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Environmental deterioration in rapid urbanisation: evidence from assessment of ecosystem service value in Wujiang, Suzhou

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Abstract
Land use change is the most prominent feature of Chinese urbanisation. In China, the expansion of land consumed for urban development is inevitable given the rapid increases in the urban economy and urban population, but also in meeting the population's increasing demand for better quality of life. This paper is based on a research study of Wujiang district in Suzhou, which is considered representative of many of the rapid urbanisation areas within the nation. The objective is to develop an in-depth understanding of the characteristics of land use change and how this change contributes to environmental deterioration, as assessed by changes in the ecosystem service value (ESV). In this study, ESV is defined as the environmental products and functions provided for human well-being. Based on local planning documents, Landsat TM remote-sensing images and field surveys, the research analyses the cost to the environment when traditional land uses are transformed into urbanisation. The research demonstrates that conversion to urban land use which ignores the limit and capacity of the environment can generate significant environmental costs, as assessed by ESV, which in turn, can lead to a deterioration of quality of life for inhabitants, the exact opposite of the original intention. The research demonstrates that by mapping the spatial distribution of ecological service values, ESV can be used as a guide to urban sustainable development.

Keywords Land use change · Ecological environment · Ecosystem service value · Sustainability · Urbanisation

1 Introduction

Urbanisation requires land. Too often this means that urban development takes place on land that was previously ecologically protected land (such as agricultural land, forest and wetlands). Such transformations have a major impact on the ecological environment, and in turn, on the benefits that the population receives from such lands, known as the ecosystem service system, and acts as a constraint on achieving sustainable development.

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Ecosystem services are of importance to humans as they bring benefits to people, including goods and services (Burkhard et al. 2010). These benefits can be divided into four categories: supply services, regulatory services, cultural services and support services. The assessment of ecosystem services has become a popular and useful method of measuring such benefits and identifying and analysing the degree of interdependence between human activities and the impacts on nature (Jørgensen 2010). It matters not only how much it produced but also when and where, as its economic value varies across space and time. Following the argument of de Groot et al. (2010), the main challenge in achieving sustainability is how to decide on the optimal allocation and management of different land use options. It is important to document their value to ensure an urbanisation that reflects people's preferences and the services they provide and, as a result, there have been an increasing number of quantitative estimations of ecosystem services. Nevertheless, research in this field is still constrained by the poor quality of data. As a result, most research in the field focuses on the quantitative evaluation of such services rather than on their spatial distribution.

China's rapid urbanisation has been achieved through the expansion of urban land uses. This approach to urbanisation has resulted in extensive environment deterioration (Yuan et al. 2018). Consequently, ecosystem services have been adversely affected (Li et al. 2016). Therefore, this research on the impacts on the environment in the areas with rapid urbanisation is significant. It illustrates the challenges and risks of environmental deterioration in the Chinese context.

The objective of this paper is to develop a better understanding of the potential risks resulting from land use changes caused by urban expansion. The paper also strives to pinpoint the primary factors that lead to his risk. The research is based on-both quantitative and qualitative approaches, critically and comprehensively exploring the relationship between land use change, ecosystem services and human well-being. Through the analysis, this paper identifies the deficiencies and limitations of current research methods and strategies. Based on the evaluation and mapping of ESV, land use change is simulated to effectively minimise its aggregate impacts, aiming at guiding reasonable and scientific land use planning, covering expansion of urban development land as well as the preservation of ecological protection areas in the inevitable urbanisation process (Keller et al. 2015).

This paper is divided into six parts. Section 2 reviews the literature on the debates concerning ecosystem services and sustainability. Section 3 discusses the application of ecosystem services in this research project. Section 4 develops data on ecosystem services of various land uses, while Sect. 5 presents the results of the analysis of these data. Section 6 concludes with assessment of these findings in terms of environmental damage resulting from urbanisation. It argues that natural resource limitations must be incorporated into the urban policy-making process and that this can be done by use of ESV.

2 Reviews on debates in ecosystem services and sustainability

2.1 Sustainable development

A report by the World Commission on Environment and Development (Brundtland 1987) defined sustainable development as meeting the present generation's demands without compromising the needs of future generations. This definition is still widely used and quoted. However, for some scholars, it is not beyond criticism (Daly 1995). For instance,

as it is broadly accepted that it is made up of three main pillars, including environmental, economic and social sustainability, yet there are no specifications to them in the report. Nor are there definite limits for each part, especially explicit quantification limits of environmental and social sustainable development which are essential if sustainability goals are to be achieved (Attfield and Wilkins 1992). Moreover, the report fails to provide guidance for what must be preserved for the future generations when it comes to the criteria of 'need', partly because of its subjectivity and partly due to the absence of quantification of need in different periods and circumstances (Beckerman 2007).

To deal with these issues, as people's needs are subjective and difficult to quantify, it is useful to carry out research on the capacity of the 'environment' to provide, and on how much it can preserve as well as on the approach to maximise efficiency of resources for later generations (Esteva 2009). Research into baselines and limits of 'environment sustainability' as a means of valuing its capabilities has to be specified and prioritised (The Club of Rome 1981).

The debates on 'sustainable development' can be viewed as seeking a blending of concerns with respect to the economy, society and the environment, and the priorities that can result in sustainability. Sustainable development, which highlights natural capital, developing within the capability of supporting ecosystems, and valuing the quality of nature continuously, has to be run under the 'core spirit' of strong sustainability (Beckerman 1994) while taking all those three components into consideration. Besides, interpretation of sustainable development needs to be constantly enriched and improved as uncertainties and disagreements can always be expected to lead to further studies.

2.2 Ecosystem services and its approaches to use

The ecosystem contributes to human welfare by supplying goods, controlling energy flows and providing opportunities of cultural experiences (Costanza et al. 1997). However, it faces great challenges, including the imbalance between socially driven economic growth and naturally limited availability of resources; impropriate use of resources because usage limits are known by the few; and resources that are seldom used in a sustainable manner. In this world, the majority of people fail to realise the relationship between the human being and nature and the dependency on ecosystems, adding to the difficulties in pushing forward sustainable ecosystem development. It was not until Millennium Ecosystem Assessment that people began to realise the degradation of ecosystem services and no longer took nature's benefits for granted. Since the introduction of the concept of ecosystem services and later development in the academic literature, it has experienced a growing popularity among scholars worldwide (Fisher et al. 2011; Haase et al. 2014).

According to Petter et al. (2013), the application of ecosystem services, e.g. its quantification and mapping, is critical and necessary as it provides evidence for identifying areas with the ability of providing a higher value of service which must be protected or managed and of providing specific ecosystem functions or service. The outcomes of ecosystem service assessment can be used to deal with environmental issues and guide decision-making (Burkhard et al. 2012).

The quantification of ecosystem services helps estimate how much of a service is produced, which is regarded as the ecosystem service value (ESV). Mapping helps in understanding how the service value changes and where it is produced, which comprises the spatial distribution of ecosystem services (Swetnam et al. 2011; Troy and Wilson 2006). However, ecological service integration has been reported as poor and limited in general

decision-making, specifically in spatial planning (Geneletti 2011) and development planning which leads to the inability to provide consistent description, quantification and mapping of ecosystem services (Bagstad et al. 2013).

2.2.1 Quantifying ecosystem services

Although much debate surrounds the defining of services and their evaluation (Costanza et al. 2008; Fisher, Turner and Morling 2009), there is one accepted point-of-view: 'ecosystem service production and flow is spatially explicit and temporally dependent'.

Valuation of ecosystem services could be used to address the trade-offs in land use decisions by putting costs and benefits on the same monetary scale (Harrison-Atlas et al. 2016). Ecosystem services are increasingly becoming popular as a tool for integrating both ecological and social value in ecological restoration. However, there are still some issues that hinder the adoption of the ecosystem services approach in ecological restoration, including the disparity in the spatial scale of data available to assess ecosystem services and difficulties in integrating the assessment of multiple ecosystem services and uncertainties about the spatial management (Song 2018). Studies tackling these issues have usually focused on a limited number of services (Allan et al. 2015; Chan et al. 2006). Although the assessment of ecological services has already been utilised to guide land management (Geneletti 2011), there is still a lack of an integrated approach to valuing ecological services comprehensively, which is essential for effective land management (Comín et al. 2018).

There has recently been a growing use by decision-makers to adopt ESV as a guide to reasonable spatial planning for land use, and researchers are attempting to make the valuation of ESV more objective, truly reflecting the impacts on human welfare due to ecological changes (Martín-López et al. 2014). Acting as a bridge between the social and ecological systems, ESV can not only measure the ecological influence on human beings and social value but also predict uncertainties and possible outcomes of decisions upon planning, and generate a more effective communication with the public (Mol et al. 2014). Although many researchers focus on the assessment of ESV, only a few have effectively influenced land use changes in development since there is a gap between scientific research and practical application. Moreover, there are still some limitations in the methods of measurement process.

2.2.2 Mapping ecosystem services

Recently, mapping ecosystem services has focussed on developing methodologies to better capture dynamic changes in space (Bagstad et al. 2013; Palomo et al. 2013) so that characteristics of changes can be understood, and potential values can be identified and incorporated into the decision-making process. Mapping techniques can also provide a powerful support for communication and decision-making as they facilitate the integration of complex, interdisciplinary information related to ecosystem services into landscape management and environmental decision-making (Daily and Matson 2008 Swetnam et al. 2011). Mapping and modelling practices have been used to analyse the spatial distribution of multiple ecosystem service at local (Naidoo and Ricketts 2006; Nelson et al. 2009), regional (Chan et al. 2006) and global (Fisher et al. 2011) spatial scales. It is critical to grasp the dynamics of ecosystem service values in development since ecosystem services have characteristics of spatial heterogeneity (de Groot et al. 2010). However, currently, few mapping

approaches have considered the problem of spatial heterogeneity and then been applied to spatial planning and policy making.

Early efforts to map ecosystem services via modelling (Chan et al. 2006) or spatially explicit value transfer (Troy and Wilson 2006) paid little attention to ecosystem service flow, which refers to the transmission of a service from ecosystems to people. Although dynamic changes have been noticed, more emphasis is still put on depicting ecosystem services as site-bound on static maps (Bagstad et al. 2013) instead of considering the importance of a dynamic transformation process. The ignorance and lack of research in dynamic analysis may reduce the value and efficiency of application in spatial planning as it lacks the capability to deal with changes and to predict the future (Bagstad et al. 2013). However, only a few scholars seem to have noticed this and therefore focus on dynamic analysis.

3 Methods and material: application of ecosystem services in the research

3.1 Process of this research

The objectives of this study were to study the relationship between changes of land use and ecosystem services, and to analyse the implications of scientific and reasonable guidance for land use changes to enhance ecological environment development and achieve sustainable development goals. In order to achieve these objectives, a deductive reasoning process was devised, starting by clarifying and formulating a research hypothesis along with specific research questions which would establish the relationship between land use changes and ESV, based on the relevant literature. Various questions were considered in preparing for this research, such as how the ecosystem services are defined, and what challenges and difficulties the ecosystem services are faced with in studying ecological environment? How the ecosystem services are characterised, measured, and applied in current studies? Why and how the ecosystem services are evaluated and applied? What are the merits and limitations of quantifying and mapping ecosystem services?

To pursue these points, Wujiang district in Suzhou Province was selected as a case study area. This case study area was selected as it seemed typical of Chinese areas which have been subject to rapid urbanisation. The important characteristics of the area were its background and current condition, the rapid urbanisation it has experienced in recent years, the continuous and dramatic land use changes that have resulted because of this urbanisation, and their impacts upon local ecosystems, the ecological environment and sustainability. Wujiang was seen as an excellent case study area for the examination of the balancing of the contradictory demands for environment protection and economic growth (Liang et al. 2018).

3.2 Data on land use changes

Land use change is seen as a primary factor leading to changes in ecosystem services. Therefore, the collection of land use data is essential for ESV analysis. The land use data used in this research was mainly extracted from the *Wujiang Comprehensive Plan (2006–2020)*, the *Wujiang Yearbooks (2005–2015)*, the *Wujiang General Land Use Plan (2006–2020)* (WLRB 2010) and other relevant data and materials provided by the *Wujiang Land and Resources Bureau*, as well as a reconnaissance field research by the authors. The

data collected from the survey covered the years from 2004 to 2016, from which data from 2004, 2008, 2012, 2016 were selected to develop for further analysis. This included Landsat TM remote-sensing images of Wujiang district in the research years.

The measures of processing the land use data included multiband data combination, geometric rectification, remote-sensing image mosaic and clipping and remote-sensing image enhancement.

In order to determine the characteristics and tendencies in land use changes, especially those that resulted in changes in ecosystem services, several indices were selected to provide evidence of the contributing factors. For example, a land use transfer matrix was applied to view the changes in land use. As a result, characteristics of land use change in Wujiang district could be quantitatively analysed and qualitatively evaluated.

3.3 An approach to ecosystem services

In this research, an ecosystem service approach was adopted, which involved quantifying and mapping of the services. Based on Chinese evaluation indices and parameters of ecosystem service values, correction and adjustment were necessary to improve the accuracy of the evaluation with respect to the agricultural land output and economic development status in Wujiang district (Crouzat et al. 2015). Processing collected data in the field of ecosystem services mainly focuses on establishing a Wujiang district value equivalent factor table and calculating its value of each service as well as each type of land use.

Based on the processing of the raw data, the changes in the ecosystem service can be analysed temporally and spatially by quantitative analysis and the mapping of statistics. For example, an index is utilised to identify dynamic changes and to capture their features and the significance of different services, providing valuable information for future protection and development. Also, models are adopted to simulate the spatial distribution of the ecosystem service by mapping ESV. For instance, a minimum cost accumulative model (MCRM) is applied to identify unreasonable factors of current land use changes and predict reasonable spatial planning for urban development land expansion and ecological land protection.

Following the classification and initial processing of the data, it was possible to transfer the raw data into purposeful and usable categories. Then, various statistical measures could be applied to reveal the specific relationships between variables and test various hypotheses. In this manner, interpretations and generalisations were generated.

4 Analysis of ecosystem service values in Wujiang

Wujiang district has, as a result of recent rapid urbanisation, experienced significant socioeconomic development. This has led to serious challenges, such as a shortage of land resources, a gradual decline of ecological security, the loss of traditional regional characteristics and development pressure on historical and cultural interests. Land use change has had a negative impact on ecosystem services (Zhou et al. 2017), which not only influences sustainability, but also affects the health of the local population In this section, the current land use policies and management in Wujiang district and their impact on ecosystem service values are assessed.

4.1 Land use ESVs

4.1.1 Applying Chinese ESV equivalent values

The 'value equivalent factor of ecosystem services' refers to the potential capacity of the relative contributions of ecosystem services. It is defined with respect to the economic value of national average agricultural yield of 1 ha/year. This agricultural land ecosystem standard is defined by the value unity, and other land uses are defined in relative terms to it.

The principle of ESV and its method of calculation, as proposed by Costanza et al. (1997), were considered to be scientific at the time. More recently, this approach has been criticised as biased, primarily because of unreasonable estimates of ESV for agricultural land and wetlands. In a recent study of ecosystem services, Xie et al. (2017) clarified the division of ecosystem services and functions more specifically, proposing a comprehensive system services and establishing the 'Chinese ecosystem service equivalent value per unit area' matrix. This is based on a questionnaire survey with 200 ecologists nationwide. The matrix is considered to be scientific, applicable and authoritative. As a result, it is widely referred to in evaluating ESV by scholars. The values applied to the data in this research are given in Table 1.

According to Song (2018), among all ecosystems, natural ecosystems account for over 90% of total ESV, while urban ecosystem makes up less than 10%. It is also proposed by Xie et al. (2017) that because the urban ecosystem is such a minor contributor to ESV, the urban ecosystem is excluded from the matrix. An underlying objective of this study, and hopefully an important contribution, is to test the suitability of this dataset to an agricultural area that has been transformed by urbanisation.

4.1.2 ESV equivalent values in Wujiang district

The Chinese ecosystem service equivalent values from *Wujiang Yearbook (2010)* and other official documents were used to modify the statistics in the equivalent value table. Based on annual grain output, annual equivalent values were estimated.

According to the definition of ecosystem service equivalent values and adopting the modification method, Wujiang district ecosystem service equivalent value can be

Table 1 Chinese ecosystem service equivalent value per unit area. *Source*: Xie et al. (2017)

Service	Categorisation of service functions	Agricultural land	Forest	Wetland	Bare land
Provisioning service	Food production	2.21	1.01	1.31	0.01
	Material production	0.49	2.32	0.73	0.03
	Water resources	− 2.61	1.2	13.04	0.02
Regulating service	Gas regulation	1.78	7.63	2.85	0.13
	Climate control	0.93	22.83	6.43	0.1
	Purify environment	0.27	6.69	9.31	0.41
	Hydrology adjustment	2.99	14.94	133.6	0.24
Supporting service	Soil conservation	1.04	9.29	3.24	0.15
	Nutrients cycle maintenance	0.31	0.71	0.25	0.01
	Biodiversity	0.34	8.46	10.43	0.14
Cultural service	Aesthetic landscape	0.15	3.71	6.71	0.06

estimated. In 2010, national grain output was 546.4 million tons in total, while the national agricultural land area was 109.872 million hectares. In Wujiang district, the agricultural output value was 196 billion Yuan, grain total output was 158,923 tons, and cultivated area was 20,300 hectares. Following the formula '$\alpha = \frac{Q_w}{Q_R}$' α is 0.6353, P_α in the formula '$P_n = \alpha \times P_g \times P_\alpha$)' is 96.55 thousand yuan (in Chinese currency) and P_n can be estimated (as is shown in Table 2).

4.1.3 Urban development land, ecological protection land and ESV

It is crucial to define and classify urban development land and ecological protection land in the process of urbanisation as it is accompanied by an inevitable transformation and conflict between different types of land use which exert significant impacts on the ecological environment. To deal with environmental problems and promote sustainable development, ESV is applied to set up baselines and to provide evidence for the definition and classification of urban development and ecological protection land uses, which are significant in the planning process.

4.1.3.1 Urban development land As economic development is at the heart of city survival and various activities take place in the urban development area, urban expansion is seen as an inevitable trend in development. Such land generates little ESV (Song 2018) while contributing in a major way to urban economic growth. Urban development land largely relies on services provided by ecological protection land.

4.1.3.2 Ecological protection land Ecological protection land refers to the land use that provides the majority of ecosystem services and contributes significantly to ESV. It is highly sensitive to changes in ESV and forms the basis of the ecological environment. According to calculations of ESV for each land use in Table 2, agricultural land, forest and wetland with

Table 2 EVS values after adjustment for Wujiang, 2004–2016 (1000 yuan/ha). *Source*: Authors' calculations

Service	Categorisation of service functions	Agricultural land	Forest	Wetland	Bare land
Provisioning service	Food production	5.561	2.541	3.296	0.025
	Material production	1.233	5.838	1.837	0.075
	Water resources	− 6.568	3.020	32.813	0.050
Regulating service	Gas regulation	4.479	19.200	7.172	0.327
	Climate control	2.340	57.449	16.180	0.252
	Purify environment	0.679	16.834	23.427	1.032
	Hydrology adjustment	7.524	37.595	336.187	0.604
Supporting service	Soil conservation	2.617	23.377	8.153	0.377
	Nutrients cycle maintenance	0.780	1.787	0.629	0.025
	Biodiversity	0.856	21.288	26.246	0.352
Cultural service	Aesthetic landscape	0.377	9.336	16.884	0.151
Total		19.878	198.264	472.825	3.271

values of 19.878, 198.264 and 472.825 per hectare respectively, are regarded as ecological protection land.

Depending upon the clear definition and classification of urban development and ecological protection land uses, as well as an overall understanding of their characteristics and functions, the process of urban expansion can be critically analysed. Ecological protection land and urban development land must be viewed in an interdependent manner in order to understand how economic growth can be promoted through urbanisation without sacrificing the value and services of ecosystems in the quest to achieve sustainable development.

5 Outcomes of analysis and discussion

5.1 Urban expansion, an inevitable trend of urbanisation and people's increasing demand of living quality

Past research to identify the major factor generating urban development land (as defined) and urban expansion focuses primarily on economic growth (Deng et al. 2010), while the major consequence of such growth is economic structural change (Beauchemin and Schoumaker 2005).

According to the *Wujiang Comprehensive Plan (2005–2020)*, whereas the urbanisation level was 62.3% in 2005 and 70.4% in 2010, it is projected to rise to 81.3% in 2020. Rapid urbanisation stimulates continuous demands for and growth of urban land use. Between 2004 and 2008, agricultural land, forest, wetland and bare land declined generally, while the area of urban land increased from 182.33 km^2 in 2004 (14.7% of the total land area of the district) to 329.19 km^2 in 2008 (26.6% of the total). In terms of economic structure, as shown in Fig. 1, land for tertiary industry increased over the period while that for primary and secondary industries declined. The spatial impact of urbanisation is illustrated most clearly in Fig. 2, showing the increasing amount of urban development land in 2004, 2008, 2012 and 2016.

Chinese research has shown that improvement in the living quality of residents contributes significantly to urban land expansion in order to meet the demands of existing urban residents and the increasing number of migrants moving from countryside to
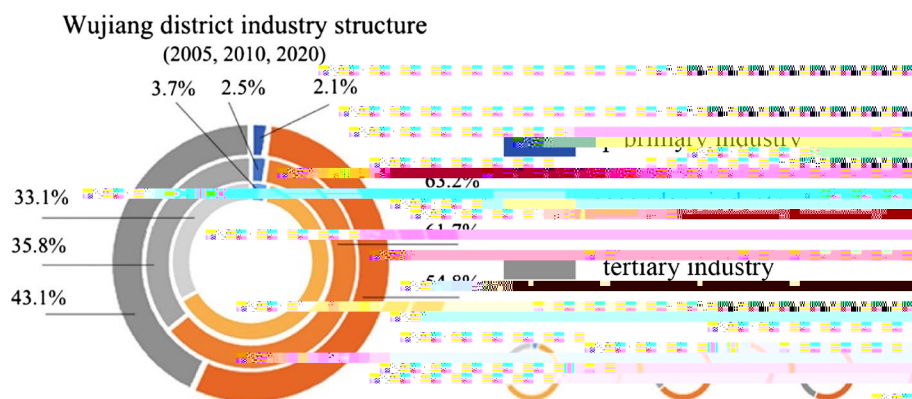

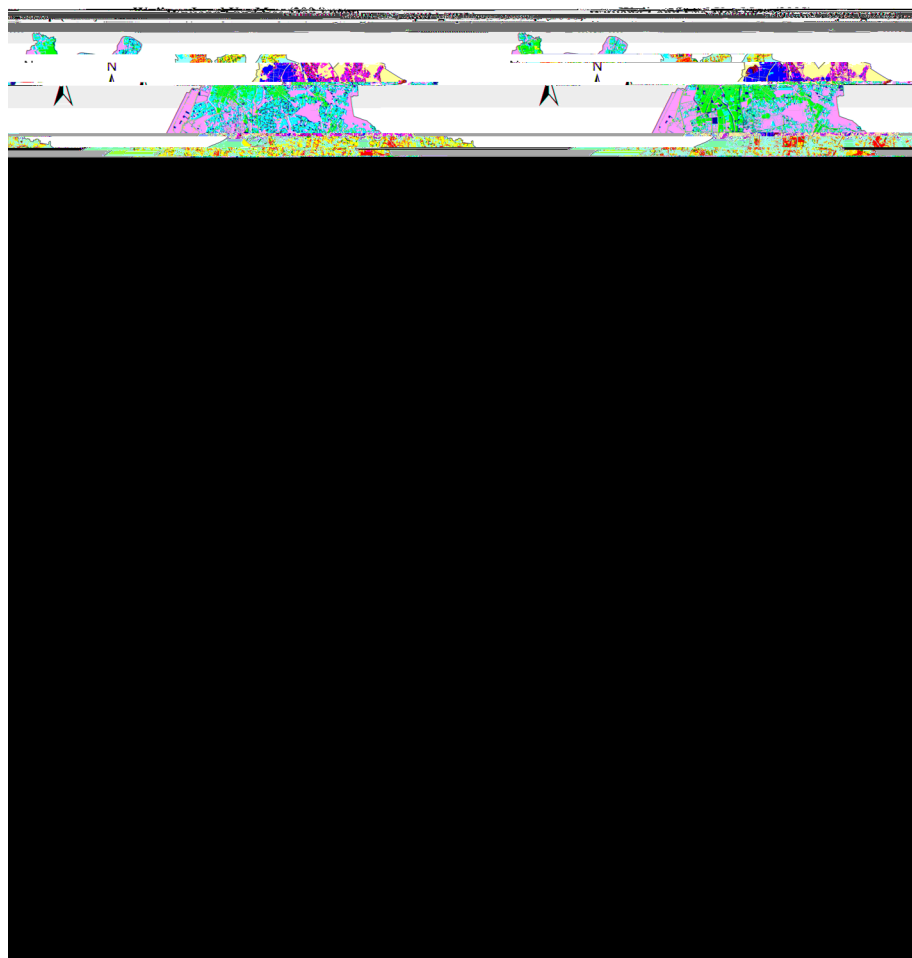Fig. 1 Wujiang economic structure. *Source*: Wujiang General Land Use Plan (2006–2020)

Fig. 2 Urban expansion of Wujiang from 2004 to 2016. *Source*: Produced by the authors

cities in the process of urbanisation by supplying land uses for housing, entertainment, public services and other activities (Chen et al. 2014; Luo et al. 2017).

Research carried out during the preparation of the Wujiang Comprehensive Plan revealed that urban residents tended to have higher disposable personal income than that of residents in rural areas. As a consequence, the consumption of urban residents in terms of recreation, housing, shopping and other demands are much higher than that in rural areas. Residents are seeking better living standards and quality of life. The demand for urban land uses increases as a result. However, as ecological resources are limited, urban land use expansion as a result of economic growth and demands from residents without control creates risks in ecological environment. In this sense, urban land development and preservation of the ecological environment are seen to be in conflict.

5.2 Decline of land with higher ESV due to urban expansion

Urban expansion will inevitably occupy other types of land use. In this research, the land use transfer matrix (LUTM) is applied to explore the transformation relationship between different land uses along with its features in Wujiang in order to provide evidence and guidance for further research in land use changes. The formulation of the LUTM is:

$$U_{ij} = \begin{matrix} U_{11} & U_{1n} \\ U_{n1} & U_{nn} \end{matrix} ,$$

in which, U is area, i and j, respectively, refer to initial and final type of land use, n is the number of land uses.

According to the data analysis and the outcome of the calculations associated with the LUTM, increased urban development land in 2012 is mainly by transfer from agricultural land in the previous period (2008), accounting for 5.9%, with lesser contributions from wetlands and forests, occupying 6.5% in total. Approximately, 70% of bare land is occupied by urban development. However, less than 1% of the land used for development has been transferred to other forms of land, in which, agricultural land comes the first, accounting for 0.802% (Table 3).

Table 3 Wujiang District LUTM (2008–2012). *Source*: Authors' calculations

(km^2)	Bare land	Agricultural land	Forest	Urban	Wetland	Total
2008 land use						
Bare land	0.30					0.30
Conversion rate	29.682%					
Contribution rate	100.000%					
2012 land use						
Agricultural land		249.40	0.37	2.64	12.54	264.95
Conversion rate		91.864%	0.291%	**0.802%**	2.465%	
Contribution rate		94.130%	0.140%	0.996%	4.734%	
Forest		0.003	117.61	0.000008	0.02	117.64
Conversion rate		0.001%	92.619%	0.000%	0.004%	
Contribution rate		0.003%	99.978%	0.000%	0.019%	
Urban	0.72	21.98	8.95	326.53	15.40	373.58
Conversion rate	70.318%	8.096%	7.050%	99.193%	3.026%	
Contribution rate	0.193%	5.884%	2.396%	87.406%	4.121%	
Wetland		0.10	0.05	0.02	480.91	481.08
Conversion rate		0.038%	0.040%	0.006%	94.505%	
Contribution rate		0.038%	0.011%	0.004%	99.964%	
Total	1.023	271.49	126.98	329.19	508.87	1237.55

Explanation: T represents transformation rate ($T = U_{ij}/T_i$) and indicates the degree of land transfer from type i land to type j, namely the proportion of area of transferred land and area of type i in the initial time of the research period. While C refers to contribution rate ($C = U_{ij}/T_j$) and suggests the contribution degree of type i land use to type j. It is the proportion of transferred area and the area of type j at the end of the research period. The change trend and internal characteristics can be clearly analysed from transfer rate and contribution rate, which provides a guidance for predication

From 2012 to 2016, increased urban development land in 2016 was mainly converted from wetlands (2.5%), followed by agricultural land (2.0%) (Table 4). There has been a tendency for urban development land to occupy wetlands rather than agricultural lands and forests because the quota allocation for agricultural land transformation is directly controlled by the central government and there is less emphasis on the protection of ecological land, e.g. wetlands. Protection of agricultural land for food safety has been regarded as a priority by the Chinese central government. However, the ecological land uses, such as wetlands, were treated as less important. The transformation trends and characteristics of land uses for urban development to others are consistent with the previous period (from 2008 to 2012). Compared with the circumstances from 2008 to 2012, the contribution rate of urban development land in the last period to the same type in the next period is increasing, while both the conversion rate and contribution rate of other land uses are decreasing, among which the most apparent change tendency takes place on, in order of importance, forests, agricultural lands and wetlands. This suggests that the expansion trend of urban development land is gradually slowing down.

5.3 Impacts on the ecological environment as a consequence of land use changes

5.3.1 Wujiang district ESV in the period between 2004 and 2016

In order to explore the changing ESV of Wujiang and to determine the impact on ecosystem service values, this research examines the land use data changes during each 5-year period between 2004 and 2016. The formulation of 'ESV $= \sum_{i=1}^{n} (VC_i \times A_i)$' is adopted to explore and identify the changing ESV of Wujiang in the process of rapid urbanisation and to understand and quantify the impact on environmental deterioration. In this formulation, VC_i is the unit area ecosystem service value with type i ecosystem, using the unit area ecosystem service value of Wujiang district ecosystem service equivalent value. A_i is the area of type i ecosystem in Wujiang district, and n refers to the number of the types of ecosystems. The estimates for ESVs in Wujiang district in 2004, 2008, 2012 and 2016 are given in Table 5. Estimates are given for four ecosystems: the agricultural land ecosystem, the forest ecosystem, the wetland ecosystem and the bare land ecosystem and for four services of each ecosystem: provisioning service, regulating service, supporting service and cultural service.

5.3.2 Decline of ecosystem service values in Wujiang district

This analysis provides evidence that ESV has declined as a result of urban development land supplanting other types of land use, especially ecological lands. Specific statistics of ESV in Table 5 show a continuous decreasing trend from 2004 to 2016. The total value declines from 274×10^8 Yuan to 250×10^8 Yuan. It can be seen that between 2004 and 2008, the effect of urbanisation was relatively slight, as measured in terms of ESV. This may be attributed to encroachment on agricultural land rather than forests and wetlands, given that agricultural land has a lower ESV. However, between 2008 and 2012, total ESV dropped sharply as urban areas in the district expanded rapidly, with development land taking a large area of (15.4 km^2) wetland, which experienced the highest ESV decline.

Between 2012 and 2016, the downward trend of ESV continued, although at a slower rate. During this period, nearly 95% of urban land came from the land use quota allocation to urban development land use in the previous period.

Table 4 Wujiang District LUTM (2012–2016). *Source*: Authors' calculations

(km²)	Bare land	Agricultural land	Forest	Urban	Wetland	Total
2012 land use						
Bare land	0.29					0.29
Conversion rate	95.097%					
Contribution rate	100.000%					
2016 land use						
Agricultural land		257.00	0.08	2.63	2.42	262.13
Conversion rate		96.998%	0.066%	0.703%	0.504%	
Contribution rate		98.044%	0.030%	1.002%	0.925%	
Forest		0.000075	114.84	0.00013		114.84
Conversion rate		0.000%	97.622%	0.000%		
Contribution rate		0.000%	100.000%	0.000%		
Urban	0.01	7.84	2.71	370.82	9.94	391.32
Conversion rate	4.903%	2.958%	2.303%	99.261%	2.066%	
Contribution rate	0.004%	2.003%	0.692%	94.761%	2.540%	
Wetland		0.11	0.01	0.13	468.71	468.97
Conversion rate		0.043%	0.009%	0.036%	99.945%	
Contribution rate		0.024%	0.002%	0.029%	99.945%	97.430%
Total	0.30	264.95	117.64	373.58	481.08	1237.55

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Table 5 Changing ESV of Wujiang District 2004–2016 (*10^8 Chinese Yuan). *Source*: Calculated and produced by the authors

Year	Agricultural land		Forest		Wetland		Bare land		Total value
	ESV	Per cent	ESV	Per cent	ESV	Per cent	ESV	Per cent	
2004	8.176	2.987	25.606	9.354	239.931	87.650	0.024	0.0088	273.737
2008	5.397	1.990	25.176	9.284	240.607	88.725	0.0033	0.0012	271.183
2012	5.267	2.057	23.324	9.109	227.467	88.834	0.00099	0.0004	256.059
2016	5.211	2.087	22.769	9.118	221.741	88.795	0.00095	0.0004	249.721

Although the 'Chinese ecosystem service equivalent value per unit area' matrix proposed by Xie et al. (2017) is able to reflect different values of various functions and is used for this research, it is based on assessment of static values. Through analysis of different ecosystem services and related functions in Wujiang district between the period of 2004 and 2016, it was found in this research that the values may be changed in real world. In the other words, the different functions may be of different importance in the process of environmental protection and/or restoration.

It is, then, necessary to consider the importance index '$\beta_i = \frac{V_i}{\overline{V}} (i = 1, 2, 3 \dots 11)$', in which, β_i refers to index of type i ecosystem service, where V_i is the average annual change rate of type i ecosystem service value over decades and $\overline{V}$ refers to average annual change rate of all ecosystem services within decades, the importance index of each ecosystem service is calculated and recorded in Table 6. In order to effectively evaluate and protect various ecosystem services and functions, the ecosystem service values in Wujiang have been optimised by analysing the dynamic changes of various services and functions depending upon their assignment.

Following '$ESV = \sum_{i=1}^{11} \sum_{k=1}^{n} \frac{\beta_i ESV_i}{A}$', in which, ESV is the total service value of the reconstructed ecosystem, ESV_i is the total static value of type i ecosystem service. A refers to the area of the study area, Wujiang district ESV equivalent value table is modified as is shown in Table 7.

Table 6 Importance index of each ecosystem service. Source: Authors' calculations

Service	Categorisation of service functions	Change rate (%)	Important Index
Provisioning service	Food production	− 23.150	1.916
	Material production	− 15.436	1.278
	Water resources	− 2.276	0.188
Regulating service	Gas regulation	− 15.332	1.269
	Climate control	− 10.819	0.895
	Purify environment	− 8.717	0.721
	Hydrology adjustment	− 8.176	0.677
Supporting service	Soil conservation	− 12.642	1.046
	Nutrients cycle maintenance	− 19.092	1.580
	Biodiversity	− 8.796	0.728
Cultural service	Aesthetic landscape	− 8.464	0.701
Average		− 12.082	

Table 7 Wujiang district ESV optimised equivalent value (*10^3 Chinese yuan/ha). *Source*: Authors' calculations

Service	Categorisation of service functions	Agricultural land	Forest	Wetland	Bare land
Provisioning service	Food production	10.66	4.87	6.32	0.05
	Material production	1.58	7.46	2.35	0.10
	Water resources	− 1.24	0.57	6.18	0.009
Regulating service	Gas regulation	5.68	24.37	9.10	0.42
	Climate control	2.10	51.44	14.49	0.23
	Purify environment	0.49	12.15	16.90	0.74
	Hydrology adjustment	5.09	25.44	227.49	0.41
Supporting service	Soil conservation	2.74	24.46	8.53	0.39
	Nutrients cycle maintenance	1.23	2.82	0.99	0.04
	Biodiversity	0.62	15.50	19.11	0.26
Cultural service	Aesthetic landscape	0.26	6.54	11.83	0.11
Total		29.21	175.62	323.29	2.74
Value		292	1756	3233	27

Based on the optimised equivalent values of ecosystem services, land use maps for 2004, 2008, 2012 and 2016 can be assigned a new value by using the reclassification tool in ARCGIS. In the reclassification, urban development land, bare land, agricultural land and wetland are assigned with a value of 1, 27, 292, 1756 and 3233 respectively per unit area.

Social demand is considered in this process. For instance, comparing the supply of ecosystem services with the actual demand as reflected in interviews and questionnaires, and combining the evaluation of both quantity and quality to guarantee the maintenance and sustainability of affected ecosystems and survival environment, provide a better understanding of the phenomena taking place (Syrbe and Grunewald 2017).

The Wujiang research illustrates the continuous declines of ESV that occur in the process of Chinese urbanisation. Ecosystem services and their functions are suffering from different degrees of decline and destruction which can be identified in this analysis. Ecological deterioration results posing a threat to the achievement of sustainable development.

The high rate of decline of wetlands in total ESV suggests that this type of land is playing an indispensable role in guaranteeing sustainable development of ecosystem services and their functions. The encroachment of urban development land on wetlands, particularly between 2008 and 2012, can be seen as a major threat to achieving sustainable ecological development. One must conclude that urban policy makers do not fully understand the importance of such wetlands. Wetlands are particularly vulnerable because of the concerns of food supply and safety and strict control of agricultural land protection. In the end, the challenge of Chinese urbanisation remains and the quality of life for local residents cannot be stopped. The rising demands for urban land will inevitably increase. The only solution under such circumstances must be compact/high density urban development and/or decentralised compact development (Yu 2007). China does, after all, have the largest population in the world and nearly half of this population is still in rural areas. As a result, it is inevitable that urbanisation will continue.

6 Conclusion

The Chinese environmental has suffered significantly in the process of rapid urbanisation. This paper has attempted to identify and quantify this impact on environmental deterioration. Using Wujiang district in Suzhou as a case study area that is thought to be typical of many urbanisation experiences around the country, a method has been developed and tested of transforming major coefficients of change to local conditions. Using these adjusted ESV values, it was shown that from 2004 to 2016, urban development land in Wujiang district expanded significantly as a result of economic growth, but at the expense of the local environment.

The study analysed the land use changes for 5-year periods between 2004 and 2016 both qualitatively and quantitatively, to better understand the general trend and specific characteristics of land use changes. The analysis of the impacts on the ecological environment that has been presented is based on ecosystem service values (ESV). This approach clearly identified the risks to the environment that is posed by rapid urbanisation, as well as the challenges that inevitable threaten the attainment of sustainable development within the Chinese context. It is found from this research that urban expansion brings about significant challenges and risks in ecological environment, which are reflected by the decrease in ESV.

China, as a country, has the largest population in the world. Although incomes are rising, it is still a lower middle-income nation. As a result, economic development is a national priority. Economic development and the quest for increasing personal incomes almost inevitably imply an increase in the urbanisation rate, particularly in a country like China, where a large proportion of the country's residents reside in rural areas. Economic development and urbanisation will make significant demands upon the national supply of natural resources, especially land resources. To date, urban policy makers seem to have overlooked this basic fact of economic life. The result has been a massive transformation of ecological lands into urban development land. This is a trend that must be checked, as it will lead to further environmental deterioration of the country.

The present research has implications for urban policy makers. A new kind of urbanisation is required to avoid this environmental deterioration. Urban sprawl must be contained. Densities must be increased. Urban development on environmentally sensitive lands much be avoided. Urban development should be decentralised into areas where natural resource and land restraints are less severe.

ESV, as can be seen in this study, provides an important tool for urban policy makers. It can be used to provide an understanding of the environmental cost of urban development, but also as a scientifically based guide on ways to reduce this cost. If integrated into the urban planning process, ESV can facilitate the achievement of sustainable development, and this should be the guiding light for Chinese policy makers.

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