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ORIGINAL PAPER

Forest soil conservation based on eco-service provision unit method and its value in Anji County, Huzhou, Zhejiang, China

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Abstract We propose an eco-service provision unit method for estimating the benefit and spatial differences of forests in controlling soil erosion. A total of 197 eco-service provision units were grouped on 1424.43 km^2 of forest according to differences in vegetation, slope, soil, and rainfall. The amount of soil conservation and its economic value were estimated. The forests in Anji County prevent 4.08 $\times$ 10^5 tons of soil from eroding annually, thereby avoiding 1.36 $\times$ 10^4 tons of nutrient loss (on-site cost) and preventing 149 tons of nutritive elements from entering water systems (off-site cost). From an economic perspective, the soil nutrient conservation in the forests of Anji County generated an annual benefit of 43.37 million RMB (Chinese Currency, 6.20 RMB = US$1). On average, each hectare of ecological forest contributed up to 436 RMB annually because of soil conservation. Ecological complexes with higher rainfall intensity, such as broadleaf forest and red soil on slope gradients >25°, contributed the highest soil conservation benefits. This study identified and quantified the dominant contributors and magnitudes of soil conservation provided by forests. This information can benefit decision making regarding differentiated ecological compensation policies.

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Introduction

Soil erosion is a natural process in which the land surface is worn away by water and/or wind. In addition to causing on-site loss of topsoil and reducing land productivity, soil erosion results in off-site environmental effects, such as water pollution and eutrophication (Morgan 1995; He et al. 2003). According to Pimentel et al. (1995), nearly one-third of the world's arable land has been lost through erosion, and land loss continues at a rate of more than 10 million ha per year. Although soil erosion is natural and unstoppable, its rate is variable and is affected by human activities and land management practices. Kuhlman et al. (2010) categorized soil conservation measures into agricultural practices, forestry measures, and anti-erosion techniques used in construction work. For example, conservation agriculture seeks to avoid unsustainable soil losses while maintaining stable yields (Zhao et al. 2007; Li et al. 2011). Other common measures that reduce erosion include no-till farming (Zhou et al. 2005), the Conservation Reserve Program(USA), cover cropping, strip cropping, vegetation barriers, elimination of summer fallow, and installation of conservation devices, such as terraces, waterways, diversion ditches, gabions, and drop structures (Zobeck and Schillinger 2010; Rejani and Yadukumar 2010; Guto et al. 2011). Kuhlman et al. (2010) estimated the costs and benefits of eight soil conservation measures in Europe and found that the on-site benefits of soil protection measures in forests were less than their costs, whereas the off-site benefits were large. Taihu Basin is located in the lower reaches of the Yangtze River Basin and is one of the most developed zones in China. Over the past decades, this basin has been undergoing intensive change in land use because of rapid economic growth and urbanization. Meanwhile, the eutrophication and deterioration of water quality in Taihu Lake, Jiangsu, is increasingly worsening. Therefore, increasing attention has been directed toward the input of nutrients from the upper reaches of Taihu Lake and its environmental effects (Xie et al. 2001; Yu et al. 2003; Li et al. 2004a, 2006). Wang et al. (2003) found that the substance migration resulting from soil erosion was the main carrier of non-point nutrients into the lake. Despite rapidly growing awareness about soil erosion in Taihu Lake Basin (Cao et al. 2002; Wang et al. 2003; Zeng et al. 2008), few studies have quantified the cost and benefit of soil conservation provided by forests in reducing soil erosion and nutrient loss, particularly in water catchment areas.

Eco-compensation is a type of institutional arrangement for maintaining the sustainable use of ecosystem services. This approach adjusts the distribution of costs and benefits between different actors and stakeholders primarily through economic measures (Tack Force on Eco-compensation Mechanisms and Policies 2008). Previous studies on ecological compensation policy in China have analyzed the scope, targets, and standards of compensation by estimating the economic benefits of ecosystem services. Nevertheless, most evaluation methods on ecosystem functions or services that apply to homogeneous ecosystems fail to reveal the spatial heterogeneity and the main contributors of ecosystem services (Zhang et al. 2010). Thus, such methods cannot provide a baseline for diverse and differentiated ecological compensation policies. For example, the majority of modern ecological compensation policies in China adopt a single standard (i.e., area) without considering the differences in natural and/or social characteristics (Qin and Kang 2007). We assume that a recognized ecosystem service is jointly generated by numerous eco-service provision units. Some mileage can be gained from estimating the benefits of an individual eco-service provision unit in an economic sense, and the differentiated ecological compensation standards can be addressed in terms of the potential positive effects of the ecosystem service.

Therefore, this work estimates the economic value of soil conservation service in Anji County, Huzhou, Zhejiang forests and subsequently analyzes the dominant contributors and their magnitudes to propose a highly diverse standard for ecological compensation policy. This goal requires a detailed inventory to objectively describe the characteristics of a forest ecosystem and to conduct field investigations on soil erosion and nutrient content. This paper is organized as follows: "Materials and methods" section provides a background of the study area. Section "Results and discussion" presents the data and evaluation method. The results are discussed in "Suggestions for ecological compensation policy" section. The policy recommendation and conclusion are given in "Conclusion" section and 6, respectively.

Materials and methods

Study area

Anji County (30°23′ to 30°53′N, 119°14′ to 119°53′E) is located northwest of Zhejiang Province, China (Fig. 1). The area administrated by the Anji County government is 1886 km^2 and is composed of 15 villages and towns. This county has undulating topography, with elevation ranging from 500 m to 1000 m. Anji County has a subtropical oceanic climate with annual precipitation of 1400 mm and mean temperature of 15.6 °C. Xitiaoxi, located in Anji County, is one of the most important tributaries in the upstream of Taihu Lake, as it supplies 27.7 % of the water volume to Taihu Lake. We selected Anji County as the study site on the basis of the following characteristics of the county: (1) its plentiful forest resources are composed of various forest types; (2) it is located in the headwater of Taihu Lake, where ecological services such as soil conservation and nutrient control are vital to water environment security; and (3) the complete utilization of bamboo forest and economic forest causes severe disturbance (Yu et al. 2003).

According to the data of the Forest Resource Survey of 2007, Anji County's forest ecosystem has a total area of 142,443 ha, of which 15.53, 17.35 and 3.57 % is coniferous forest, broadleaved forest, and broadleaved-coniferous mixed forest, respectively. These forest types account for a total area of 51,932 ha. Economic forest and shrub forest dominate 15,987 and 235 ha, covering 11.22 and 0.16 % of the total forest area, respectively. The remaining 52.15 % is devoted to bamboo forest. Figure 1 shows the spatial distribution of forest resources in Anji County.

Methodology and data

Eco-service provision unit

The heterogeneity of ecosystem structures and environmental elements results in spatial variability of functions or services (Guo and Gan 2003). A clear recognition of the spatial heterogeneity of ecosystem services and their main contributors is an advantage for policy making regarding ecological compensation. To identify the link between a group of individuals (from a given species makes to an

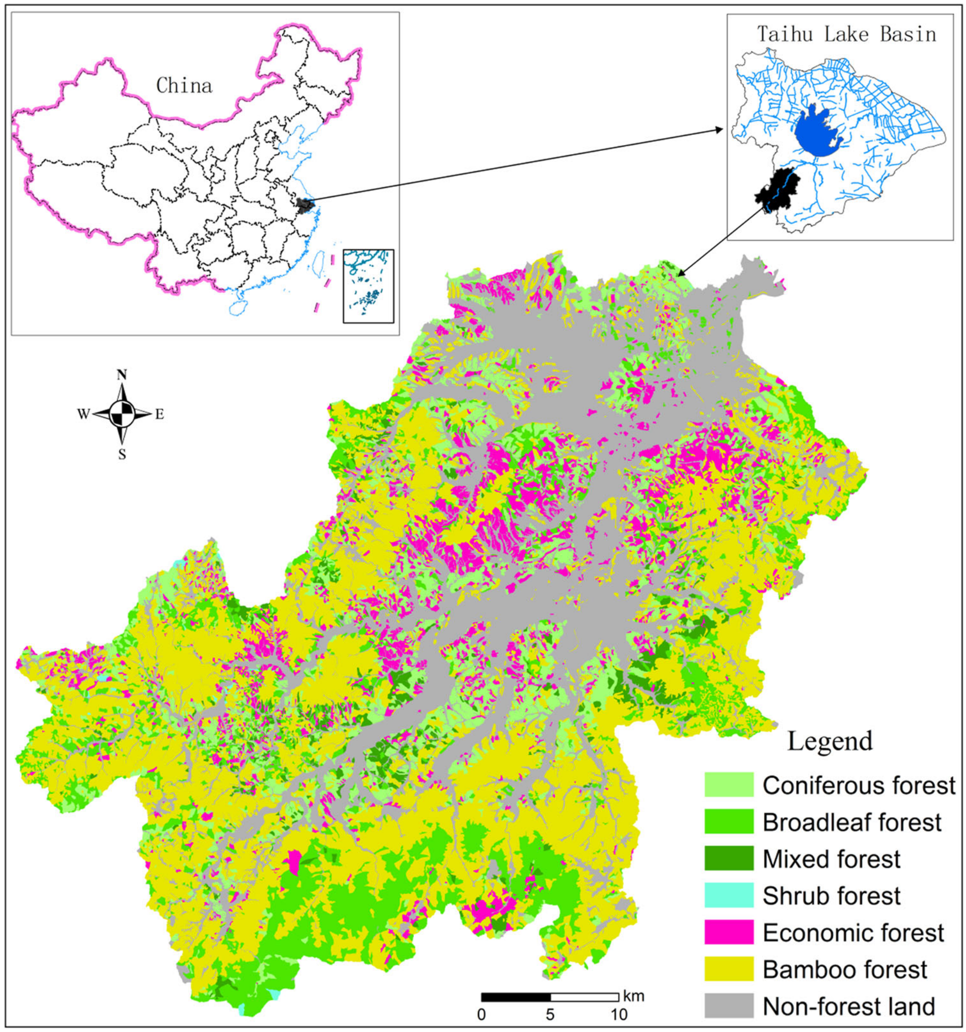

Fig. 1 Study area and its forest distribution

ecosystem service) and the ecosystem service(s) that they provide, Luck et al. (2003) proposed a new population categorization called "service-providing unit (SPU)". SPUs provide, or might provide in the future, a recognized ecosystem services at some temporal or spatial scale. Thus, SPUs should be delineated when assessing the consequences of population change on the provision of ecosystem services. Likewise, we propose an eco-service provision unit (ESPU) as the basic unit of ecosystem service research in this study. ESPU is an ecological complex with the same or similar ecosystem structure and/or environmental attributes (such as climatic, soil, or topography) and can therefore provide the same magnitude of ecosystem services. In the case of soil conservation service, numerous factors such as precipitation, vegetation, soil, and slope jointly influence soil erosion (Zhang et al. 2009). Therefore, a spatial database embodied within a geographic information system (GIS) should be developed as a foundation.

In this study, a spatial database containing information on precipitation, vegetation, soil, and topography was organized using data from the Forest Resource Inventory in Anji County. According to the monthly rainfall data, the rainfall erosivity in Anji County was calculated by using a modified Fournier's index model (Renard and Freimund 1994) and was divided into five classes: higher (<120 MJ mm hm^{-2} h^{-1} a^{-1}), high (121 MJ mm hm^{-2} h^{-1} a^{-1}–130 MJ mm hm^{-2} h^{-1} a^{-1}), middle (131 MJ mm hm^{-2} h^{-1} a^{-1}–140 MJ mm hm^{-2} h^{-1} a^{-1}), low (141 MJ mm hm^{-2} h^{-1} a^{-1}–150 MJ mm hm^{-2} h^{-1} a^{-1}), and lower (>150 MJ mm hm^{-2} h^{-1} a^{-1}). We considered six forest types, namely, conifer, broadleaf, conifer and broadleaf mixed, bamboo, shrub, and economic forest. Soils were of five types: red, yellow, purple, rice, and lime soil. We assigned four slope gradient categories as: less than 5°, 5° to 15°, 15° to 25°, and more than 25°. In theory, the entire county could be grouped into 600 rainfall–vegetation–soil–slope complexes ($5 \times 6 \times 5 \times 4$); however, according to the spatial database of forest resources, only 197 complexes actually existed.

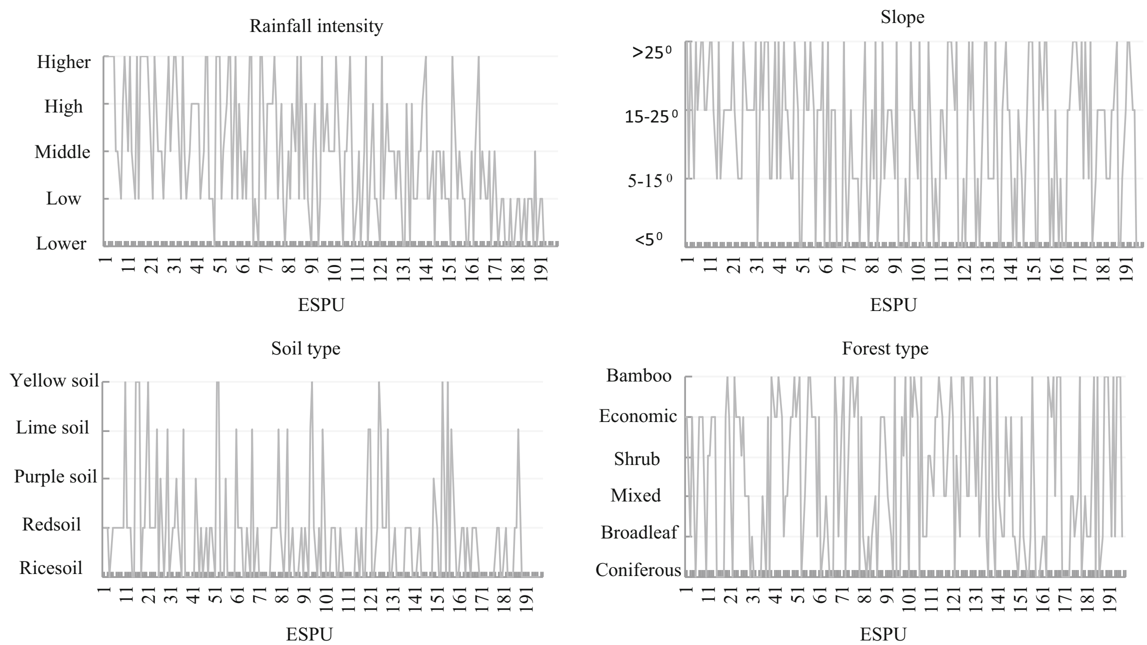

Fig. 2 Information on the precipitation, vegetation, soil, and topography of each ESPU

Figure 2 illustrates the information on precipitation, vegetation, soil, and topography of each ESPU. We focused primarily on the environmental benefits of soil conservation provided by the 197 ESPUs.

Amount of soil conservation

We assumed that the amount of soil conservation can be regarded as the difference between soil erosion quantities arising from forested versus non-forest land in Anji County. Although recent studies have proposed numerous models and methods for predicting the amount of soil erosion (Fu and Liu 2002; Liu et al. 2011), such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) or revised USLE model (Renard et al. 1997), the actual magnitude of soil erosion remains difficult to quantify. Therefore, we assumed that the modulus of soil erosion can be estimated on the basis of various influencing factors such as climate (rainfall, wind, etc.), soil character (soil erodibility of a specific soil type), topography (slope and length of the field), and land utilization (crop management and erosion control practices) (Seckler 1987). We choose three influencing factors (i.e., rainfall erosivity, soil erodibility, and slope angle) of soil erosion and the field survey results derived from empirical studies to calculate the amount of soil erosion in each ESPU. Rainfall intensity was graded into five categories to represent the rainfall erosivity of each ESPU. We assumed slope to be positively correlated with erosion volume and classified slopes into four levels in accordance with the data from site surveys (Guo et al. 2001). Soil erodibility, which is independent of other factors associated with erosion, such as slope angle, rainfall intensity, or crop management (McIntosh and Laffan 2005), can be assessed by using a combination of laboratory measurements on soil horizons and field descriptions of soil profiles. On the basis of a broad correlation between soil erodibility and soil classification (Grant et al. 1995; Laffan et al. 2003), the soil erodibility of each ESPU was approximately identified by individual soil type with published soil descriptions (Zhang and Han 2000; Bu et al. 2002). Table 1 shows the relative coefficients of rainfall erosivity, slope angle, and soil erodibility in Anji County.

The soil erosion modulus for each forest type was compiled from a wide variety of publications of site surveys (Table 2). Thus, the overall amount of soil conservation in Anji County forests was estimated using the following formula:

$$ES = \sum_{i=1}^{197} \alpha_i \times \beta_i \times \gamma_i \times (S_{Non} - S_i) \times A_i \qquad (1)$$

where ES is the total amount of soil conservation (ton/yr); S_i and S_{Non} are moduli of soil erosion of different forest types and non-forest land (ton/km^2), respectively; A_i represents the area of an individual ESPU (ha); and the i subscript indicates the relevant ESPUs.

Table 1 Adjustment coefficients of soil erodibility (α), rainfall erosivity (β), and slope angle (γ)

Soil type	Soil erodibility (α)	Rainfall intensity	Rainfall erosivity (β)	Slope	Slope gradient (γ)
Rice	1	Higher	1	<5°	0.1
Red	0.74	High	0.8	Between 5° and 15°	0.33
Purple	0.64	Middle	0.6	Between 15° and 25°	0.54
Lime	0.47	Low	0.4	>25°	1
Yellow	0.20	Lower	0.2		

α roughly identified by corresponding soil type in publications (Zhang and Han 2000; Bu et al. 2002)

β graded into five categories based on rainfall intensity

γ classified from the site survey data (Guo et al. 2001)

Table 2 Soil erosion moduli of different forest types in Anji County

Forest type	Coniferous[a]	Broadleaf[a]	Mixed[b]	Bamboo[a]	Economic[c]	Shrub[d]	Non-forest[c]
Erosion modulus(ton/km^2 year)	352.15	294.5	186.6	722.78	1469.13	200	1681.2

[a] Kong et al. (2009)

[b] Zeng et al. (2008)

[c] Wang et al. (2003)

[d] Wang et al. (2010)

Table 3 Nutrient contents of different types of forestland in Anji County

Nutrient content (mg/g)	Coniferous	Broadleaf	Mixed	Bamboo	Economic	Shrub
TN	0.617	1.176	0.964	0.859	0.838	1.355
TP	0.267	0.534	0.416	0.361	0.325	0.388
TK	10.204	17.386	11.202	9.212	13.167	11.326
OM	14.643	21.779	17.485	21.208	15.004	26.986

Source Dong et al. (2011), Zhang et al. (2011)

Amount of nutrient control

The quantifiable effects of soil erosion are frequently divided along two axes: on-site and off-site effects. Soil erosion causes on-site shortages of basic plant nutrients, such as nitrogen, phosphorus, and potassium, and organic matter, which are essential for crop production (Pimentel et al. 1995). The amount of on-site nutrient loss prevented by forests can be estimated from the amount of soil conservation and the content of relevant nutrients. Thus, we needed data on soil nutrients for different points in time; such data exist only for specific locations and cannot be generalized. In a recent study, we investigated the soil nutrients of a forest near Xitiaoxi River in the upper reaches of Taihu Basin (Zhang et al. 2011). We selected 34 typical plots of bamboo forest, economic forest, pure forest, and mix forest within 1 km of Xitiaoxi River and tested the contents of effective phosphorus, hydrolysis nitrogen, total nitrogen (TN), and total phosphorus (TP). By studying more than 30 soil properties, such as soil physical and chemical properties for different forest soils in the Anji mountain region, Jiang et al. (2004) quantified variation in these properties by soil depth in forest soil (Table 3). We used this information to calculate the potential amount of on-site nutrient control for TN, TP, total potassium (TK), and organic matter (OM) by using the following formula:

$$N_{ij} = \sum_{\substack{i=1 \\ j=1}}^{197} \beta_{ij} \times S_{ij} \quad (2)$$

where N_{ij} represents the total amount of j-th nutrient fixation attributed to soil conservation (ton/year), β_{ij} is the j-th soil nutrient content of different types of forest land (mg/g), and the j subscript indicates the nutrient types (TN, TP, TK, and OM).

In environmental science, nitrogen and phosphorus are the main non-point source pollutants of surface water and groundwater. The removal of excess nitrogen and phosphorus from soil through erosion may result in environmental problems, such as agricultural non-point

Table 4 Loss rates and pollutant degradation coefficients of TN and TP

Pollutant	Lost rate (λ)[a]	Pollutant degradation coefficient (η)[b]
TN	0.9	0.3539
TP	0.9	0.2148

[a] Cheng et al. (2006)

[b] Li et al. (2004b)

Table 5 Nutrient contents and prices of different types of fertilizers

Fertilizer types	Content (ρ_j) (%)	Price (RMB/ton)
DAP (diammonium phosphate)	14 (TN)	2400
DAP (diammonium phosphate)	15 (TP)	2400
Potassium chloride	50 (TK)	2200
Organic matter	100 (OM)	320

Source State Forestry Administration of China (2008)

source pollution and water quality degradation in both freshwater and marine ecosystems (Page et al. 2005; Gassman et al. 2006). The loss rate, which is an important parameter for describing the process of pollutant entrance into a water body, expresses the ratio of pollutants entering the river through watershed concentration to the accumulated pollutant load coming from the basin slope (Cheng et al. 2006). Meanwhile, the degradation coefficient indicates the fraction of pollution stock that is degraded during a period because of the self-purification capacity of the water body. If no soil conservation occurs, the amount of TN and TP that would run downstream can be predicted by using the appropriate loss rate and degradation coefficient. Therefore, the potential amount of off-site nutrient fixation can be described by the following equation:

$$M_i = \sum_{i=1}^{197} N_i \times \lambda \times (1 - \eta) \quad (3)$$

where M_i represents the total amount of TN or TP prevented from entering the river because of soil conservation (ton/year), is the loss rate of the pollutant, and η is the pollutant degradation coefficient (Table 4).

Economic value of soil conservation

The costs of soil erosion often combine on-site and off-site effects. The major on-site costs of erosion by water are those expended to replace lost soil nutrients. For example, in the United States, an estimated 4×10^9 tons of soil and 130×10^9 tons of water are lost from 160×10^9 ha of cropland each year, and this values translates into an on-site economic loss of over \$20 billion for nutrient replacement (Pimentel et al. 1995). Chemical fertilizers can compensate the loss of soil nutrients. Thus, the on-site benefit of nutrient fixation attributed to soil conservation can be estimated by the replacement cost method. Soil erosion not only damages the immediate agricultural area where it occurs but also negatively affects the downstream environment. The most serious off-site damages are caused by soil particles entering the water systems. Transfer pricing is generally considered a relatively simple method for moving goods and services between entities. Several different methods can be used to determine transfer prices (Antic and Jablanovic 2000). Basing on *the regional compensation standards of environmental resource in Jiangsu* Province, China, we determined the transfer price of ecological service on controlling moved pollutants in Taihu Lake Basin. We estimated the total economic value of soil conservation using the following formula:

$$V_i = \sum_{\substack{i=1 \\ j=1}}^{197} (N_{ij} \times P_1/\rho_j + M_i \times P_2) \quad (4)$$

where V_i represents the economic value of soil conservation (RMB/year); P_i and P_2 are the prices of relevant fertilizer and regional compensation for pollutants (RMB/ton), respectively; and ρ_j is the nutrient content of different types of fertilizers (%), as shown in Table 5. However, we note that V_i is not the total soil conservation benefit but is rather the total of what can be estimated from the available data.

Data

This work aimed to quantify the positive effect of forests in mitigating soil erosion and maintaining soil nutrients and to convert these effects into monetary terms. A significant amount of data was used in the estimation process. Most of the data were obtained from Category II of the Anji County forest resource inventory, which was conducted in 2007 by Anji County Forestry Bureau and Zhejiang Forest Resource Monitoring Center by applying 3S technologies (GIS, Remote Sensing and Global Position System) and field investigation. We obtained data for 21,082 forest subplots,[1] of which 20,069 were represented by forest, 726 were other forest (canopy density <0.2), and the remainder was devoted to non-forest. This study focused on the 20,069 forest subplots. The spatial location (latitude and longitude), forest type, tree species, slope angle, and soil type of individual subplots were compiled and stored in a forest

[1] The basic unit of the survey data and management of forest resources, divided on the basis of the differences of land right, land type, forest category, and so on.

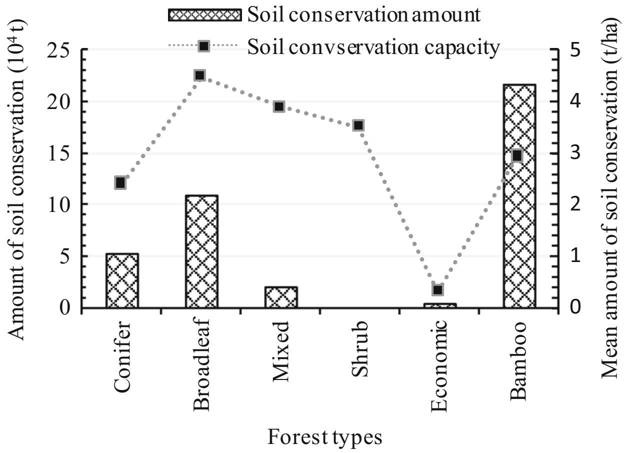

Fig. 3 Amount and capacity of soil conservation in various forest types

resource inventory database on a Web-based GIS managed by the Anji County Forestry Bureau. Abundant precipitation and temperature data from 1975 to 2009 were obtained from Anji County Hydrological Bureau, thus facilitating the assessment of rainfall erosivity. In addition, we consulted numerous case studies on soil erosion and nutrient content in Anji County.

Results and discussion

Amount of soil conservation

In general, vegetation can significantly reduce soil erosion. Thus, the soil conservation service of forest ecosystems often attracts significant attention. We calculated that in comparison with non-forest, the 142,443 ha of forest in Anji County could prevent 4.08×10^5 tons of soil from eroding annually. However, large differences were observed in the soil conservation between different forest types. Bamboo forest could reduce 2.18×10^5 tons of soil erosion, thus providing the highest percentage of soil conservation (53 %). Broadleaf forest prevented 1.11×10^5 tons of soil erosion, comprising 27 % of soil conserved. Conifer forest, conifer and broadleaf mixed forest, and economic forest prevented 5.34×10^4, 1.99×10^4, and 5×10^3 tons of soil erosion, comprising 13, 4.9 and 1.2 % of soil conserved, respectively. Shrub forest conserved only 800 tons of soil and thus made the lowest contribution (0.19 %). The variation in soil conservation was mainly related to forest areas. Figure 3 presents the amounts of soil conservation provided by the different types of forest in Anji County.

Soil conservation capacity per hectare of forest did not follow the same rank order because it is unrelated to forest area. Broadleaf forest had the highest capacity for soil conservation (4.49 ton/ha). Per hectare conifer and broadleaf mixed forest could conserve 3.9 tons of soil, and the soil conservation capacities of shrub, bamboo, and conifer forest were 3.51, 2.93 and 2.41 ton/ha, respectively. Economic forest had the lowest capacity of soil conservation (0.5 ton/ha). The average capacity for soil conservation was 2.86 ton/ha, which coincides with the field survey result in Beijing forests (3 ton/ha) (Feng et al. 1998; Yu and Wang 1999). However, it is far less than 1454 ton/ha in the Lancang River Basin (Mekong River), which was calculated using USLE (Chen et al. 2012). Although theoretically all forest types can reduce soil erosion, in reality, the amount of soil conservation is largely dependent on the erosion risk of the study area. For example, the actual function of soil conservation provided by forests may be restricted by low erosion risk (such as flat ground); However, soil conservation can also be effective in the areas with high erosion risk (Zhang et al. 2009). In this study, the erosion risk of each ESPU was determined on the basis of rainfall erosivity, soil erodibility, and slope angle. Eco-service provision unit method generates a highly reliable result for the actual amount of soil conservation.

Amount of nutrient control

The on-site cost of soil erosion is the shortage of nutrients that are essential for crop production. However, the soil conservation service of forest ecosystems can avoid related nutrients loss. In Anji County, the widely distributed bamboo forest, economic forest, and farmlands are often repeatedly fertilized each year (Yu et al. 2003). Thus, the maintenance of soil nutrients is of great importance for the sustainable development of the local economy. The forests in Anji County could annually prevent 277 tons of TN, 120 tons of TP, and 3532 tons of TK from eroding, and 5693 tons of OM (organic matter) could be protected through soil conservation. Therefore, the total amount of soil nutrients protected by Anji County's forest was 1.36×10^4 tons, and the mean capacity for soil nutrient fixation was 95.48 kg/ha. In addition to substantial on-site losses of nutrients, soil erosion negatively affects the surrounding environment, such as roadway, sewer, and basement siltation, drainage disruption, undermining of foundations and pavements, gullying of roads, earth dam failures, eutrophication of waterways, siltation of harbors and channels, loss of reservoir storage, loss of wildlife habitat and disruption of stream ecology, flooding, damage to public health, and increased water treatment costs (Pimentel et al. 1995). The eutrophication and deterioration of water quality in Taihu Lake is worsening, and the substance migration resulting from soil erosion is the main carrier of non-point nutrients into the lake (Wang et al.

2003). Results of nutrient fixation assessment showed that the forests of Anji County, which are located upstream of Taihu Lake, could annually prevent 118 tons of TN and 30.68 tons of TP from entering water systems.

Economic value of soil nutrient conservation

In contrast to the cost of soil conservation efforts, environmental benefits of decreasing soil erosion are difficult to measure (Hansen and Ribaudo 2008). This study evaluated the economic value of soil conservation on the basis of the on-site and off-site costs of soil erosion. The total economic value of Anji County forests for soil conservation was 43.37 million RMB (Chinese yuan) per year. The per hectare soil conservation value of ecological forest (including conifer, broadleaf, mixed, and shrub forest) was 436 RMB. Bamboo forest made the highest contribution at approximately 20 million RMB, accounting for 46 % of the total value. The next was broadleaf forest, which contributed approximately 16 million RMB. Conifer and mixed forests made minor contributions to the total value (43.7 thousand and 20.9 thousand RMB, respectively). The economic benefits of soil conservation provided by economic forest and shrub forest were only 5.7 thousand and 1 thousand RMB, respectively. The economic benefits of six types of forest were in proportion to their areas. Significant variances were observed in the relative economic contributions of different types of forest in Anji County. The highest contributor was broadleaf forest at 655 RMB/ha. The economic benefits of soil conservation per unit area of mixed and shrub forests ranged from 410 to 430 RMB/ha. Bamboo and conifer forest contributed 270 and 198 RMB/ha, respectively. Economic forest made a minor economic contribution of 36 RMB/ha. The total and average values of soil conservation in different types of forest are shown in Fig. 4.

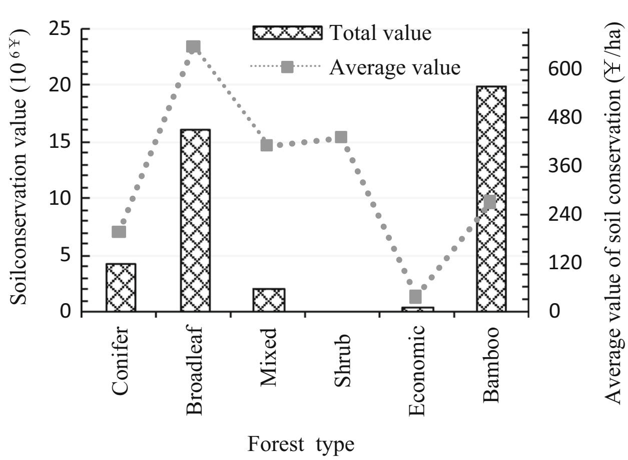

Fig. 4 Soil conservation value of different forest types

Economic value of each ESPU

Specific knowledge of the economic benefits of per hectare forest in different regions can help in policy design for eco-compensation. Figure 5 shows the total economic value of each ESPU and its average value per hectare. The highest soil conservation benefit was provided by broadleaf forest on slopes of >25° with high rainfall intensity and red soil. Broadleaf forest contributed an estimated 6.58 million RMB annually through soil conservation service, and all forest categories combined provided 1498 RMB/ha. The next was bamboo forest with similar slope, rainfall, and soil parameters, which generated an estimated 4.66 million RMB in soil conservation value. Table 6 lists the information on the precipitation, vegetation, soil, and topography of the 11 ESPUs, the cumulative proportion of total economic value of which reached 70 %.

Average economic value per unit area did not follow the same rank order because it was unrelated to area of ESPU coverage. The highest value was estimated for broadleaf forest on slopes of >25° with high rainfall intensity and red soil. The ecological complexes providing the highest soil conservation service value per hectare are listed in Table 7. The differences in the total and average values of soil conservation service derived from ESPUs are also displayed in Fig. 5. Based on these results, we can identify the dominant contributors and their magnitudes. Clear recognition of the heterogeneity of ecosystem services and their main contributors aids in policy making for ecological compensation.

Suggestions for ecological compensation policy

Watershed eco-compensation mechanisms and policy have become hot topics in society. However, the absence of economic policies related to watershed eco-compensation often results in the unequal distribution of ecological and

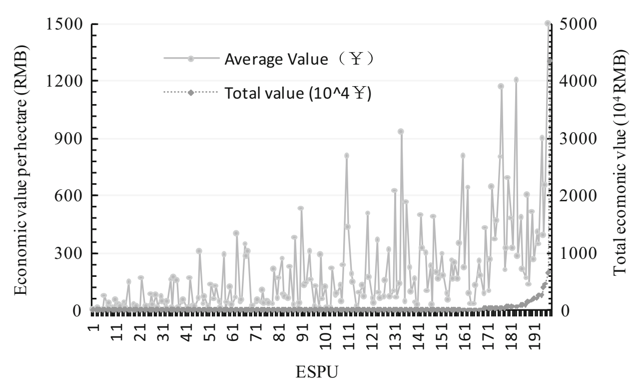

Fig. 5 Soil conservation service value of each ESPU

Table 6 Information on the precipitation, vegetation, soil, and topography of 11 ESPUs

Total economic value (10^6 ¥)	Rainfall intensity	Soil type	Slope	Forest type
6.58	High	Red soil	>25°	Broadleaf forest
4.66	High	Red soil	>25°	Bamboo forest
3.58	Middle	Red soil	>25°	Bamboo forest
2.65	Middle	Red soil	>25°	Broadleaf forest
2.64	High	Red soil	Between 15° and 25°	Bamboo forest
2.10	High	Yellow soil	>25°	Broadleaf forest
1.92	Low	Red soil	>25°	Bamboo forest
1.90	High	Red soil	>25°	Bamboo forest
1.56	Low	Red soil	Between 15° and 25°	Bamboo forest
1.47	Low	Red soil	>25°	Broadleaf forest
0.94	Low	Red soil	Between 15° and 25°	Coniferous forest

These 11 ESPUs contribute 70 % of total economic value

Table 7 Information on the precipitation, vegetation, soil, and topography of nine ESPUs

Economic value per hectare (¥ /ha)	Rainfall intensity	Soil type	Slope	Forest type
1498	High	Red soil	>25°	Broadleaf forest
1198	High	Red soil	>25°	Broadleaf forest
1165	High	Red soil	>25°	Mixed forest
932	High	Red soil	>25°	Mixed forest
899	Middle	Red soil	>25°	Broadleaf forest
809	High	Red soil	Between 15° and 25°	Broadleaf forest
805	High	Red soil	>25°	Coniferous forest
804	Middle	Red soil	>25°	Shrub forest
699	Middle	Red soil	>25°	Mixed forest

These nine ESPUs provided the highest soil conservation service value per hectare

Table 8 Economic benefits of per hectare ecological forests and their rates to current standard

Ecological forest type	Economic value (RMB/ha)	Rates to current standard (%)
Conifer forest	197.61	88
Broadleaf forest	655.08	291
Mixed forest	411.18	183
Shrub forest	429.74	191
Average	436.27	194

economic benefits among protectors and beneficiaries. Communities in the upper reaches of most rivers in China have poor economies and fragile ecosystems, and the people living in these regions require alleviation from poverty. Thus, a balance between economic development and environmental protection should exist in such areas. Effective and acceptable institutional arrangements could encourage upstream water users (small-scale farmers) to reduce erosion from their farms to create benefits for downstream water users such as hydroelectric producers (Guo et al. 2000; Pimentel et al. 1995). Thus, establishing a watershed eco-compensation mechanism is helpful in dealing with the ecological and economic relationships between upstream and downstream communities.

Anji County is located in the upper reaches of Taihu Lake and requires high expenditure for the protection and maintenance of its abundant forest resources, which provide essential eco-services, such as soil conservation and nutrient control for the overall watershed. However, the current ecological compensation standard for noncommercial forest is 225 RMB/ha, which corresponds to half of the economic benefit of forest in soil conservation. Notably, the evaluation method based on eco-service provision unit clearly reveals the dominant contributors to and magnitudes of soil conservation service. Moreover, this method provides the baseline for differentiated ecological compensation standards. From the perspective of soil conservation benefit, broadleaf forest in Anji County should be compensated at thrice the current standard of 225 RMB/ha, whereas the mixed and shrub forests should be compensated at twice this standard. Conifer forest only requires 0.88 times of the current standard because its actual eco-service may be restricted at low erosion risk. Table 8 indicates the economic benefits of per hectare ecological forests and their rates relative to the current standard of 225 RMB/ha. In addition to soil and nutrient conservation discussed here there are other forest eco-service benefits that should be considered such as recreation and biodiversity conservation. As a result, the monetary value derived from this study is likely to be a lower-bound estimate of the ecological benefits of Anji County forests.

Conclusion

This study quantified the soil conservation effects of forests in Anji County and converted these effects into monetary terms by using an eco-service unit evaluation method. The forests of Anji County were estimated to reduce soil erosion by 4.08×10^5 tons year^{-1} or 2.86 tons ha^{-1} year^{-1} by avoiding on-site nutrient loss. From an economic perspective, we estimated the forests of Anji County could provide a benefit of 43.37 million RMB year^{-1} as a result of soil conservation service and a per unit ecological forest contribution of 436 RMB ha^{-1} year^{-1}, which is twice the current standard of ecological compensation. The ecological complexes with higher rainfall intensity, broadleaf forest, red soil, and slope gradients $>25°$ had the highest contributions to soil conservation benefits.

In addition, the eco-service provision unit method in this study attempted to combine erosion risk and soil conservation capacity, as well as to reconcile the scientific requirement of rigorous analysis with a political analysis to provide guidelines to arrive at a decision. Nevertheless, even with this correction for soil erosion risk, only a rough estimated can be made because of the lack of actual experiments on soil erosion and nutrient content. Although extensive efforts have been exerted to determine the effects of forest on soil erosion and nutrient control in Anji County, some weaknesses remain because of the limitations on the precision of the economic models and the biological, physical, and ecological process models available. For instance, whether the soil nutrients and their benefits can simply be added to the total effect of forest soil protection as a whole remains unclear. Some approaches are alternatives for each other. Another issue is private versus public costs and benefits: how do the goals of private land users differ from the public good, how can this difference help us to predict land-user behavior, and what incentives would be appropriate to make land-users behave in such a way as to maximize the public good? Therefore, further research should be conducted. Nevertheless, this study contributes to clear identification of the main contributors to ecosystem services and their magnitudes, and can benefit decision making for ecological compensation policy.

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