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Land use pattern, socio-economic development, and assessment of their impacts on ecosystem service value: study on natural wetlands distribution area (NWDA) in Fuzhou city, southeastern China

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Abstract This paper quantifies the allocation of ecosystem services value (ESV) associated with land use pattern and qualitatively examined impacts of land use changes and socio-economic factors on spatiotemporal variation of ESV in the Natural Wetland Distribution Area (NWDA), Fuzhou city, China. The results showed that total ESV of the study area decreased from $4,332.16 \times 10^6$ RMB Yuan in 1989 to $3,697.42 \times 10^6$ RMB Yuan in 2009, mainly due to the remarkable decreases in cropland (decreased by 55.3 %) and wetland (decreased by 74.2 %). Forest, water, and wetland played major roles in providing ecosystem services, accounting for over 90 % of the total ESV. Based on time series Landsat TM/ETM+ imagery, geographic information system, and historical data, analysis of the spatiotemporal variation of ESV from 1989 to 2009 was performed. It indicated that rapid expansion of urban areas along the Minjiang River resulted in significant changes in land use types, leading to a dramatic decline in ecosystem services. Meanwhile, because of land scarcity and unique ecosystem functions, the emergency of wetland and cropland protection in built-up area has become an urgent task of local authorities to the local government. Furthermore, there was still a significant negative correlation between ESV of cropland and wetland and the GDP. The results suggest that future planning of land use pattern should control encroachment of urban areas into cropland and wetland in addition to scientific and rational policies towards minimizing the adverse effects of urbanization.

Keywords Land use pattern · Ecosystem service value · Geographic information system (GIS) · Remote sensing (RS) · Spatiotemporal changes

Introduction

Urban sprawl can produce more urban ecosystem services while occupying a large amount of land (Bolund and Hunhammar 1999). People living in urban areas

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now account for almost 50 % of the world's population, and the prospect is that the urbanization rate will reach 60 % by 2030 (Avelar et al. 2009). A number of problems are created by the urbanization process though urbanization also creates opportunities for human life. Some landscape planners regard urban sprawl as an opportunity to improve quality of life and to promote economic development (Burchell et al. 2000). For instance, people live in dense concentrations, environmentally benign solutions like public transport and district heating become feasible (Rees and Wackernagel 1996). However, rapid urbanization has resulted in many ecological problems worldwide (Matteucci and Morello 2009). Most of the problems present in urban areas are locally generated. Therefore, often the most effective and, in some cases, the only way to deal with these local problems is through local solutions. In this respect, the urban ecosystems are vital (Bolund and Hunhammar 1999). Monitoring landscape pattern changes provides an indirect approach for characterizing the ecological consequences of urbanization (Shrestha et al. 2011; Solon 2009; Weng 2007).

Land use/cover change (LUCC) induced by rapid urbanization has impaired ecosystem service functions of estuarine regions (Goss-Custard and Yates 1992; Sato and Azuma 2002). Urbanization exerts significant influences on the structure and functions of natural ecosystem, mainly through modifying the hydrological and sedimentation regimes, and the dynamics of nutrients and chemical pollutants, which resulted in ecosystem service valuation (ESV) changes. Remote sensing (RS) and geographic information systems (GIS) are regarded as promising tools for investigating landscape pattern changes at various scales. Recently, the comprehensive application of RS, GIS, and landscape metrics has been utilized in ecosystem service value studies regarding the ecological consequences of urbanization (Gao and Li 2011; Geri et al. 2010; Li et al. 2011; Su et al. 2011a, b).

Costanza et al. (1997a, b) classified the global biosphere into 16 ecosystems and 17 service functions, and then estimated the ESV of each, but their results have been severely criticized by many researchers (e.g., Serafy 1998; Heal 2000; Wilson and Howarth 2002) due to the underestimation on ESV of farmland and the overestimation on ESV of wetland, and so on. Xie et al. (2003) improved the valuation method of ESV mainly included the merging of some ecosystem service functions suggested by Costanza et al. (1997a, b) and extraction of the equivalent weighting factors for ecosystem services per hectare for terrestrial ecosystems in China based on the survey on 200 Chinese ecologists. Combined with land use data, the equivalent weighting factors have been used widely to evaluate the *ESV* in some cities (e.g., Li et al. 2010b), terrains (e.g., Wang et al. 2004; Li et al. 2010a), and watersheds (e.g., Zhao et al. 2010) of China. Their results indicate that land use types can be the proxy for ecosystem services by matching them to equivalent biomes, thereby facilitating the valuation of ecosystem services for large areas using remote sensing data.

This study principally focuses on the Natural Wetlands Distribution Area (NWDA) in Fuzhou city, southeastern China. The NWDA is a key area for natural conservation within the domain of the west side economic zone adjacent to the Taiwan Straits. Dramatic changes in land use have occurred here in recent decades as a result of urban sprawl and a policy of returning cropland to forest. This study area provides a useful example for its location advantages, economic power, and supporting function. Accordingly, our specific objectives are (1) to apply evaluation method based on an integrated approach of RS and GIS to estimate land use pattern and recognize the impacts on spatiotemporal variation of ecosystem service value; (2) to find the relationship between ESV of different land use type and the total gross domestic product (GDP) using time series of information from remote sensing data and statistical methods; and (3) to provide useful experiences for planning sustainable policies among researchers, urban planners, and decision makers. Moreover, the key areas can be recognized more simply in the combination of GIS and RS technology, then the best management practice (BMP) would be adopted immediately to protect wetland areas for sustainable development. Therefore, this case study will significantly have practical implications for the other cities in estuarine areas and similar cities worldwide.

Materials and methods

Study area

The study area is located between latitudes 25°55′N and 26°13′N, and longitudes 119°1′E and 119°42′E

(Fig. 1). The region has a northern subtropical monsoon climate with an average annual temperature of about 20.8 °C. The highest temperature was 41 °C in the 20 years in summer 2003 and the lowest was −4 °C in winter 1991. Annual precipitation within the study area varies widely from 796.5 to 1,913.6 mm, of which approximately 33 % is received during the May and June flood seasons. Topographically, the Minjiang River is the major river throughout the NWDA. This area, which is known as the Fuzhou basin, is mainly located at an estuarine terrace enclosed by the hills and mountains. Elevation of the area ranges between 1 and 802.4 m.

Fuzhou, the capital city of Fujian Province, consists of five administrative wards (namely Gulou district, Taijiang district, Jin'an district, Cangshan district, and Mawei district) and two county-level municipalities, namely Changle county and Minhou county. The NWDA in Fuzhou covers an area of approximately 1,491 km^2 with a total population of 2.71 million. In the end of 2009, local GDP per capita is approximately 36,851 RMB Yuan (equivalent to $5,395 US dollars, current exchange rate is about 6.83), approximately 50.1 % over the nationwide average (Fuzhou Municipal Bureau of Statistics 2011).

Data sources, pre-processing, and land use dynamics information

Data sources

In this study, both time series LUCC data and census data were used. These data were produced by using classification of multi-temporal Landsat TM/ETM+ imagery (1989–2009). Regional total GDP was extracted from the Fuzhou Statistical Yearbook (Fuzhou Municipal Bureau of Statistics 1990, 1995, 2001, 2007, 2010) and China's Urban Statistical Yearbook (National Bureau of Statistics of China, 2010).

Remotely sensed imagery processing and change detection of LUCC

In this paper, five remotely sensed images dated June 15, 1989, March 11, 1994, May 18, 2000, August 4, 2006, and June 6, 2009 were selected for this study. All of the images were clear and nearly free of clouds. Therefore, the study period covered about 20 years. All the images were rectified and georeferenced to the UTM map projection prior to interpretation. Subsequently, the images were resampled to 30 m using the nearest-neighbor algorithm to keep the unchanged original brightness values of pixels, and the RMSE

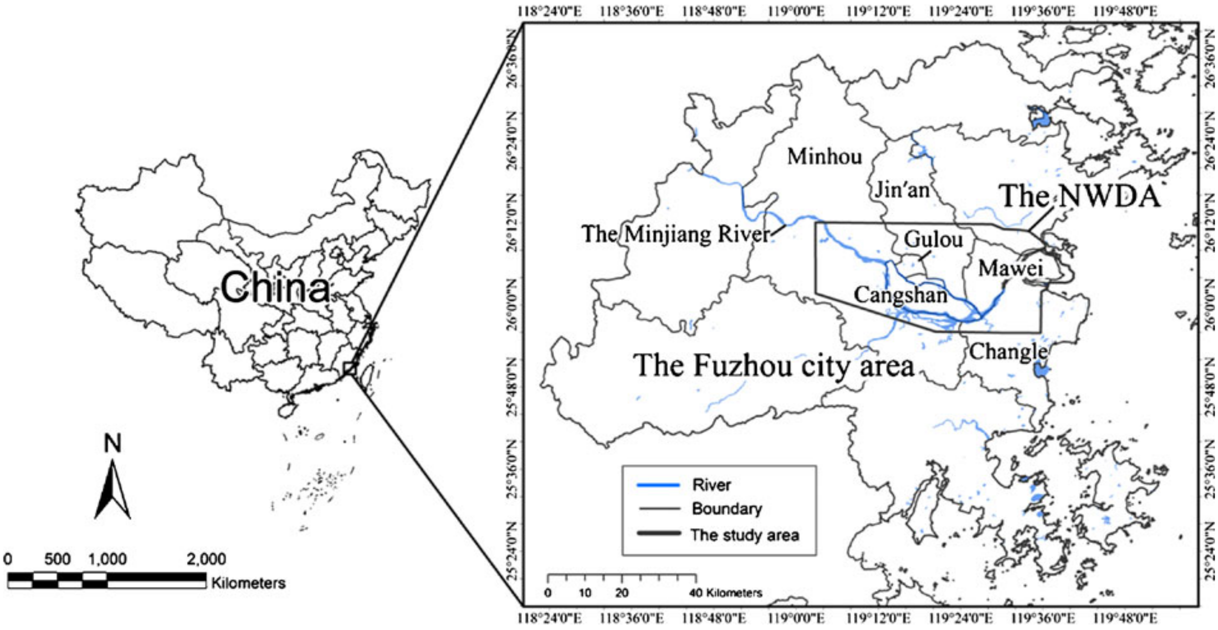

Fig. 1 Location of the study area

were both found within 1 pixel. The image processing and data manipulation were conducted using algorithms supplied with the ENVI 4.8® image processing software. Furthermore, ESRI ArcGIS 10.0® was used for spatial analyses.

Land use and land cover patterns were mapped by the use of Landsat TM and ETM+ data from 1989 to 2009, respectively. As part of the planned routine, a field survey of land use in Fuzhou has been carried out every 3 years since 2000. According to a predetermined classification scheme of six categories of land covers present within the study area and their image characteristics, false-color images were produced by combining bands 5, 4, and 3 of the Landsat TM/ETM+ images. These covers include forest and shrub, urban or built-up land, cropland, water (mainly rivers, channels, and ponds), wetland, and bare land. Herein, the classification scheme of the study area was modified on the basis of the land use classification system by the China National Committee of Agricultural Divisions (1984). Subsequently, the supervised signature extraction with the maximum likelihood algorithm was employed to classify the images.

For accuracy assessment of imagery classification, ancillary data, including land use survey data derived from historical aerial photos acquired in 2000 and 2007, a SPOT image with 2.5 m resolution acquired in 2007, the 1:10,000 digitalized topographic map, and 1:250,000 digitalized land use maps acquired in 1995, 2000, and 2007 were used. For each image, 289 training sites were randomly chosen to ensure that all spectral classes cover each land use. After classification, for each image 289 samples were randomly selected to check the accuracy of the classified maps. The overall accuracy of the land use and land cover maps for 1989, 1994, 2000, 2006, and 2009 were 78.20 %, 77.16 %, 79.58 %, 77.85 %, and 81.66 %, respectively. Accordingly, the Kappa indices for 1989, 1994, 2000, 2006, and 2009 were 0.74, 0.72, 0.75, 0.73, and 0.78, respectively, with an average of 0.74. These indices meet the recommended value by Jassen et al (1994). Therefore, these data were available for further study.

Finally, a cross-tabulation detection analysis was employed to perform LUCC. The land use change matrix, which showed quantitative data of the overall land use and land cover changes during 1989 and 2009 in the study area, was observably produced. Based on the six main types of gains and losses in each category indicated by the change matrix, land use transfer images and land use transfer matrix for each category were also produced.

Assignment of ESV

The equivalent weighted factors listed in Table 1 can be applied to different regions across China by localizing the average natural food production (Xie et al. 2003). The factor for the economic value of average natural food production of farmland per hectare per year was set at 1.0. All the other coefficients were adjusted on the basis of this factor. The proposed natural food production is one seventh of the actual food production. From 1989 to 2009, the average actual food production of farmland in this study area was 5,176.19 kg ha^{-1}; the average 2009 price for grain was 1.90 RMB Yuan kg^{-1}.

Table 1 Equivalent weighting of ecosystem services per hectare of terrestrial ecosystems in China[a]

	Forest	Cropland	Wetland	Water body	Bare land
Gas regulation	3.50	0.50	1.80	0.00	0.00
Climate regulation	2.70	0.89	17.10	0.46	0.00
Water supply	3.20	0.60	15.50	20.40	0.03
Soil formation and protection	3.90	1.46	1.71	0.01	0.02
Waste treatment	1.31	1.64	18.18	18.20	0.01
Biodiversity protection	3.26	0.71	2.50	2.49	0.34
Food production	0.10	1.00	0.30	0.10	0.01
Raw material	2.60	0.10	0.07	0.01	0.00
Recreation and culture	1.28	0.01	5.55	4.34	0.01
Total	21.85	6.91	62.71	46.01	0.42

[a] From Xie et al. (2003)

Applying the ecosystem service coefficient of 1.0 yields an ecosystem value of 1,404.97 RMB Yuan ha^{-1} (1.0×5,176.19×1.90/7).

For each land use type in the NWDA of Fuzhou, ESV of per unit area was then assigned based on the nearest equivalent ecosystems suggested by Xie et al. (2003) as given in Table 2. Additionally, ESV of the shrub is approximately assigned to that of forest type for the lack of ecosystem service value suggested by Xie et al. (2003). Although the biomes we used as proxies are not perfect matches with land use types in every case (Kreuter et al. 2001), they are related (Li et al. 2010b).

Calculation of ESV

After we determined the ESV per unit area for each land use type, we determined the service value for each land use type, each service function, and for the total ESV as follows:

$$\mathrm{ESV}_k = A_k \times \mathrm{VC}_k \tag{1}$$

$$\mathrm{ESV}_\mathrm{t} = \sum\nolimits_k A_k \times \mathrm{VC}_k \tag{2}$$

$$\mathrm{ESV}_f = \sum\nolimits_k A_k \times \mathrm{VC}_{kf} \tag{3}$$

where ESV_k, ESV_f, and ESV_t refer to the ESV for land use type k, service function f, and the total ecosystem, respectively; A_k is the area (ha) for land use type k; VC_k is the value coefficient (RMB Yuan ha^{-1} year^{-1}) for land use type k; and VC_{kf} is the value coefficient (RMB Yuan ha^{-1} year^{-1}) for land use type k with ecosystem service function type f.

Results

Land use changes in the NWDA

Tables 3, 4, 5, 6, and 7 describe the overall patterns of LUCC of the NWDA in Fuzhou during 1989 and 2009. The classification results indicate that the land cover types varied significantly across different years. As a matter of fact, a summarized description of LUCC of the NWDA over the study period is shown in Table 7. The urban/built-up area between 1989 and 2009 increased by 232.60 km^2, from 151.16 km^2 to 383.76 km^2 with the average of 1,162.99 ha year^{-1}, followed by forest and shrub and water, which grew on average by 35.81 ha year^{-1} and 5.08 ha year^{-1}, respectively. In contrast, cropland decreased by 185.49 km^2 or nearly by 927.43 ha year^{-1} on average, followed by wetland and bare land, which decreased on average by 274.24 ha year^{-1} and 2.22 ha year^{-1}, respectively (Fig. 2). Meanwhile, considerable former built-up land in remote rural areas was converted to other land use/cover types such as cropland, forest, and shrub due to land reclamation associated with rural–urban migration. However, significant increase in urbanized land from the other land cover types exceeded the conversion from the urban land to the other land cover types, especially in the north.

Table 2 Unitary ESV (Yuan ha^{-1} year^{-1}) of different land use types in the NWDA in Fuzhou city

	Forest	Cropland	Wetland	Water body	Bare land	Built-up land
Gas regulation	4,917.40	702.49	2,528.95	0.00	0.00	0.00
Climate regulation	3,793.42	1,250.42	24,024.99	646.29	0.00	0.00
Water supply	4,495.90	842.98	21,777.04	28,661.39	42.15	0.00
Soil formation and protection	5,479.38	2,051.26	2,402.50	14.05	28.10	0.00
Waste treatment	1,840.51	2,304.15	25,542.35	25,570.45	14.05	0.00
Biodiversity protection	4,580.20	997.53	3,512.43	3,498.38	477.69	0.00
Food production	140.50	1,404.97	421.49	140.50	14.05	0.00
Raw material	3,652.92	140.50	98.35	14.05	0.00	0.00
Recreation and culture	1,798.36	14.05	7,797.58	6,097.57	14.05	0.00
Total	30,698.59	9,708.34	88,105.67	64,642.67	590.09	0.00

Table 3 Land use transformation matrix in 1989–1994 (unit km^2)

Class	Built-up land	Cropland	Forest and shrub	Water	Wetland	Bare land	Sum_1989
Built-up land	104.64	14.48	23.90	5.42	0.90	1.82	151.16
Cropland	57.93	171.49	81.95	20.82	0.26	2.97	335.43
Forest and shrub	24.71	111.07	621.00	4.92	0.08	2.85	764.64
Water	12.14	17.09	0.50	115.25	9.93	0.86	155.77
Wetland	5.66	6.13	14.44	2.27	41.86	3.61	73.96
Bare land	1.16	1.50	0.28	1.25	1.10	4.93	10.22
Sum_1994	206.25	321.76	742.07	149.94	54.13	17.04	1,491.18

The rows and columns contain data from 1989 and 1994, respectively

ESV changes in the NWDA

Total ESV for each land use type from 1989 to 2009

The ESV for each land use type was calculated using the value coefficients (Table 2) and the area covered by each land use type (Fig. 2). Table 8 shows that approximately the total ESV in the NWDA decreased by 14.65 % over the study period. This can be explained with sharp decreases in cropland and wetland. Actually, the tiny growth of ESV in other land use type could not offset the decreases.

As can be seen, forest with a high value coefficient type (Table 2) covers the largest area in the NWDA (Fig. 2). Therefore, the ESV of forest is the highest of the six land use types, accounting for 54.18 %, 56.42 %, 60.91 %, 63.52 %, and 64.08 % of the annual total value (1989–2009), respectively. Water also generates higher service value owing to its higher value coefficient; the combined ESV for forest and water accounted for over 75 % of the total ESV over the study period. Although the value coefficient of wetland is higher, it covers a small area relatively in the NWDA. Cropland value is just the opposite, and therefore the calculated value for cropland is low. However, both wetland and cropland cannot be ignored due to their unique ecosystem service function. For bare land and built-up land, it is apparent that their ESVs are much lower due to their lower value coefficients.

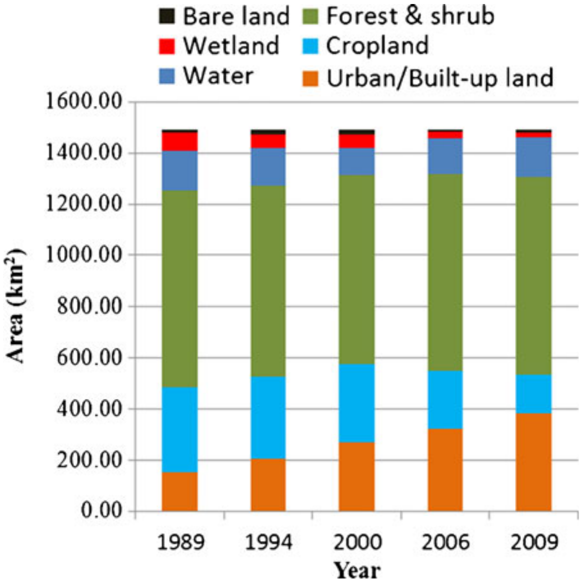

Fig. 2 Land use/cover changes in the NWDA from 1989 to 2009

Value of ecosystem service functions from 1989 to 2009

The total value of ecosystem service functions during the study period was also calculated based on Table 2 and the land use type (Fig. 2). It is observed that biodiversity protection contribute most to the overall ESV, followed by water supply. This is likely a result of the function of forest—the largest land use—to protect biodiversity. The values of individual ecosystem functions (ESV_f) are shown in Table 9. In general, the changes in the contribution of each ecosystem function type to the total ESV are small.

Spatiotemporal variation of ESV from 1989 to 2009

Based on distribution maps of ESV from 1989 to 2009, the spatiotemporally varying images in the NWDA were generated by spatial analysis and map calculator tools in ArcGIS 10.0® software (Fig. 3).

Obviously, the ESV changed dramatically in the past 20 years. Benefited from the protection of forest and cropland, ESV in most regions increased from 1989 to 1994. Correspondingly, the decrease occurred in only a small portion of the upper region along the Minjiang River. From 1994 to 2000, the Minjiang River limited spatial expansion of the city proper. Therefore, the decrease of ESV mostly happened in the built-up areas in the NWDA. Besides, a downward trend of ESV spread to the estuary. During 2000 and 2006, the development of the region was greatly affected by typhoons and tidal effect, thus local authorities and communities began to pay more attention on the afforestation along the Minjiang River. As a result, this led to a temporary increase of ESV. Ultimately, areas with decreasing ESV were limited in the NWDA due to slowdown of land development. In 2006, with the warming relationship between mainland China and Taiwan province, the state council of China had issued a series of policies which support the great-leap-forward development of the economic zone. This resulted in the establishment of intensive industrial parks, settlements, college parks, commercial facilities, and expressway systems linking the city proper, suburban, and rural areas. As a result, the local economy experienced a rapid growth period, leading to the sharp decrease in ESV in most areas. In general, the characteristics of spatiotemporal changes in ESV were very obvious from 1989 to 2009, with the increased value surrounding the built-up land and decreased value along the main stream of the Minjiang River. This indicated the ongoing trend of agricultural land loss, which was witnessed with rapid urban expansion. In addition, the riparian wetland ecosystem had become dysfunctional due to the construction of expressway and bridge linking the north and south.

Economic growth pattern and its effect on ESV in the NWDA

The ESV (1989–2009) shown in Table 8 was converted into US dollars (current exchange rate is about 6.83). Then, making regional total GDP as independent variable, and total ESV of cropland and wetland as dependent variable, linear regression analysis was carried out and a scatter diagram was also made (Fig. 4).

The achievement in local economic development can be evaluated with the total gross domestic product (GDP). Over this study period, regional total GDP

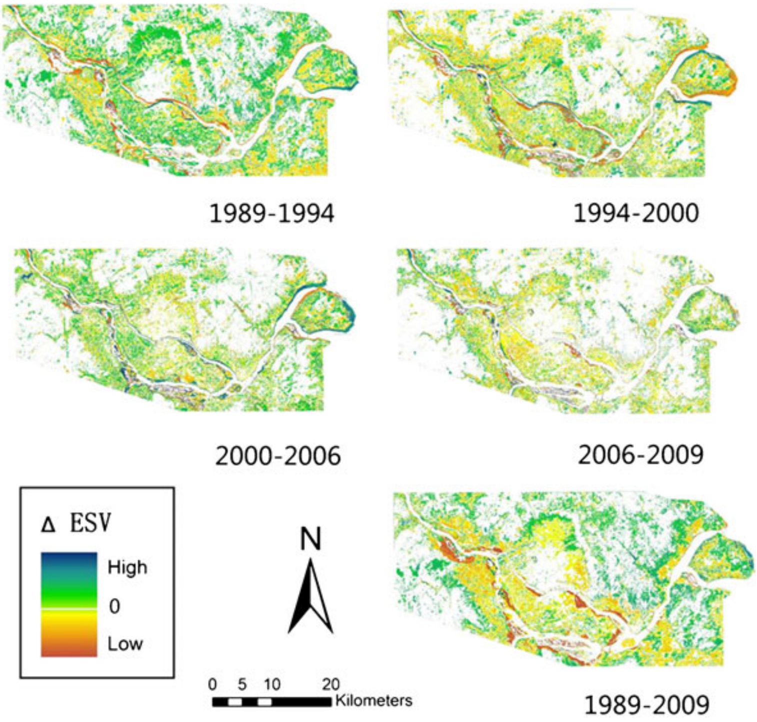

Fig. 3 The spatiotemporal variation of ESV across different stages in the NWDA

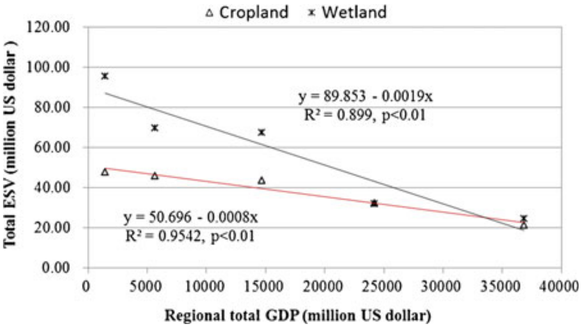

Fig. 4 Correlation graph between ESV of land use type and GDP. Note: in this table, both GDP and total ESV measured in RMB Yuan were converted to US dollars

increased by 24.6 times, from 9,820.0 million RMB Yuan (equivalent to $1,437.8 million US dollars) in 1989 to 251,692.7 million RMB Yuan (equivalent to $36,851.1 million US dollars) in 2009, with an annual average growth rate of 5.67 %. Obviously, economic growth boosted the process of urban construction with a large demand for land resources, which demonstrated that increasing economic activities and economic output led to increasing land use for urban growth. Therefore, as shown in Fig. 2, the areas of wetland and cropland were reduced. Thus, linear correlation analysis showed that there was a significant negative correlation between ESV of cropland and wetland and the GDP, that is, when GDP became larger, the total ESV became smaller. It is noted that the ESV of wetland was much higher than that of cropland in 1989. However, ESV of wetland decreased remarkably and got near that of cropland since 2006 due to faster decline in wetland.

Discussion

There were both advantages and disadvantages when applying ESV methods worldwide. The method we chose to estimate ESV was modified by Xie et al. (2003) and derives ESV by multiplying the area of a given land use type by the corresponding ecosystem value coefficient (Liu et al. 2012). However, the generated results have high variation, high uncertainty, and low resolution due to the complex, dynamic, and nonlinear properties of ecosystems (Limburg et al. 2002; Turner et al. 2003). In addition, there are limitations on the economic valuation of land use types (Costanza et al. 1997b) and problems including double-counting and scales (Konarska et al. 2002; Turner et al. 2003; Hein et al. 2006).

Considering ecosystem heterogeneity, the accuracy of the modified value coefficients is doubtful. For example, the built-up land might have negative effects on the ecosystem for the emission of pollutants. However, the value coefficient of built-up land is set null. Therefore, multiplying the area of land use type by the ecosystem value coefficient would generate only rough estimates of ESV with a potential high level of uncertainty. Moreover, the biomes used as proxies are not perfect matches with land use types in every case (Kreuter et al. 2001), and land use is used as a proxy measure of ecosystem services (Liu et al. 2012).

In fact, the estimation of ESV based on land use data has been used successfully in many case studies (Yoshida et al. 2010; Li et al. 2010a, b). Other methods such as indirect market evaluation were also used to calculate value coefficients. Although different valuation methods may lead to different estimated values, entangling more accurate coefficients are becoming less critical for time series analyses than for cross-sectional analyses because these coefficients tend to affect estimates of directional change less than they affect estimates of the magnitude of ecosystem values at specific points in time (Li et al. 2010a, b). Furthermore, the case study focused on the spatiotemporal variation of ESV in the NWDA over time, so the results are credible, particularly in qualitative terms. Meanwhile, the sensitivity analysis was carried out by Liu et al. (2012), which demonstrated that the results were robust despite uncertainties in the value coefficients. By calculating the ESV from 1989 to 2009 and analyzing changes across this time period, uncertainties and errors would be reduced or offset.

The powerful functions developed for spatial visualization and analysis of ecosystem services make GIS widely available and easy-to-use tools as implied by studies involved in evaluating and mapping ecosystem services (Lant et al. 2005; Egoh et al. 2008). Based on the analysis supported by GIS and RS technology, the patterns of spatiotemporal changes in ESV were very obvious from 1989 to 2009, with the increased value surrounding the built-up land and decreased value along the main stream of the Minjiang River (Fig. 3).

Over the past three decades, rapid economic development in China greatly improved the people's living standards. On macro level, it is widely accepted that the objective of a state political system must serve the economic development during China’s recent transition from a planned economy to a market-oriented economy. Owing to the "1992 Consensus within the framework of one-China" released by Chinese mainland's Association for Relations Across the Taiwan Strait and Taiwan's Straits Exchange Foundation in Hong Kong in 1992, the dream for business across the straits has come true. Since 2006, both the mainland and Taiwan called for a closer Cross-Strait economic cooperation, and economic cooperation across Taiwan Strait gained momentum. Therefore, Fuzhou benefited greatly from the political favorites, witnessed with prosperous investments from Taiwan province. Thereafter, the state council of China had released a series of policies to support the development of the economic zones around the city proper and along the Minjiang River. Undoubtedly, the Minjiang River is a lifeline in the NWDA and also the lifeblood of local economy. In order to protect the river, to conserve soil and water, a series of countermeasures have been adopted by local residents. At the same time, unreasonable human activities may also lead to unreasonable land use/land cover changes near the river line. Therefore, the sharp decrease in ESV in these areas occurred over 1989 to 2009. Admittedly, the government has a consciousness of environmental protection; however, the space in built-up area is limited and afforestation had to take place surrounding the built-up areas. Thus, in the long term, much attention should be paid for the protection of built-up areas of the NWDA, especially on the wetland and cropland. The key areas can be recognized more simply in the combination of GIS and RS technology, then the BMP would be adopted immediately to protect those areas for sustainable development. Besides, it is noteworthy that coordination between the administrative agencies should be strengthened to balance for sustainable development.

Conclusion

Taking the NWDA in Fuzhou as an example, this study profiled and highlighted the relationship between the ecosystem service value and its spatiotemporal variation for land use changes and socio-economic factors of Fuzhou, southeastern China from 1989 to 2009. A method combining GIS and RS was proposed in ESV calculation. Besides land use transformation matrix, the relationships between ESV of different land use types and GDP growth were also explored in this methodology to make further analysis in both time and space scales. The findings of the case study can be summarized as follows:

1. The ESV changed dramatically in the past 20 years with the significant changes in land use types. The total ESV for the NWDA in Fuzhou city decreased from $4,332.16\times10^6$ Yuan in 1989 to $3,697.42\times10^6$ Yuan in 2009, mainly due to the decreases in cropland and wetland. Forest produced the largest proportion of the total ESV (about 60 %), and combined water and wetland accounted for over 90 % of the total ESV, indicating that the three land use types play major roles in providing ecosystem services.
2. The ecological function of biodiversity protection contributes most to the overall ESV, followed by water supply. Both of them account for about 50 % of the total. In general, the changes of proportion in the contribution of each ecosystem function to the total ESV are small.
3. The spatiotemporal characteristic of ESV changes has a close relationship with economic development in the NWDA from 1989 to 2009. As a whole, for the land use changes and socio-economic factors, the pattern of ESV is obvious, with the increased value surrounding the built-up areas and decreased value along the river bank. Thus, the BMP must be adopted immediately to protect those decreased areas for sustainable development.
4. We found a significant negative correlation between ESV of cropland and wetland and the GDP. The ESV of wetland with higher value in 1989 declined faster than that of cropland, thus two numerical values reached similar in 2006. Furthermore, because of the scarcity of land resource and unique ecosystem functions, the emergency of wetland and cropland protection in built-up areas has become more and more critical to the local government.
5. On macro level, changes in ESV are closely correlated with the policies. A series of policies released from the state council of China support the development of the economic zones around the city proper, leading to changes of the total GDP and land use pattern in the NWDA.

Therefore, economic development played key roles in affecting spatiotemporal changes of ESV through land use changes. The Minjiang River as a lifeline in the NWDA is also the lifeblood of the economy. For the NWDA in Fuzhou city, sustainable development is critical due to its fragile ecological environment and unique geographical position. A compromise between economic development and ecological protection must be reached. It is suggested that a reasonable land use planning should be made, with emphasis on controlling construction land encroachment (industrial, commercial, and residential) on wetland and cropland. Furthermore, coordination among the administrative agencies should be urgently strengthened to balance the conflicts between urban development and ecological conservation.

On the other hand, with the help of RS and GIS, land use type can be a proxy for ecosystem services by matching the land use types to equivalent biomes, thereafter facilitating the ecosystem services valuation in long time series for large areas. Future research should focus on methods which can calculate ecosystem value coefficients more accurately for the reliability of the resulting estimates. However, for time-series analysis such as we made above, useful results become possible in spite of relatively imprecise coefficients.

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Appendices

Table 4 Land use transformation matrix in 1994–2000 (unit km^2)

Class	Built-up land	Cropland	Forest and shrub	Water	Wetland	Bare land	Sum_1994
Built-up land	98.62	52.73	42.05	5.20	5.29	2.36	206.25
Cropland	86.31	139.87	73.97	8.31	7.95	5.34	321.76
Forest and shrub	51.41	89.57	590.40	2.39	4.02	4.28	742.07
Water	22.79	17.26	12.58	81.44	12.05	3.83	149.94
Wetland	8.85	4.05	11.17	6.76	21.61	1.69	54.13
Bare land	2.45	3.40	5.35	2.61	1.27	1.93	17.01
Sum_2000	270.42	306.88	735.52	106.71	52.20	19.43	1,491.16

The rows and columns contain data from 1994 and 2000, respectively

Table 5 Land use transformation matrix in 2000–2006 (unit km^2)

Class	Built-up land	Cropland	Forest and shrub	Water	Wetland	Bare land	Sum_2000
Built-up land	149.29	54.34	42.02	20.09	3.99	0.69	270.42
Cropland	93.72	91.91	114.05	5.08	1.01	1.11	306.88
Forest and shrub	56.76	60.96	601.83	15.51	0.40	0.06	735.52
Water	6.90	7.34	2.48	85.06	2.25	2.68	106.71
Wetland	11.27	6.91	4.72	12.89	16.00	0.41	52.20
Bare land	4.14	5.21	3.60	3.02	1.22	2.25	19.44
Sum_2006	322.08	226.67	768.70	141.65	24.87	7.21	1,491.18

The rows and columns contain data from 2000 and 2006, respectively

Table 6 Land use transformation matrix in 2006–2009 (unit km^2)

Class	Built-up land	Cropland	Forest and shrub	Water	Wetland	Bare land	Sum_2006
Built-up land	214.23	43.77	48.30	10.80	2.52	2.47	322.08
Cropland	85.11	62.22	75.20	3.32	0.03	0.79	226.67
Forest and shrub	66.75	37.71	646.04	12.45	1.63	4.12	768.70
Water	10.67	4.76	1.53	122.92	1.50	0.27	141.65
Wetland	4.39	0.97	0.60	5.34	13.11	0.46	24.87
Bare land	2.61	0.52	0.14	1.95	0.33	1.66	7.21
Sum_2009	383.76	149.94	771.81	156.78	19.12	9.77	1,491.18

The rows and columns contain data from 2006 and 2009, respectively

Table 7 Land use transformation matrix in 1989–2009 (unit km^2)

Class	Built-up land	Cropland	Forest and shrub	Water	Wetland	Bare land	Sum_1989
Built-up land	137.19	2.87	8.63	0.82	0.22	1.43	151.16
Cropland	113.11	30.80	180.70	8.47	0.03	2.33	335.43
Forest and shrub	98.95	85.24	574.57	3.50	0.00	2.38	764.64
Water	14.31	5.33	1.66	130.15	2.97	1.34	155.77
Wetland	17.68	24.91	4.63	9.76	15.60	1.39	73.96
Bare land	2.53	0.79	1.62	4.08	0.30	0.91	10.22
Sum_2009	383.76	149.94	771.81	156.78	19.12	9.77	1,491.18

The rows and columns contain data from 1989 and 2009, respectively

Table 8 Total ESV for each land use type in the NWDA, Fuzhou city from 1989 to 2009

Land use type	ESV ($\times 10^6$ Yuan year^{-1})					Change (1989–2009)[a]	
	1989	1994	2000	2006	2009	$\times 10^6$ Yuan	%
Cropland	325.65	312.38	297.93	220.06	145.57	−180.08	−55.30
Forest and shrub	2,347.34	2,278.05	2,257.94	2,359.80	2,369.35	22.01	0.94
Water	1,006.94	969.25	689.80	915.66	1,013.47	6.53	0.65
Wetland	651.63	476.92	459.91	219.12	168.46	−483.17	−74.15
Bare land	0.60	1.00	1.15	0.43	0.58	−0.03	−4.60
Urban/built-up land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4,332.16	4,037.60	3,706.73	3,715.07	3,697.42	−634.74	−14.65

[a] Positive and negative values represent increases and decreases, respectively

Table 9 Value of ecosystem service functions (ESV_f) in the NWDA, Fuzhou city (unit $\times 10^6$ RMB Yuan year^{-1})

	1989		1994		2000		2006		2009	
	ESV_f	%	ESV_f	%	ESV_f	%	ESV_f	%	ESV_f	%
Gas regulation	418.27	9.66	401.20	9.94	396.44	10.70	400.21	10.77	394.90	10.68
Climate regulation	519.76	12.00	461.47	11.43	449.69	12.13	388.85	10.47	367.60	9.94
Water supply	938.03	21.65	862.67	21.37	846.14	22.83	789.06	21.24	762.49	20.62
Soil formation and protection	505.80	11.68	485.87	12.03	478.71	12.91	473.89	12.76	458.50	12.40
Waste treatment	805.26	18.59	732.41	18.14	612.30	16.52	619.45	16.67	626.35	16.94
Biodiversity protection	1,311.05	30.26	1,218.28	30.17	1,091.02	29.43	1,093.34	29.43	1,084.85	29.34
Food production	63.19	1.46	60.04	1.49	57.18	1.54	45.69	1.23	34.93	0.94
Raw material	284.98	6.58	276.34	6.84	273.65	7.38	284.43	7.66	284.45	7.69
Recreation and culture	348.17	8.04	336.38	8.33	330.83	8.93	330.12	8.89	319.38	8.64
Total	4,332.16	100.00	4,037.60	100.00	3,706.73	100.00	3,715.07	100.00	3,697.42	100.00

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