Valuation of ecosystem services for Huzhou City, Zhejiang Province from 2001 to 2003 by Remote Sensing data

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Abstract: The land covers of Huzhou City (119°14'–120°29'E, 30°22'–31°11'N) that includes five regionalisms of Anji County, Changxing County, Deqing County, Wuxing District and Nanxun District were classified into eight types by using Remote Sensing data, which were forest, grassland, shrub, paddy field, dry land, bare land, water and wetland. The indexes of ecosystem services of each type of land cover were divided six items, such as the producing organic matter, assimilating CO_2, releasing O_2, recycling nutrient matter, holding water, and conserving soil and water. The results showed that the value of ecosystem services for Huzhou City in 2001, 2002, and 2003 was 194.82×10^8 yuan, 207.68×10^8 yuan, 173.56×10^8 yuan, respectively. Anji County of five regionalisms had the best environment conditions among all the districts, which played the most important role in ameliorating the ecological environment for Huzhou City. Environment conditions of Deqing County were at the worst level. The GDP per capita and per unit area of each county (district) was in inverse proportion to the value of ecosystem services per capita and per unit area, which implied that the higher GDP was, the more severe contamination of environment was.

Keywords: Ecosystem services; Value; Remote Sensing; Huzhou City
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Introduction

Ecosystem services generally mean the processes that natural ecosystems support and maintain humans' survival and the living conditions. As the global problems of ecosystems and environment, such as forest areas sharply decreasing and temperature warming up in the global area, become more and more severe, people have to pay more attention to the research on ecosystem services. Both domestic and overseas scientists have conducted many researches on ecosystem process, ecosystem services, valuing systems methods and value structure (Costanza *et al.* 1997; Zong *et al.* 2002; Zhang 2004). Costanza *et al.* (1997) and classified ecosystem services into 17 types, not including irreproducible fuel, mineral, and the atmosphere, etc.. Ouyang *et al.* (1999) generalized these services into 6 types. Xie (2001), Potschin (2003) and Pan (2004) evaluated the ecosystem services from different views. Most of these studies focused on the temporal and spatial changes in the large geographical scales of province, country, continent and even the whole globe. However, these studies usually attached little importance to relations between the changes of ecosystem-service values, climate, environment, and the human economic activities, and at the same time could hardly acquire the changing characteristic of ecosystem services in relatively small areas. The rapid development of economics of China has brought great achievements, but the environment is being contaminated and the efficiency of utilizing resources is relatively low, which have restricted the ability of the society's sustainable development. Consequently, studying the annual changing mode of ecosystem service functions, understanding the affection extent of human activity on ecosystems in time, and advocating scientific development ideas are all important for building a harmony relationship of human's society with natural environment.

Materials and methods

Study area

Huzhou City (126 km × 90 km), with jurisdiction over Anji County, Changxing County, Deqing County, Wuxing District and Nanxun District, is located in the north of Zhejiang Province (119°14'–120°29'E, 30°22'–31°11'N). The city lies in the central position of the 15 cities of Changjiang Delta, thus it has been a distributing centre of commodities and transportation junction since ancient times. The general topography of Huzhou City has a characteristic that the southeast is high and steep and the northwest is relatively low and flat. There are generally three types of landforms, namely plain in the east, hill in the middle part and mountain in the west. The proportion of three types of landforms is about 5:3:2.

Data sets and processing

Image data: the image data sets included 500 m-resolution MODIS image data and climate data (the average temperature, precipitation and radiation data of the corresponding months) of 2001, 2002 and 2003. Each kind of data had a time series of 11 months and the climate data were interpolated into raster image data according to the observing data of the weather station. In addition, there were 30-m resolution TM image data of the corresponding year and the digitized soil-type map with a scale of 1: 4000 000. The land of Huzhou City was classified into 8 land-cover types as forest, grassland, brush, paddy field, dry land, bare land, water and wetland, through supervised classification of the TM data. Since the MODIS data has a resolution of 500 m, this paper developed a method of linear decomposition to improve the MODIS-NDVI data's resolution on the basis of the TM

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classification data.

Statistic data: The price of organic matter (yuan·g^{-1}) is substituted by that of Standardized Coal. The price of CO_2 (yuan·g^{-1}) is $0.15 per kilogram from the carbon tax method in Sweden. Furthermore, the value system must include: (1) the prices of O_2 (yuan·g^{-1}) produced in industry; (2) the average price of nitrogenous fertilizer, phosphorus fertilizer and potassium fertilizer (yuan·g^{-1}); (3) the cost of building reservoir of 1 m^3 (yuan·m^{-3}); (4) the average income of forestry and herd (yuan·hm^{-2}); (5) the average price of firewood (yuan·kg^{-1}); (6) the proportion of sediment in reservoirs, rivers and lakes to the total soil erosion.

Index of valuation of regional ecosystem services by Remote Sensing

The index of valuation of regional ecosystem services (Fig. 1) was finally founded from the view of macro ecology, on the basis of the characteristics of the Remote Sensing (RS) method and Chinese actual conditions (Ouyang *et al.* 1999). The valuation methods of ecosystem services include shadow engineering method, market value technique, opportunity cost method, and substitutive value method. The total value can be described as Equation (1).

$$V = \sum_{c=1}^{n} V_c \tag{1}$$

where, C is the ecosystem type, V_c is the value produced by the ecosystem of type C;

$$V_c = \sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij} \times V_{ci} \times S_{ij} \tag{2}$$

where, i is the type of the ecosystem service of ecosystem C, V_{ci} is the value per unit area of ecosystem service i of ecosystem C, j is the number of patches of V_{ci} in certain area, S_{ij} is the area of each patch, and R_{ij} is the adjusting coefficient of V_{ci} in different patches and is decided by the qualitative condition of the ecosystem.

In this study, on the basis of Remote Sensing data, we chose net primary productivity and vegetation fraction of the ecosystem as the parameters to express the qualitative conditions of ecosystems.

$$R_{ij} = F(A_1, A_2, \ldots A_n) \tag{3}$$

where, $A_1, A_2 \ldots A_n$ are parameters to express the qualitative condition of ecosystems. The V_{ci} of the same ecosystem type in different qualitative conditions is different, and the difference is expressed thorough R_{ij}.

Valuation of each ecosystem service

The value of producing organic matter

Net primary productivity that is the mass of organic matter produced by vegetation in certain time (such as a year), is an important index to reflect the production of organic matter.

$$Vn(x) = Npp(x) \times T(x) \qquad Vn = \sum Vn(x) \tag{4}$$

where, $Vn(x)$ is the value of producing organic matter in pixel X per year, $NPP(x)$ is the mass of organic matter produced in pixel x per year (g), $T(x)$ is the value of producing organic matter per mass unit in pixel x (yuan·g^{-1}), Vn is the value of producing organic matter in certain area per year.

The value of assimilating CO_2

According to the equations of photosynthesis and respiration, we can get the result that 1.62g of CO_2 are needed when 1g of dry substances are created in the ecosystem.

$$Vr(x) = 1.62 \times NPP(x) x R \qquad Vr = \sum Vr(X) \tag{5}$$

where, $Vr(x)$ is the value of assimilating CO_2 in pixel x per year, $NPP(x)$ is the organic matter produced in pixel x per year (g), R is the value of CO_2 per mass unit in carbon tax method(yuan·g^{-1}), Vr is the value of assimilating CO_2 in certain area per year.

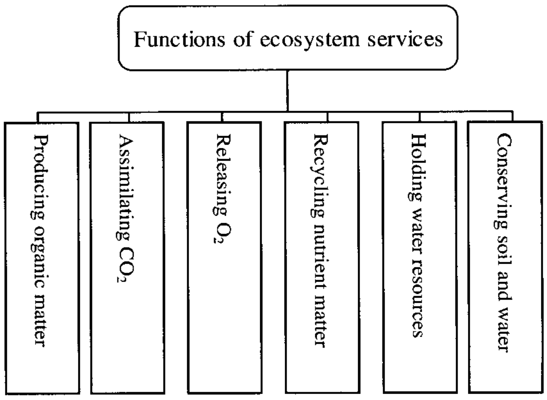

Fig. 1 Indexes of valuation of ecosystem services by Remote Sensing

The value of releasing O_2

On the basis of the production of organic matter, the result was achieved that 1.2-g O_2 was needed when 1-g dry substance was created according to the equations of photosynthesis and respiration.

$$V(x) = 1.2 \times NPP(x) \times R \qquad V = \sum V(x) \tag{6}$$

where, $V(x)$ is the value of releasing O_2 in pixel x per year; $NPP(x)$ is the organic matter produced in pixel x per year(g); R is the price of producing O_2 in industry(yuan·g^{-1}); V is the value of releasing O_2 in certain area per year.

The value of recycling nutrient matter

The value of recycling nutrient matter is estimated according to the distributive ratios of N, P and K in ecosystems, on the basis of the biological mass and NPP of ecosystems.

$$Va = Vna + Vpa + Vka \tag{7}$$

where, Va is the value of nutrient matter assimilated in certain area per year (yuan), Vna is the value of nitrogen assimilated in certain area per year (yuan), Vpa is the value of phosphor assimilated in certain area per year (yuan), Vka is the value of potassium assimilated in certain area per year (yuan).

$$Vna(x) = NPP(x) \times r_1 \times r_2 \times M \qquad Vna = \sum Vna(x) \tag{8}$$

where, $Vna(x)$ is the value of nitrogen assimilated in pixel x per year, $NPP(x)$ is the organic matter produced in pixel x per year (g), r_1 is the distributive ratio of nitrogen in organic matter in corresponding ecosystem ($g \cdot g^{-1}$), r_2 is the ratio of pure nitrogen converted to nitrogenous fertilizer; M is the average price of nitrogenous fertilizer ($yuan \cdot g^{-1}$), *Vna* is the value of assimilating nitrogen in certain area per year. The valuation of P and K is just as that of N.

The value of holding water resources

The value of holding water resources is estimated according to the following Equation.

$$V(x) = Q(x) \times p \times Sp \qquad V = \sum V(x) \tag{9}$$

where, $V(x)$ is the value of holding water in pixel x per year, $Q(x)$ is the reservation of rain water per unit area in pixel x per year (m^3/m^2), p is the cost of building reservoir of 1 m^3 ($yuan/m^3$), Sp is the area of each pixel (m^2), and V is the value of holding water in certain area per year.

The value of conserving soil and water

The value of conserving soil and water is estimated in the aspects of protecting soil fertility, reducing the land abandonment and lightening sedimentation.

$$V(x) = V_1(x) + V_2(x) + V_3(x) \tag{10}$$

where, $V(x)$ is the value of conserving soil and water in pixel x per year (yuan), $V_1(x)$ is the value of protecting soil fertility in pixel x per year (yuan), $V_2(x)$ is the value of reducing the land abandonment in pixel x per year (yuan), and $V_3(x)$ is the value of lightening sedimentation in pixel x per year (yuan).

Conclusion and discussion

Valuation of ecosystem services in Huzhou City each year from 2001 to 2003

The values of ecosystem services in Huzhou City from 2001 to 2003 were 194.82×10^8yuan, 207.68×10^8 yuan, 173.56×10^8 yuan, respectively (Table1). The main factors that affected the ecological benefit of ecosystems were artificial and natural factor. The impact of the artificial factor in 2002 was greater than that of 2001 and 2003.

Table 1. Value of ecosystem service for Huzhou City in 2001, 2002 and 2003

District	Year	Area (hm^2)	Producing original matter (10^4yuan)	Assimilating CO_2 (10^4yuan)	Releasing O_2 (10^4yuan)	Holding water (10^4yuan)	Cycling nutrient matter (10^4yuan)	Conserving soil and water (10^4yuan)	Total (10^4yuan)
Municipal districts	2001	158949.91	13532.2	31055.92	27386.17	50974.8	1877.49	251636.69	376463.27
Changxing		143252.15	16721.28	38374.77	33840.19	52290.05	1979.24	253169.80	396375.33
Anji		188701.15	28866.74	66248.17	58419.91	68109.60	2479.12	704738.22	928861.75
Deqing		92371.59	9135.27	20965.13	18487.77	30081.24	885.61	166969.42	246524.45
Municipal districts	2002	158949.91	14329.05	32884.68	28998.84	60285.95	1991.43	292262.66	430752.62
Changxing		143252.15	17251.54	39591.69	34913.31	55539.63	2040.03	272028.11	421364.31
Anji		188701.15	29716.75	68198.92	60140.14	69678.73	2554.83	732366.70	962656.07
Deqing		92371.59	9624.55	22088.00	19477.96	33168.03	936.94	176714.78	262010.26
Municipal districts	2003	158949.91	15402.23	35347.6	31170.72	41767.26	2210.98	230016.73	355915.52
Changxing		143252.15	18795.70	43135.48	38038.34	44390.77	2204.93	232251.65	378816.87
Anji		188701.15	26475.45	60760.25	53580.47	55649.85	2493.01	597292.56	796251.60
Deqing		92371.59	8699.24	19964.47	17605.35	24296.98	1138.93	132934.39	204639.36

Integrated analysis of the natural, social and economic indexes in every county (district) of Huzhou from 2001 to 2003

The population of Municipal districts is larger than that of other counties, occupying about 42% of the whole population of the city (Fig. 2). The values of ecosystem services in different districts in 2001 and 2003 were ranked in the following order: Anji County > Changxign County > Municipal districts > Deqing County, and in 2002 the order was Anji County > Municipal districts > Changxing County > Deqing County (Fig. 3). The biological benefit was the highest for Anji County and the least for Deqing County. Anji County was the main district of forest resource of Huzhou City and had the greatest contribution to the ecosystem services in Huzhou City, while Deqing County with the smallest area of forest resource had the smallest contribution to the ecosystem services. The loss caused by contamination in different districts was ordered as follows: Municipal districts > Changxing County > Deqing County > Anji County (Fig. 4). The reason is that the Municipal districts has the highest level of urbanization and thus has the most industrial factories, letting out a lot of contaminants. By contrast, Anji County had the highest value of ecosystem services and the least contamination to the environment. Consequently, compared with the results in Fig. 4 and Fig. 3, the result of Fig. 5 showed that rank order of yearly GDP was the same as that of their contaminations for different districts in Fig. 4, which indicated that there was a positive relation between GDP and negative effect caused by contamination. In Fig. 7 and 6, Anji County had the highest value of ecosystem services per capita and per unit area in other districts; In Fig. 8, the order of loss caused by contamination per capita of different districts in Huzhou City was Deqing County > Municipal districts > Changxing County > Anji County, which was directly related to the few population (about 42 thousands of population), compared with that other districts. According to Fig. 9, the loss caused by contamination per unit area of different districts was the highest for Deqing County, and the least for Anji County. So it was concluded that the environmental capacity of Anji County was obviously higher than that of other districts, which of Deqing County was the lowest. According to Fig. 10 and Fig. 11, the GDP per capita and per unit area was highest for Municipal district and the lowest for Anji County, and value of ecosystem services per capita of different districts had just the reverse order in contrast with results of Fig. 6 and Fig. 7. Accordingly, it was also concluded that the GDP per capita and per unit area was in inverse proportion to the value of ecosystem services per capita and per unit area.

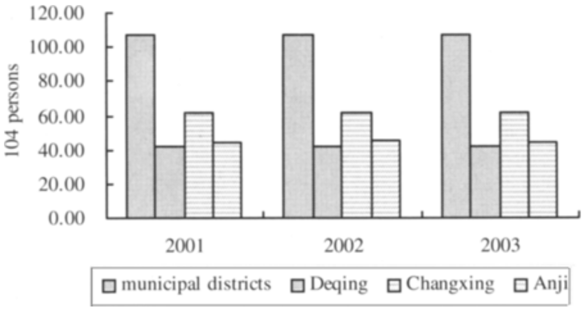

Fig. 2 Population of every county (district) in Huzhou City from 2001 to 200

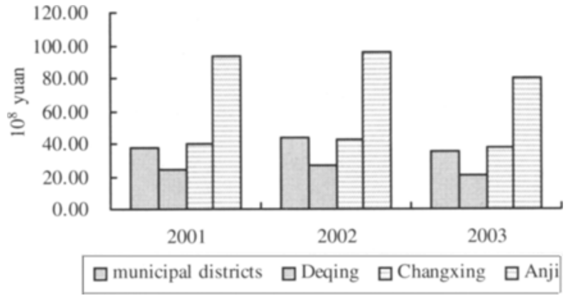

Fig. 3 Value of ecosystem services in different counties (district) in Huzhou City from 2001 to 2003

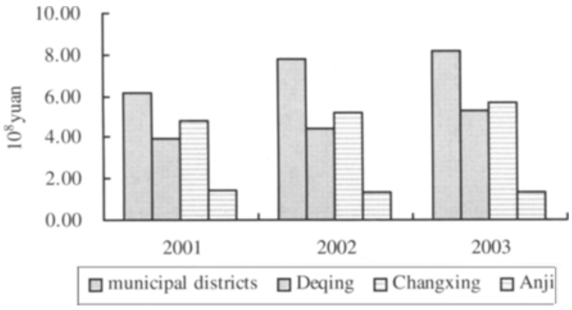

Fig. 4 Loss caused by contamination in every county (district) in Huzhou City from 2001 to 2003

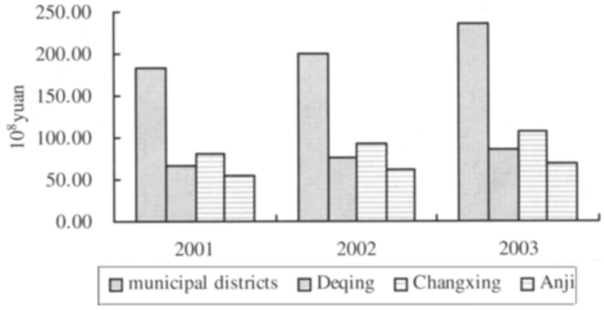

Fig. 5 GDP of every county (district) in Huzhou City from 2001 to 2003

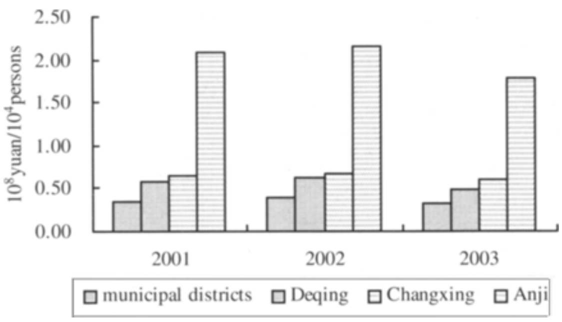

Fig. 6 Value of ecosystem services per capita in every county (district) in Huzhou City from 2001 to 2003

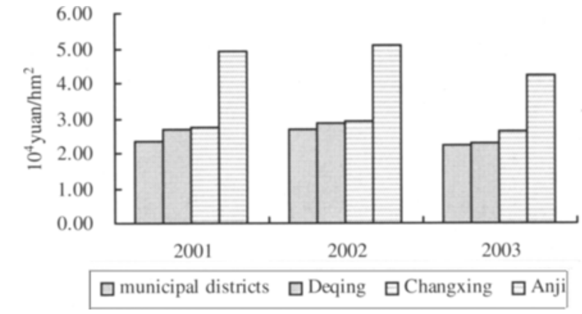

Fig. 7 Value of ecosystem services per unit area in every county (district) in Huzhou City from 2001 to 200

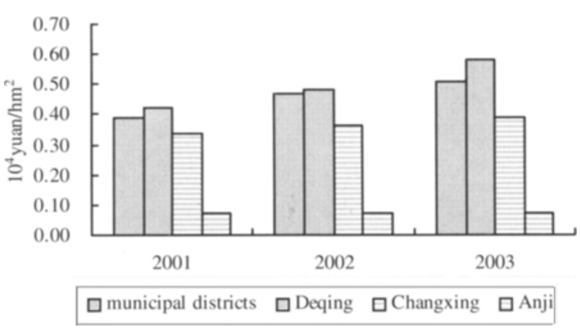

Fig. 8 Loss caused by contamination per unit area in every county (district) in Huzhou City from 2001 to 2003

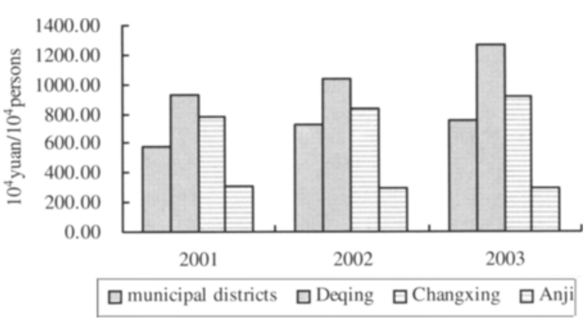

Fig. 9 Loss caused by contamination per capita of every county (districs) in Huzhou City from 2001 to 2003

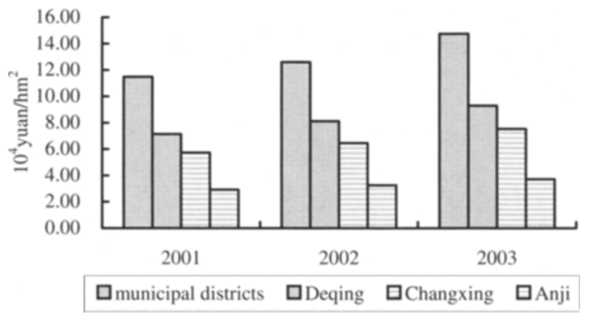

Fig. 10 GDP per unit area in every county (district) in Huzhou City from 2001 to 2003

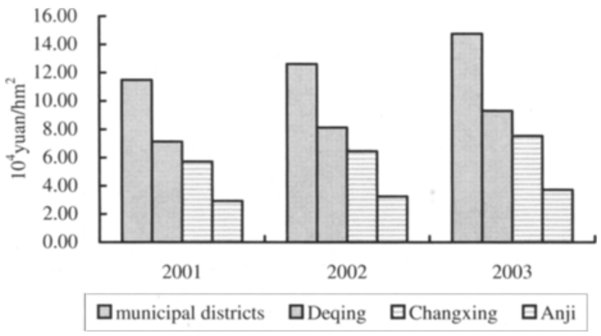

Fig. 11 GDP per capita in every county (district) in Huzhou City from 2001 to 2003

Above analysis, Anji County had the best environmental condition. The results showed that the higher the GDP was, the more severe contamination of environment was. There is a prevalent phenomenon in our country, which is the high-speed development of economics in the city resulting in the mode of consuming too much resources and contaminating the environment. These problems are so crucial that they may limit some areas to economically sustainable development. It is very important to adopt the "green GDP" accounting mechanism in improving the efficiency of resources application. Because the districts with better environmental conditions has greater contribution to the ecosystem services and can mitigate the negative effect caused by pollutions, it is recommended to establish ecological compensation mechanisms that the districts with good environmental conditions may compensate the districts polluted relatively severely. In order to save limited resources and protect ecological environment, it is important to build compensation funds, such as imposing taxes on utilization of mineral resources and water resources.

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