshine hours of 1,900–2,600 h, and average annual temperature of 7.8°C. Soil types are mainly mountain yellow-brown soil and mountain brown soil, with distinct dry and wet seasons.

Garzê contains various ecosystem types including forest, shrub, grassland, wetland, farmland, glaciers and snowfields, and bare land. Grassland ecosystems have the largest area, followed by forest and shrub ecosystems. Table 1 shows the area and spatial distribution of each ecosystem type in Garzê.

Table 1 Ecosystem types and their area in Garzê

2. Data Sources

The main data used in this study were obtained from: - Ecosystem type maps derived from object-oriented classification technology using Landsat TM data from the National Ecological Environment Ten-Year Change Remote Sensing Survey and Assessment Project database - Digital Elevation Model (DEM) with 90 m spatial resolution from the International Scientific Data Service Platform - Precipitation and temperature data interpolated based on ordinary and local thin-plate spline functions from the National Meteorological Information Center/China Meteorological Administration (NMIC/CMA) - Actual evapotranspiration data from the MODIS Global Evapotranspiration Product (MOD16) and the Land Processes Distributed Active Archive Center (LP DAAC) - Soil property data and multi-year average solar radiation data provided by the Cold and Arid Regions Science Data Center

3. Accounting Indicator System

Based on the characteristics of Garzê' s ecosystems, structure, and ecological processes, this study adopted the theoretical framework and methods of ecosystem service value accounting. Supporting services were not accounted for as their functions (such as organic matter production, nutrient cycling, and biodiversity maintenance) are already reflected in provisioning and regulating services. Garzê' s GEP accounting was divided into three components: ecosystem provisioning service value, regulating service value, and cultural service value, comprising 17 functional indicators in total (Table 2).

Table 2 Evaluation index system of Garzê' s Gross Ecosystem Product (GEP)

4. Ecosystem Provisioning Service Value

Ecosystem provisioning services in Garzê refer to final products provided to humans, including agricultural products, livestock products, forestry products, water resources, and hydropower.

Agricultural, forestry, and fishery product value: Calculated using the market value method. Agricultural products include grains, beans, potatoes, and oil crops. Livestock products include all animal husbandry except fishery and their by-products. Forestry products include timber, bamboo, and resin. Fishery products include aquatic animals and algae. The 2010 net output value of agriculture, forestry, animal husbandry, and fishery was used as the value of these provisioning services.

Water resources provision value: Includes domestic water use (150.17 million m^3), industrial water use (12.29 million m^3), and agricultural water use (22.07 million m^3) in 2010. Valued using market prices.

Hydropower value: Garzê has numerous rivers with abundant hydropower resources including the Jinsha River, Yalong River, and Dadu River. The market value method was applied to assess hydropower value based on 2010 electricity generation.

5. Ecosystem Regulating Service Value

5.1 Water Conservation Value

Water conservation capacity was selected as the indicator, calculated using the water balance equation:

$$Q_w = \sum_{i=1}^{j} A_i(P_i - R_i - ET_i)$$

where Q_w is water conservation capacity, P_i is precipitation, R_i is storm runoff, ET_i is evapotranspiration, A_i is area of ecosystem type i, and j is the number of ecosystem types.

The value was assessed using the shadow project method with reservoir construction cost:

$$V_w = Q_w \cdot P_w$$

where V_w is water conservation value and P_w is the engineering cost per unit reservoir capacity.

5.2 Soil Conservation Value

Soil conservation capacity (the difference between potential and actual soil erosion) was selected as the indicator, calculated using the Universal Soil Loss Equation (USLE). Value was assessed using the replacement cost method from two aspects:

Reducing sedimentation value:

$$V_s = A_s \cdot \lambda \cdot C_s / \rho$$

where V_s is sedimentation reduction value, A_s is soil conservation amount, λ is sedimentation coefficient, ρ is soil bulk density, and C_s is reservoir dredging cost.

Reducing non-point source pollution value:

$$V_n = A_s \cdot (P_N \cdot C_N + P_P \cdot C_P)$$

where V_n is pollution reduction value, P_N and P_P are nitrogen and phosphorus content in soil, and C_N and C_P are environmental engineering costs for nitrogen and phosphorus treatment.

5.3 Windbreak and Sand Fixation Value

Windbreak and sand fixation capacity (difference between potential and actual wind erosion) was selected as the indicator, calculated using the Revised Wind Erosion Equation (RWEQ). Value was assessed using the replacement cost method:

$$V_f = Q_f \cdot h \cdot P_f / \rho$$

where V_f is windbreak value, Q_f is sand fixation amount, ρ is sand bulk density, h is standard sand coverage thickness, and P_f is average sand control engineering cost.

5.4 Flood Regulation Value

Total flood regulation capacity of lakes, reservoirs, and marshes was selected as the indicator. Value was assessed using the shadow project method:

Lake flood regulation capacity model:

$$C_l = 0.678 \cdot A^{0.636} \cdot T$$

where C_l is lake flood regulation capacity, A is total lake area, and T is water exchange frequency.

Reservoir flood regulation capacity:

$$C_r = C_t \cdot 0.67$$

where C_r is reservoir flood regulation capacity and C_t is total reservoir capacity.

Marsh flood regulation capacity model:

$$C_m = S \cdot 0.6$$

where C_m is marsh flood regulation capacity and S is total marsh area.

Total flood regulation value:

$$V_t = (C_l + C_r + C_m) \cdot P_w$$

5.5 Air Purification Value

Selected indicators: SO absorption, dust retention, and NOx absorption. Value was estimated using the prevention cost method based on pollution control costs.

5.6 Water Quality Purification Value

Selected indicators: COD and ammonia nitrogen absorption by wetland ecosystems. Value was estimated using the prevention cost method.

5.7 Carbon Sequestration and Oxygen Release Value

Selected indicators: carbon sequestration (CO) and oxygen release (O) based on vegetation net primary productivity (NPP). Value was assessed using afforestation cost and industrial oxygen production cost methods:

$$V_g = Q_C \cdot P_C + Q_O \cdot P_O$$

where V_g is total value, Q_C is carbon sequestration amount, P_C is afforestation cost, Q_O is oxygen release amount, and P_O is industrial oxygen production cost.

5.8 Climate Regulation Value

Energy consumed by evapotranspiration was selected as the indicator. Value was assessed using the replacement cost method based on electricity costs for equivalent air conditioning and humidification:

Vegetation transpiration:

$$V_a = \sum_{i=1}^{n} S_i \cdot GPP_i \cdot d/(R \cdot 3600) \cdot m$$

Water surface evaporation:

$$V_e = E \cdot \rho \cdot q/\gamma \cdot m$$

where variables represent energy consumption, area, growing period days, air conditioner efficiency, electricity price, evaporation, water density, latent heat, and humidifier energy consumption.

5.9 Pest Control Value

Pest control by ecosystems through enhanced biodiversity was valued using the prevention cost method based on self-recovery area and artificial control costs.

6. Ecosystem Cultural Service Value

Cultural services refer to non-material benefits from spiritual experience, knowledge acquisition, and recreation. This study only considered landscape recreation value, assessed using the travel cost method based on total tourist visits and tourism revenue.

7. Results

7.1 Provisioning Services

In 2010, the total value of ecosystem provisioning services in Garzê was 63.264 billion Yuan, accounting for 8.38% of GEP. This included: - Livestock products: 54.536 billion Yuan - Water resources: 2.238 billion Yuan (domestic: 1.229 billion, industrial: 2.208 billion, agricultural: 0.356 billion) - Hydropower: 5.051 billion Yuan (based on 17.31 billion kWh generation)

Table 3 Ecosystem service quantities and values of Garzê in 2010

7.2 Regulating Services

The total value of regulating services was 684.228 billion Yuan (90.68% of GEP), with key services being:

Water conservation: Total capacity of 321.49 billion m³ valued at 226.971 billion Yuan (30.08% of GEP). Grassland ecosystems contributed the most value

(99.356 billion Yuan), followed by shrub (61.693 billion) and forest (61.709 billion), together accounting for 98.14% of water conservation value.

Soil conservation: Total soil retention of 2.67×10 t valued at 39.96 billion Yuan. Forest ecosystems showed the strongest capacity with the highest per-unit-area value.

Windbreak and sand fixation: Total fixation of 779.42 million t valued at 12.582 billion Yuan. Grassland ecosystems contributed 65.35% of this value, demonstrating their critical role.

Flood regulation: Total flood regulation capacity of 2.799×10 m^3 valued at 5.956 billion Yuan. Marshes contributed 71.09% of this value, highlighting their importance.

Air purification: Total value of 0.068 billion Yuan for SO , NOx, and dust control.

Water quality purification: Total value of 0.038 billion Yuan, with wetlands contributing 87.41%.

Carbon sequestration and oxygen release: Total value of 18.219 billion Yuan. Forest, grassland, and shrub ecosystems contributed 95.76% of this value.

Climate regulation: Total energy consumption of 3.587×10^{1} kJ valued at 21.579 billion Yuan. Wetland ecosystems contributed 68.75% of this value.

Pest control: Total value of 0.014 billion Yuan.

7.3 Cultural Services

In 2010, Garzê received 3.587 million tourist visits with total revenue of 2.356 billion Yuan, yielding a cultural service value of 7.067 billion Yuan (0.94% of GEP).

7.4 Gross Ecosystem Product and Composition

The total GEP of Garzê in 2010 was 754.559 billion Yuan, 61 times the GDP of the same year. By service type, water conservation, climate regulation, and carbon sequestration-oxygen release accounted for 84.38% of GEP. By ecosystem type, the value ranking was: Grassland > Forest > Shrub > Wetland > Farmland > Bare land > Glaciers & snowfield > Town. Grassland, forest, shrub, and wetland together accounted for 98.87% of GEP.

Table 4 GEP accounting results of Garzê in 2010 by ecosystem type

8. Discussion

Garzê' s ecosystems provide numerous important products and services to local and other regions' populations. However, in past development processes focused solely on GDP, these services were not fully recognized, impacting sustainable socioeconomic development. This study addresses Garzê' s characteristics of economic underdevelopment but excellent ecological condition by accounting for GEP to reveal the immense benefits of its vast forests and grasslands.

The 2010 GEP of 754.559 billion Yuan demonstrates that regulating services dominate (90.68%), particularly water conservation, climate regulation, and carbon sequestration-oxygen release, confirming Garzê' s role as a crucial water retention area and climate regulator in the upper Yangtze. The high forest and grassland coverage provides vital oxygen release functions essential for plateau inhabitants.

Grassland, forest, shrub, and wetland ecosystems are the primary sources of ecological value (98.87% of GEP). Forests excel in water conservation and soil retention; grasslands in windbreak and sand fixation; wetlands in climate regulation and flood storage. Targeted protection and management of these systems are needed.

Limitations: Uncertainties exist due to data acquisition and processing errors, parameter variations across regions and years, and the prevention cost method likely providing conservative estimates for air and water purification. Despite these errors, the results effectively communicate Garzê's ecosystem service values and provide scientific support for policymakers.

Future research should improve valuation methods and model ecosystem service changes to better support sustainable utilization and management of Garzê' s ecosystems.

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