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Linking land use change, ecosystem services and human well-being: A case study of the Manas River Basin of Xinjiang, China

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ABSTRACT

The relationship between LUCC (land-use and land-cover change), ecosystem services and human well-being is not only an important cross topic in studies of natural ecological and social economic systems but also the key research direction and content of the GLP (Global Land Project) and Future Earth program, indicating its significance to the development of regional policy and the promotion of regional sustainable development. In the present study,"3S" (GIS, RS, GPS) technology, the Equivalence Factor Evaluation Method of Ecosystem Services and the Index System Evaluation Method of Human Well-being were separately used to analyze land use changes, ecosystem services and human well-being in the Manas River Basin in 2003 and 2013 and to characterize the relationship between these factors. The following conclusions were drawn: 1. In the past ten years, driven by the market economy, the structure of land use in the basin has obviously changed. Croplands and developed lands markedly increased, leading to a marked reduction in aquatic, grassland and woodland regions. 2. The land use changes resulted in a large increase in human economic income, in contrast with the obvious decrease in the value of climate regulation, gas regulation and other various types of ecosystem services influenced by the decrease in grasslands, woodlands and aquatic regions. 3. Most aspects of human well-being were improved. The most important aspect was the economic income well-being as a result of land use changes. However, the well-being associated with natural ecological resources showed a significant decline. 4. The extreme increase of croplands and developed lands has resulted in a structural imbalance of the ecosystem services and abnormal development of the structure of human well-being. Thus, to enhance the stability of the "nature-society-economy" system of the basin and pursue sustainable development, it is imperative to slow down or even stop the existing development trend of land use, and it is urgent to improve the structure of ecosystem services and human well-being.

1. Introduction

The relationship between ecosystem services and human well-being under land use changes is an important cross topic in research concerning natural ecosystems and social economies. Land use is one of the most closely associated links between man and nature. Land use changes will inevitably affect the structure of natural ecosystems and subsequently change ecosystem services. Ecosystem services are the benefits directly or indirectly obtained by humans from the ecosystem, including support, provisions, regulations and cultural services (Costanza et al., 1997, 2014; MA, 2005). Human well-being is based on the experiences of the people who believe that there is value in activities and status, including maintenance of the basic material conditions of a high quality of life, health, good social relations, security and freedom of choice and action (MA, 2005). Humans are an integral part of ecosystems and they tradeoff ecosystem services by changing the manner, pattern, scale and intensity of land use, leading to changes in their well-being. The correlation between ecosystems and human well-being is positive. However, because different stakeholders are interested in different ecosystem services, the relationship between different stakeholders and overall well-being is not a simple sum-total relationship (Li et al., 2014). The optimal combination of ecosystem services, which varies with region, produces maximum human well-being. Increased research efforts concerning the relationship between ecosystem services

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and human welfare under land use changes are urgently needed to improve theory and practice (Groot et al., 2012).

As an extension of the LUCC program, the GLP (Global Land Project), a core program jointly released by the IGBP (International Geosphere-Biosphere Program) and IHDP (International Human Dimensions Program on Global Environmental Change) focuses on the coupling relationship between changes in land use, the global climate, ecosystems and human society by considering the changes in ecosystem services resulting from land use changes as important research content (Gong et al., 2014a,b). In 2012, the ICSU (International Council for Science), ISSC (International Social Science Council) and other institutions jointly launched the Future Earth program. This effort proposed that the strategic framework for the next 10 years should involve a "sustainable development route", focusing on global environmental changes, natural and human-driven global environmental changes, human well-being and the relationship between all three of these aspects (Xin and Wang, 2015; Wu et al., 2015). "FutureEarth", GLP, ecoSERVICES (Ecosystem Services) and ecoHEALTH (Ecosystem Health) worked together and established a global organization, the interdisciplinary scientific cooperation platform. Under this background, the core topics "Supply changes of ecosystem services caused by land use change," in GLP, "Assessing the impact of ecosystem services change on human well-being and human response to changes in ecosystem services" in ecoSERVICES, and so on will become the key contents of the Future Earth program. Indeed, the study of ecosystem services and human well-being under land use change will become the focus of current and future research primarily because there is a close relationship between land use change and ecosystem service, which directly or indirectly affects the ecological system structure and process and changes the abilities of ecosystem services that profoundly impact human well-being (Fu and Liu, 2014; Fu and Zhang, 2014).

Recently, several studies concerning the relationship between land use changes and ecosystem services, land use changes and human well-being or ecosystem services and human well-being have been reported. Land use changes, such as the core field of global environmental change, influence the structure and function of the ecological system, playing a decisive role in the function of ecosystem services, and an assessment of the ecosystem services value can be used to assess the ecological effects of land use planning and play a guiding role in land use planning (Zhao et al., 2013; Lawler et al., 2014). Bateman published a simulation of the interactions between the value of ecosystem services and land use policies in *Science* (Bateman et al., 2013). Lopes studied the effect of land use on the distributive issues of ecosystem services, concluding that different types of land use generate a very asymmetric distribution of income among different groups of humans: land owners, citizens of a country, and residents of earth (Lopes et al., 2015). Milner examined how land use transitions to second-generation bioenergy crops potentially impact the ecosystem services in GB (Milner et al., 2016). Furthermore, many experts have analyzed the interaction between LUCC and ecosystem services, revealing their relationship (Tolessa et al., 2017; Loc et al., 2016; Zhang et al., 2016). In addition, Gasparatos systematically introduced the related driving force, influence factors and biofuel production balance of ecosystem services and human well-being, concluding that the production and use of biofuels can directly or indirectly affect all aspects of human well-being (Gasparatos et al., 2011). Horcea-Milcu implemented a case study in Eastern Europe to clarify the disaggregated contributions of ecosystem services to human well-being, analyzing the relationship between ecosystem services and human well-being using a model and concluding that people in poor regions are more dependent on ecosystem services (Horcea-Milcu et al., 2016). Bennett have suggested that the current research on ecosystem services and human well-being have many shortcomings. In addition, these researchers suggested three strategies for improving the value of ecosystem services, human well-being and regional sustainable development (Bennett et al., 2015). Recently, many results about ecosystem services and human well-being have been obtained, promoting the development of this field (Delgado and Marín, 2016; Bryce et al., 2016). However, studies on land use changes, ecosystem services and human well-being are few, and these topics have only recently been studied in earnest. For example, in Huailai County, China, Xu analyzed the effects of land use intensity on major aspects of ecosystem services, such as grain production, soil and water conservation and climate regulation, and human well-being, particularly in terms of life and food security, by establishing the index system. The results suggested that the changing trend of ecosystem services and human well-being strongly support the development of land use policies (Xu et al., 2016). Quintas-Soriano analyzed the contradiction between economic development and the ecosystem in the arid region of southeast Spain, discussing the effects of different land use patterns on ecosystem services and characterizing the attitudes of local people to the status quo of human well-being using a questionnaire survey. The data were analyzed to obtain an understanding of the arguments affecting the improvement of land use changes and visualize the trade-offs of ecosystem services under different management strategies (Quintas-Soriano et al., 2016).

Many problems in research concerning land use changes, ecosystem services and human well-being need further study (Bennett et al., 2015). For example, one of the greatest difficulties for researchers is the lack of reliable data sources, which leads to results based on unreliable data (Fu and Liu, 2014; Fu and Zhang, 2014). Most researchers only discuss the changes in different periods, without revealing the structure and process (Eigenbrod et al., 2010; Burkhard et al., 2012). Thus, the results of these assessments of ecosystem services value and human well-being are restricted under some assumptions, and the validity of land use decision making is questioned (Fu and Liu, 2014; Fu and Zhang, 2014). All these problems make it difficult to develop relevant policies for a specific region, and the goal of developing the best ecosystem services and human well-being is not achieved. With an increasing demand for incorporating ecosystem services into land use decision-making, the deep relationship between ecosystem services and human well-being under land use changes becomes increasingly important.

The Manas River Basin, in the northern slope of the Tianshan Mountains, is an inland river basin that features an arid zone in the southern margin of the Junggar Basin. Oasis development and economic development are key models of the entire Xinjiang Uygur Autonomous Region, and even of China and the world. In this region, over the past 60 years, land use changes have generated significant economic benefits (Cheng et al., 2006). However, with the development of the social economy, environmental and economic problems resulting from land use changes have gradually appeared. Based on the results of previous studies involving the Manas River Basin as a key study area, we analyzed the complex relationship between land use changes, ecosystem services and human well-being to clarify the process and mechanism of ecosystem services in theory and to increase human well-being and promote sustainable development in policy making for the Manas River Basin in practice.

2. Framework, materials and methods

2.1. Framework

The relationship among land use change, ecosystem services and human well-being are explained in Fig. 1, which is the sources of this study's inspiration.

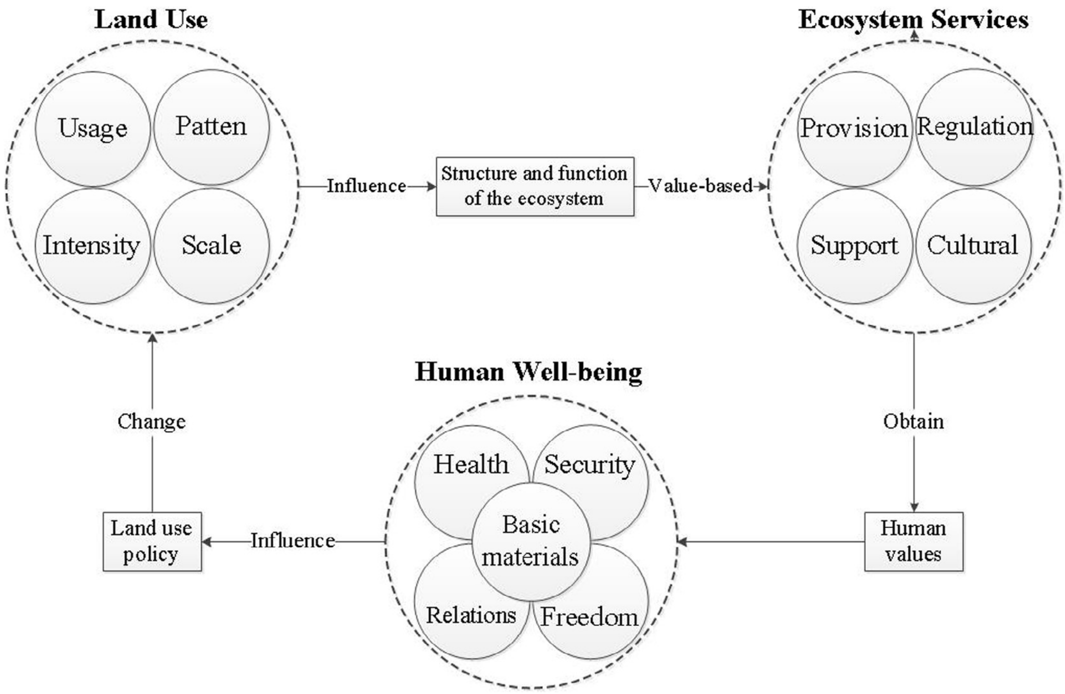

Fig. 1. Framework.

2.2. Study area

2.2.1. Geographic location

The Manas River Basin is in the Shihezi District, Xinjiang Province in the northern Tianshan Mountains of China (Fig. 2). The basin lies between 43°27′–45°21′N and 85°01′–86°32′E. The total area is 2.21×10^4 km^2, equally comprising mountains and plains. Fig. 2 shows the location of the Manas River Basin.

2.2.2. Terrain and landforms

The elevation of the Manas River Basin system ranges from 260 to 5242 m. The highest elevation is 5242 m in the southern mountainous region of the basin. The physical description of the landscape distribution by elevation is desert plains between 260 and 350 m, a marginal belt between 370 and 410 m, an alluvial fan between 410 and 800 m, and permanent ice and snow-covered regions above 3900 m. The distribution of vegetative types is temperate sand desert (260–360 m), temperate meadows and saline swamps (370–410 m), desert grasslands (800–1100 m), mountain grasslands (1100–1650 m), spruce forest (1650–2850 m), alpine meadows (2300 and 3200 m), alpine cushion vegetation and lichen (3200–3900 m), temperate sand vegetation (the plain and desert, 260–350 m), and temperate salt-marsh vegetation (the lacustrine deposit plain) from piedmont to desert. In the Manas River Basin, the oasis forms belt and patch distributions in the piedmont alluvial-pluvial fan, alluvial fan marginal belt and alluvial plain.

2.2.3. Climate

The annual mean temperature is 6.9 °C, and the annual mean precipitation is 190.3 mm (Zhang et al., 2009b). The water resources in the Manas River Basin are relatively rich for an arid region, possessing five inland rivers, including the Taxi, Manas, Ningjia, Jingou, and Bayingou Rivers, from east to west. These five inland rivers originate in the northern Tianshan Mountains and flow into the Junggar Basin.

2.2.4. Humanity and history

The Manas River Basin is a typical mountain-oasis-desert system and nature-economy-society system (Fan, 1996), which currently is an agricultural economic zone in Xinjiang with a prominent location advantage and tremendous development potential. The economy of the basin is given priority for agricultural development. Over the past few decades, the large-scale development of water conservancy and diversion for irrigation and farmland regions has rapidly increased. Several changes have occurred in the ecosystem, society and economy, including rapid population growth and strong expansion of the oasis region. The establishment of the protection forest system has abated the hazards of sand storms and improved the climate. Each year the basin provides the country with large quantities of food, animal, and industrial products and byproducts. The basin is not only one of the most successful oasis development models but also a microcosm of environmental changes in the entire dry region. However, with the development of agriculture and the economy and the increasing unsustainable use of the natural resources in this region, particularly the water resources, the contradiction between the extensive economic growth pattern and limited bearing capacity of the ecosystem is rapidly increasing, leading to the marked deterioration of the basin ecosystem. Thus, clarifying the relationship between land use changes, ecosystem services and human well-being is important for decision making and providing theoretical support for alleviating the ecological problems and promoting sustainable development of the basin.

2.3. Methods

2.3.1. Analysis of land use

Based on the OLI and TM images (Table 1) collected each summer, when visual interpretation is optimal because the vegetation coverage increases to the vertices, we analyzed the land use conditions of the Manas River Basin in 2003 and 2013. Details of the data sources are listed in Table 1. Combining slope, DEM, and GPS data

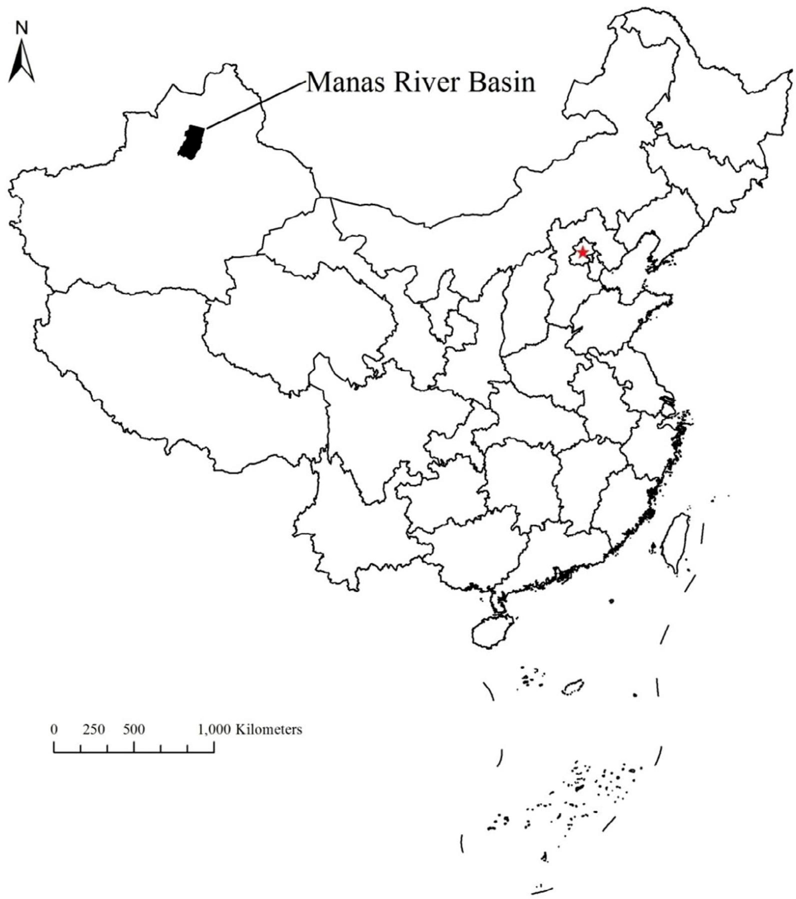

Fig. 2. Location of the Manas River Basin.

and on-site surveys as references, we used ENVI5.1 for image correction to meet the geometric accuracy requirements.

With reference to the 2007 national standard classification system ("the present situation of land use classification standard" (GB/T21010-2007)), we determined the land use/cover classification system, primarily including Forest, Cropland, Grassland, Aquatic, Urbanized and infrastructure land, Desert, Alpine moss and Alpine Ice-snow, and so on. For technical reasons, some linear features, such as rural roads, ditches and shelter forest, among others, were categorized into the above classes and no longer listed separately.

ArcGIS10.1 was used to generate a decision tree, classify land use/cover, and generate a land use thematic map.

The high-resolution data provided from Google Earth was combined with knowledge of the field observation data and experience to verify the accuracy. The kappa coefficient was 83.5% in 2003 and 87.6% in 2013. Precision met the requirement of the experiment.

2.3.2. Assignment of ecosystem service value

In 1997, Costanza published a paper on Global Ecosystem Services and Natural Capital in *Nature* (Costanza et al., 1997), clearly defining the principles and methods of estimating the value of ecosystem services in a scientific sense and estimating all aspects of the value of ecosystem services. However, because of the scale effect, the accuracy of the value of some types of ecosystem services remain in question. Therefore, his table does not apply to China entirely. Considering these shortcomings, in 2003, the Chinese scholar Xie referred to Costanza's table, coupled with a questionnaire survey of 200 Chinese scholars in the field of ecology, and generated a table of Equivalent Value Per Unit Area of Ecosystem Services in China (Xie et al., 2003). In 2008, Xie conducted another questionnaire survey on 500 Chinese scholars in the field of ecology, combining the results of the previous 200 questionnaires, and generated a new version of the table of Equivalent Value Per Unit Area of Ecosystem Services in China (Xie et al., 2008).

Table 1
Information on the data sources.

Year	Data type	Remote sensing images (path/row, collection time)
2003	TM (30 m × 30 m)	144/29, 2003-07-31
		144/30, 2003-09-01
2013	OLI (30 m × 30 m)	144/29, 2013-08-19
		144/30, 2013-08-19

Based on Xie's studies and the positive relationship between ecosystem services and the biomass of the ecosystem, the increased biomass increases the value of the ecosystem services. Furthermore, supporting services are not used by people, they do not qualify as a service but should be referred to as ecosystem functions, and they have no direct economic value, but their contribution shows in provisioning and other services (Braat and Groot, 2012). Therefore, they cannot be included in the economic valuation and we remove the Supporting Services, because there would be double-counting. Thus, we have revised the ecological services value equivalence factor of China and generated a table of Equivalent Value Per Unit Area of Ecosystem Services in Manas (Table 2). The following revised formula was used:

$$f_{ij} = (b_j/B)F_i$$

where f_{ij} is the equivalence factor of the ecosystem service value in the Manas River Basin; *i* represents different aspects of ecosystem services, such as climate regulation, gas regulation, conservation

Table 2
Equivalent value per unit area of ecosystem services in Mamas.

First class types	Second class types	Woodland	Grassland	Cropland	Wetland	Aquatic	Alpine moss	Desert
Provision services	Food production	0.66	0.33	1.90	0.36	0.53	0.04	0.02
	Raw material production	5.97	0.28	0.74	0.24	0.35	0.36	0.04
Regulation services	Gas regulation,	8.65	1.15	1.37	2.41	0.51	0.53	0.06
	Climate regulation	8.15	1.19	1.84	13.55	2.06	0.50	0.13
	Hydrological regulation	8.19	1.16	1.46	13.44	18.77	0.50	0.07
	Waste disposal	3.45	1.01	2.64	14.40	14.85	0.21	0.26
Cultural services	Aesthetic landscape	4.17	0.66	0.32	4.69	4.44	0.25	0.24

of water and soil, $i = 1,2\ldots$; j represents different aspects of the ecosystems, such as grassland, woodland, and cropland, $j = 1, 2\ldots$; F_i is the equivalence factor of different ecosystem services in the table of Equivalent Value Per Unit Area of Ecosystem Services in China; b_j is the average biomass per unit area of different ecosystems in the Manas River Basin; and B is the average biomass of the j type of ecosystems per unit area in China.

The economic value of one ecological service equivalence factor is 1/7 the grain output value per unit area (Xie et al., 2003), generating the table of the Values Per Unit Area of Ecosystem Services in Manas. The following formula was used:

$$E_a = \frac{1}{7}\sum_{n=1}^{i}\frac{m_i p_i q_i}{M}, \quad (i = 1, 2, \ldots, n)$$

where E_a is the economic value of the ecological service equivalence factor in unit area, ¥/ha; i represents different aspects of crops; p_i is the national average price of different crops, ¥/t; q_i is the per unit yield of different crops, t/ha; m_i is the area of different crops, ha; and M is the total area of all crops, ha. The main grain crops in China are barley, wheat, corn and rice. Combining the statistical and survey data, the economic value of grain output was 3976.8 ¥/ha in 2003 and 8113.5 ¥/ha in 2013. However, these results need to be adjusted for inflation. According to the agricultural price index in the China Statistical Yearbook, the inflation rate was 1.534 from 2003 to 2013. Therefore, we got the comparable prices of 3976.8 ¥/ha in 2003 and 5289.1 ¥/ha in 2013.

These values were multiplied by the data in Table 2 to obtain the values per unit area of the ecosystem services in 2003 and 2013 (Table 3) in Manas.

2.3.3. Assessment of human well-being

We collected data between September and December in 2015 using a random sampling survey and obtained 550 valid questionnaires. The demographic factors involved in the questionnaire survey included age, education level, household income, home address and family size. The subjects were primarily middle-aged, guaranteeing the authenticity of the judgment of the ecological environment changes and the life level changes in the Manas River Basin in recent years. In addition, combined with semi-structured interviews, we conducted in-depth field research to obtain a more accurate grasp of the reality of human well-being.

The questionnaire was divided into closed and open questions of four types. The first question concerned the subjects themselves and the family's basic social and economic characteristics, including age, educational level, family size and income. The second question concerned an individual's perception of the ecosystem services and changes in the local ecosystem and environment. The third question concerned the basic living conditions of the subjects, including water consumption, diet, housing, transportation, education and health care. The fourth question concerned an individual's views of the water quality, air quality, mental health status, civil cases, and occurrence of disasters.

2.3.3.1. Establishment of human well-being indicators system. Based on the division of human well-being elements in the Millennium Ecosystem Assessment and the definition of human well-being indicators (Zhang and Fu, 2014) with respect to the local "nature-society-economy" system, and the integrated opinion of almost 20 experts, we selected appropriate characterization indicators for human well-being (Table 4). Human well-being includes objective and subjective aspects. Although subjective factors influence the subjective satisfaction, they are important indicators of the quality of human life, reflecting the degree of satisfaction of the respondents to their objective needs (Costanza et al., 2007). To weaken the influence of subjective factors on the assessment of human well-being, additional objective indicators and fewer subjective indicators were included in the present study, and a subjective weighting method was used to evaluate the indicators of human well-being.

3. Results

3.1. Analysis of land use changes

We obtained the land use map (Fig. 3) and regions of different land use types (Table 5) of the Manas River Basin in 2003 and

Table 3
The values per unit area of ecosystem services in Manas (¥/ha/yr.)

First class types	Second class types	Woodland		Grassland		Cropland		Wetland		Aquatic		Alpine moss		Desert	
		2003	2013	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013
Provision services	Food production	375.6	499. 5	186.7	248.3	1078.3	1434.1	204.5	272.0	301.1	400.5	22.9	30.5	11.4	15.1
	Raw material production	3391.4	4510.5	156.3	207.9	420.5	559.3	136.4	181.3	198.8	264.5	206.9	275.1	22.7	30.2
Regulation services	Gas regulation,	4916.4	6538. 8	651.3	866.2	776.7	1032.6	1369.1	1821.0	289.7	385.4	299.9	398.9	34.1	45.3
	Climate regulation	4631.8	6160.4	677.4	900.9	1045.9	1391.1	7697.9	10238.	1170.3	1556.5	282.5	375.8	73.9	98.2
	Hydrological regulation	4654.6	6190.6	660.0	877.8	830.3	1104.3	7635.4	10155.1	10663.4	14182.4	283.9	377.6	39.8	52.9
	Waste disposal	1957.4	2603.4	573.2	762.3	1498.8	1993.4	8180.8	10880.5	8436.4	11220.5	119.4	158.8	147.7	196.5
Cultural services	Aesthetic landscape	2367.1	3148. 3	377.8	502.4	183.3	243.8	2664.4	3543.7	2522.4	3354.8	144.4	192.0	136.4	181.3

Table 4
The indicators system of human well-being and the standard level changes from 2003 to 2013.

Target arrangement	Factor arrangement	Rule arrangement	Indicator arrangement	Weights	2003	2013	Contribution rate of well-being change
Human well-being standard indicators	Income and consumption	Income	Annual per capita net income (¥)	11	5842	15916	
			Factor score		4.48	10.63	54.55
		consumption	CPI	4	102	103	
			Factor score		1.22	0.67	-4.88
			Engel's Coefficient (%)	3	45.5	34.5	
			Factor score		2.01	2.73	6.39
	Basic materials	Material supply capability	Per capita output value of agricultural products(¥)	2	1151	4028	
			Factor score		0.47	1.62	10.20
		Resources acquisition capability	Number of roads at the end of the year (km)	2	336	4205	
			Factor score		0.56	2.31	15.52
			Road freight volume (billion ton-kilometers)	1	8.2	83.74	
			Factor score		0.78	2.23	12.86
		Living condition	Per capita living area (m^2)	3	16.28	26	
			Factor score		1.94	2.86	8.16
			Housing prices at the end of the year (¥)	2	1389	4250	
			Factor score		0.82	1.07	2.22
	Security	Resources security	Annual per capita grain yield (kg)	2	353.3	368.2	
			Factor score		1.64	1.66	0.18
			Satisfaction of water quality (full mark is 5)	2	3.21	2.47	
			Factor score		1.28	0.99	-2.57
			Satisfaction of water supply (full mark is 5)	3	1.24	0.88	
			Factor score		0.744	0.528	-1.92
			Satisfaction of air quality (full mark is 5)	2	1.66	0.44	
			Factor score		0.66	0.18	-4.26
			Satisfaction of environment quality (full mark is 5)	3	1.32	0.35	
			Factor score		0.79	0.21	-5.14
			Evaluation of pollution source (full mark is 5)	2	1.98	0.79	
			Factor score		0.79	0.32	-4.17
			Land salinization ratio (%)	3	26.9	30.6	
			Factor score		0.92	0.81	-0.98
			Annual total disaster	1	8	6	
			Factor score		0.6	0.8	1.77
		Life security	Gross crime rate	3	63	103	
			Factor score		2.32	0.95	-12.15
	Health	Physical health	Average life expectancy	4	69.87	76.17	
			Factor score		1.59	1.69	0.89
			Medical insurance penetration rate (%)	3	38.38	99.6	
			Factor score		0.72	1.93	10.73
		Mental health	Mental health status (full mark is 5)	2	3.5	3	
			Factor score		1.4	1.2	-1.77
		Diet health	Annual per capita proportion of food expenditure (%)	2	25.4	20.47	
			Factor score		0.41	0.51	0.89
	Education and culture	Education	Average education years	3	7.73	8.92	
			Factor score		1.45	1.73	2.48
			Annual per capita proportion of education expenditure (%)	2	7.9	19.6	
			Factor score		0.55	1.12	5.06
			Education and culture funds cost ratio of total expenditure (%)	5	2.93	11.51	
			Factor score		1.21	2.68	13.04
			Illiteracy rate (%)	2	7.72	3.01	
			Factor score		0.6	0.78	1.60
	Social relationship	Family relationship	Dependent population	3	28	32	
			Factor score		2.4	1.32	-9.58
			Divorce rate (%)	2	3.99	4.61	
			Factor score		1.84	1.6	-2.13
			Satisfaction of family harmony (full mark is 5)	3	3.56	3.56	
			Factor score		2.14	2.14	0.00
		Interpersonal relationship	Annual per capita proportion of social interaction cost (%)	2	22.88	24.28	
			Factor score		0.46	0.49	0.27
			Satisfaction of social interaction (full mark is 5)	2	3.95	4.3	
			Factor score		1.58	1.72	1.24
	Freedom	Freedom of choice	Satisfaction of democratic rights (full mark is 5)	1	3.21	3.04	
			Factor score		0.64	0.61	-0.27
		Freedom of action	Satisfaction of action freedom (full mark is 5)	1	2.1	3.1	
			Factor score		0.42	0.62	1.77

To remove the influence of dimension, a standardization method and a membership function were adopted to calculate the data standardization and the factor score. Standardized formula: $F = (X_i - X_{min})/(X_{max} - X_{min})$.
X_{max} refers to the maximum value of the indicators of the year. X_{min} refers to the minimum value of the indicators of the year. In addition, we referenced the questionnaire data; the factor score was obtained using a standard weighted calculation of the corresponding indicators of each factor; and human well-being was calculated as the sum of the factor scores.

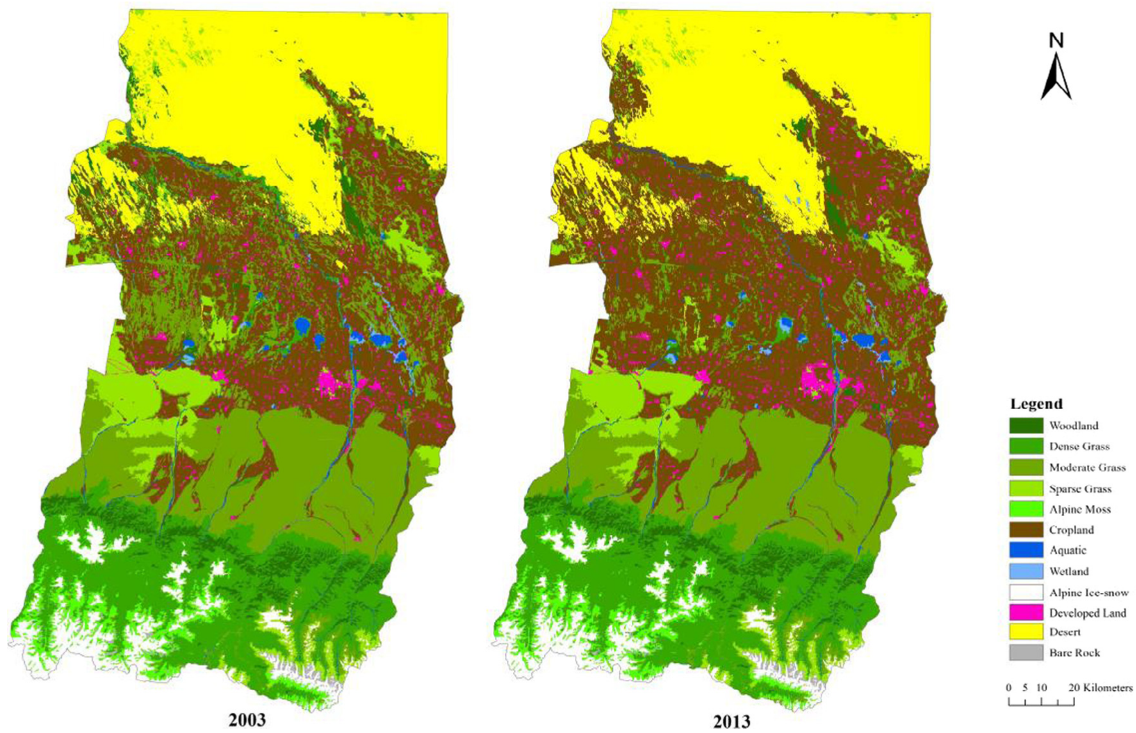

Fig. 3. Land use map of the Manas River Basin from 2003 to 2013.

Table 5
Land use changes from 2003 to 2013.

	2003 (km^2)		2013 (km^2)		Change value (km^2)	Change rate (%)
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)		
Woodland	990.84	4.49	721.89	3.27	-268.95	-27.14
Grassland	9148.67	41.42	7921.12	35.86	-1227.55	-13.42
Cropland	5121.33	23.19	6694.43	30.31	1573.10	30.72
Aquatic	203.55	0.92	187.75	0.85	-15.80	-7.76
Wetland	58.90	0.27	58.06	0.26	-0.84	-1.43
Alpine Ice-snow	815.07	3.69	816.90	3.70	1.84	0.23
Alpine moss	572.00	2.59	563.56	2.55	-8.44	-1.48
Developed land	430.66	1.95	519.75	2.35	89.10	20.69
Desert	4660.41	21.10	4531.61	20.52	-128.80	-2.76

2013. The main land use types include grassland, cropland and desert, followed by alpine snow and ice, woodland, alpine moss, developed land, aquatic and wetland.

Over the past ten years, the land use structure in the basin has significantly changed. The cropland primarily distributed in the middle and lower reaches and the alluvial fan region, whose expansion is contiguous in the core region, primarily driven by the market economy (Liang et al., 2015; Li et al., 2015). These effects resulted in an extremely unbalanced state for these croplands, which was transferred from other land use types, such as grasslands, woodlands, and so on.

The developed land is primarily distributed in the middle and lower reaches and scattered throughout the cropland, primarily reflecting the population increase and rapid urbanization. The developed land increases rapidly through infiltration and expansion.

The grasslands are primarily distributed in the middle and upper reaches, showing staggered distribution with croplands and developed lands. The grassland area in the middle and lower reaches clearly decreased and was converted to croplands and developed land.

The aquatic distribution is scattered and significantly decreased, primarily reflecting the fact that the massive expansion of cropland increased the demand for water resources, leading to river drying, lake decreases and wetland shrinking (Zhang et al., 2009a). In addition, because of the closure of reservoirs to rivers in the upper reaches and other factors, the water shortage in the middle and lower reaches was obvious and the drought probability increased. The increase in the population and the expansion of developed land also increased the demand for water resources.

Moreover, the woodland and desert were respectively decreased by 268.95 km^2 and 128.8 km^2 at a rate of 27.4% and 2.76%, respectively. All these results led to changes in the landscape patterns throughout the entire basin.

3.2. Estimation of changes in ecosystem services

According to the data shown in Tables 3 and 4 and the area of different land use types in the basin, we obtained the value and value proportion of different types of ecosystem services of the Manas River Basin in 2003 and 2013 (Table 6). Then, we obtained the values of the ecosystem services in 2003 and 2013, which were ¥13.36 billion and ¥17.50 billion, respectively.

From 2003 to 2013, the value increased by 31%.However, this increase was affected by the different economic values of the food

Table 6
The values per unit area of ecosystem services in Manas (2003–2013).

	Woodland		Grassland		Cropland		Wetland		Aquatic		Alpine moss		Desert	
	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013	2003	2013
Value per unit area (Yuan/ha)	32001.79	42562.59	5067.19	673940	8518.355	11329.47	31115.4	41383.66	25763.79	34266.01	1952.11	2596.32	789.67	1050.27
Area (ha)	99084.15	72189.36	914866.83	792111.78	512133.21	669443.13	5889.69	5805.63	20354.85	18775.26	57200.22	56356.11	466041.33	453160.89
Total value (million Yuan)	3170.87	3072.57	4635.80	5338.35	4362.53	7584.43	183.26	240.26	524.42	643.35	111.66	146.32	368.02	475.94
Proportion (%)	23.74	17.56	34.71	30.50	32.66	43.34	1.37	1.37	3.93	3.68	0.84	0.84	2.76	2.72

production services provided by the unit area during different periods resulting from technology and other factors. Although the value proportion of farmland, grassland and forest ecosystem services significantly changed, the sum of these values accounted for more than 90% of the total value, whereas other types of values did not significantly change.

Over the past 10 years, although the value proportion of forest ecosystem services decreased from 23.74% to 17.56%, the area accounted for less than 4.5% on average, ranging from 4.49% to 3.27%.The area proportion of the aquatic regions was reduced from 0.92% to 0.85%, but the proportion of the ecosystem services value reached 3.93% and 3.68%,respectively. Similar conditions were observed for croplands, showing an obvious increase in the proportion of ecosystem services value from 32.66% to 43.34%, which is larger than the area proportions of 23.19% and 30.31%, respectively. In addition, although the area proportion of the wetlands was only 0.27% and 0.26%, the value proportion reached 1.37%, suggesting that the woodlands, aquatic regions, wetlands and croplands in the Manas River Basin have larger ecosystem services values. Although the area and value proportions of the aquatic regions and wetlands are low, these regions remain an integral part of the ecosystem and play key roles in maintaining the stability and balance of the entire ecosystem.

The value proportion of grassland ecosystem services decreased from 34.71% to 30.50%, and the area proportion decreased from 41.42% to 35.86%. These changes were obvious and almost consistent, showing that the ecosystem services value of grasslands is moderate.

In contrast, the area proportion of desert exceeded 20%, but its value proportion was less than 3%, showing that the desert contains lower ecosystem services value. Similar conditions were observed for alpine moss. Even so, desert and alpine moss are key components of the ecosystem, playing indispensable roles in the protection of biological diversity.

The area proportions of wetland and alpine moss were slightly reduced, and the value proportions were unchanged. Thus, we proposed that the real value of the ecosystem services was reduced from 2003 to 2013. After verification, we calculated the value of the ecosystem services in 2003 and 2013 by taking the economic value of grain output in 2003 as a constant price, obtaining values of ¥13.36 billion and ¥13.16 billion, respectively, which conforms with the facts.

In conclusion, the main types of land use changes in the Manas River Basin were obvious. For example, the area of croplands and developed lands rapidly increased, generating significant economic benefits. However, this effect also led to an obvious reduction of woodlands, grasslands and aquatic regions, which actually decreased the entire value of the ecosystem services, reflecting a significant reduction of the indirect value of the ecosystem services.

Thus, we cannot only pursue economic benefits. Although it is impossible to reverse the cropland and developed lands to their natural condition, we should also consider the rationality and stability of the ecosystem and the efficiency and high value of the ecosystem function and reverse the extreme imbalance state resulting from the transfer of croplands from other types of land uses. Moreover, the gaps between natural services and economic development are gradually widening because of the unsustainable way in which natural resources are consumed. In this regard, studies of the tradeoff between them have been increasingly assessed to maintain the proper relationship between the services supplier (Nature) and the services demander (Human Society). Therefore, we must reduce or even stop the expansion of croplands and developed lands to protect the grasslands, forests and water resources and rationally control the distribution of water resources in the midstream and downstream to approach sustainable development.

3.3. Evaluation and analysis of human well-being

The most representative welfare factors were selected and analyzed for the assessment of human well-being in the Manas River Basin in 2003 and 2013. The human well-being level increased from 39.43 to 50.71, and the improvement was obvious.

3.3.1. Income and consumption

From 2003 to 2013, the well-being level of income and consumption increased by 81.97%, from 7.71 to 14.03, showing the largest contribution rate of well-being change of 56.06%. The annual per capita net income increased from ¥5842 to ¥15916, showing a 172.44% increase. The contribution rate of this well-being change was 54.55%. Thus, economic income plays an important role in the structure of human well-being, and its increase promotes the consumption of the basic material demands and improves the human well-being level of teaching, health care, health and freedom.

Over the past decade, under the drive of the market economy, the rapidly increasing cropland area in the Manas River Basin has resulted in a rapid increase in economic income and contributions to the value of the ecosystem services, which has greatly affected human well-being. However, negative effects were also obvious. For example, the water resources are increasingly scarce, and obvious decreases in grasslands and woodlands were observed, which has gained increasing attention (Zhang et al., 2012; Wang and Zhang, 2010). Thus, in the future, we should focus on how to formulate and improve the land use policy under the premise of ensuring a high level of human well-being. Consequently, the land use status should also be adjusted to enhance the value of ecosystem services and achieve the coordinated and orderly development of the nature-society-economy system.

3.3.2. Basic materials

The basic materials of the well-being level increased from 4.57 to 10.09 (120.79% increase). The contribution rate of the human well-being change was 48.96%. The most obvious improvement was in the aspect of resource acquisition ability, primarily reflecting an increase in the road and road freight volume at the end of the year. This observation suggests that, in the past, the economy developed rapidly and the government paid much attention to these aspects and increased the investment. In addition, the variety of resource distribution has become increasingly easier; thus, individuals can conveniently and rapidly obtain resources (Wang, 2010). This aspect greatly increases the richness and freedom of life, thereby enhancing human well-being. Per capita, the output of agricultural products has significantly increased, reflecting adequate agricultural development, and relevant levels of technology have greatly improved, thus improving the productivity and production efficiency and reducing the labor intensity.

3.3.3. Security

The security well-being level reduced from 9.74 to 6.45 (33.78% decrease), showing a −29.4% contribution rate of human well-being change. The most obvious aspect is the reduction in the level of human well-being in terms of resource security. Although aspects of the per capita grain yield and total annual disaster showed a trace of benign upgrade, other aspects of the security well-being levels significantly decreased. For example, it is more difficult to obtain water resources; the reduction in the satisfaction of water quality, air quality, the current situation of environmental and pollution source status; the deterioration of soil salinization, and so on. Over the past decade, the water resources in the basin have become increasing scarce, the soil salinization is increasingly serious, and the environment has been significantly damaged. Although the economy has rapidly developed, the price has been heavy, and it is difficult to restore the damaged environment. In 2014, Meng assessed the ecological security of the Xinjiang Construction Corps, showing that 9 of the 13 regiments assessed were in critical or less safe states, and only 4 regiments were at relatively safe levels (Meng et al., 2014), suggesting that we should not arbitrarily change nature and transform the land use pattern to pursue too many economic benefits, but rather consider the nature-society-economy system as a whole for regional sustainable development.

3.3.4. Health

The heath well-being level increased from 4.12 to 5.33 (29.37% increase). Among the health-related indicators, a significant increase in the medical insurance penetration rate was the most significant contribution to health well-being, which increased from 38.38% in 2003 to 99.6% in 2013. The well-being level increased from 0.72 to 1.94, and the contributing rate of human well-being was 10.73%. The increase in the medical insurance penetration rate reduced the economic burden of medical expenditure, reflecting improvements in local social security measures and significant improvements in living standards (Jiang, 2013).

3.3.5. Education and culture

The education and culture well-being level increased from 3.81 to 6.31 (65.62% increase). The contribution rate of human well-being was 22.74%. The increase in the education and culture funds cost ratio increased from 1.12 to 2.68, and the contribution rate of human well-being was 13.04%, suggesting that these factors play key roles in the promotion of education well-being. These findings also suggest that the government attaches great importance to cultural and educational activities. Moreover, the average years of education increased, and the illiteracy rate was significantly reduced.

3.3.6. Social relations

The social relations well-being level decreased from 8.42 to 7.27 (−10.2%). The decline in the level of family relations well-being and interpersonal relationship played the largest negative role. The number of dependent population increased from28 in 2003 to 32 in 2013, and their well-being level decreased from 2.4 to 1.32 (45%). The aggravating trend of the aging population largely reflects the increase in the dependent population (Dai et al., 2014), which increases the burden on the family. Xinjiang Province, in which the divorce rate increased from 3.99 to 4.61, has always had the highest divorce rate in China. The increase in the divorce rate affects the harmony and stability of family life, leading to a decline in family relationship satisfaction.

3.3.7. Freedom

The level of freedom well-being slightly increased from 1.06 to 1.23. Consistent with the progress of society, individuals are becoming increasingly conscious of their rights and faced with more choices. Thus, the actions of these individuals are increasingly becoming free. These factors improve the well-being level.

3.4. Brief summary

Under the influence of social, economic and policy factors, the population activity strongly expanded the area of croplands and developed lands and occupied or destroyed the woodlands, grasslands and aquatic regions. Human activities have significantly changed the status of land use in the Manas River Basin and subsequently affected the ecosystem services of this region, further affecting health and human well-being (Smith et al., 2013; Willox et al., 2013). Over the past ten years, we aggressively pursued economic benefits, which strongly affected the land use pattern in the basin and inevitably led to the excessive exploitation of natural resources and structural changes in the ecosystem services value, as well as a reduction of the rationality and stability of the structure. In addition, although the economic benefits enhanced the level of human well-being, the structure of human well-being was abnormal. The economic well-being was too large, while the proportion of other aspects of well-being was dysfunctional or even too low. Over time, these factors will lead to an increasingly fragile and unstable natural-society-economy system, and human beings will bear the consequences.

Using a questionnaire method, we obtained extremely surprising data showing that more than 90% of individuals in the basin are willing to slow down or even give up economic development to protect the environment, suggesting that the pressure of environment protection is significant, and governance or improvement of the ecosystem is urgently needed. Therefore, we should take measures to improve the current ecosystem situation to approach sustainable development. We should slow down the current land use change trend, protect the woodlands, grasslands, wetlands and so on, and rationally control the distribution of water resources in the midstream and downstream.

4. Discussion

Land use is one of the most closely related links between man and nature. Changes in land use will inevitably lead to changes in the ecosystem structure and ecosystem services. The relationship between land use changes, ecosystem services and human well-being is complex and influenced by many factors, making it difficult to clarify this relationship. Thus, the research topic "Assessing the impact of ecosystem services change on human well-being, and assessing the response of humans to ecosystem services change" in ecoSERVICES has become increasingly important to the Future Earth program. In the future, the link between ecosystem services and human well-being can be quantified. Moreover, we can reveal how things occur and how things work between LUCC, Ecosystem Services and Human Well-being using the Carbon Footprint, Nitrogen Footprint and so on. It will be a very interesting study of an urbanizing region and how that effects land-use and ecosystem services.

Land use changes will directly lead to changes in the ecosystem services value and human well-being levels, resulting in an imbalance in the structure of the ecosystem services value and an abnormal development of the human well-being structure. For example, the rapid increase in farmland and construction has increased the value of ecosystem services and promoted economic benefits in human well-being. However, this rapid increase has also damaged the ecosystem, including grasslands, woodlands and aquatic regions, thereby decreasing the ecosystem services value in terms of gas regulation, climate regulation, biodiversity protection, soil and water conservation, among other aspects and significantly reduced the corresponding resource security well-being level. These effects have resulted in a bottleneck of regional sustainable development, and land use policies play important roles in solving these problems, generating higher requirements for regional land managers.

In the present study, we have made some innovation, quantitatively analyzed the land use changes, ecosystem services, and human well-being and characterized the relationship between these parameters, potentially reflecting the actual status and providing some support for policymaking for sustainable development. Notably, the relationship among these factors needs further study, with longer-scale data for land use, focusing more on the spatial heterogeneity of ecosystem services and simulations of the changing process using models. Furthermore, thus far, most of the studies on human well-being have eliminated the non-unity of the data by establishing an index system combined with a standardized method (Cai et al., 2014; Yang et al., 2010; Huimei et al., 2014). However, differences in the index systems and the standardized methods make comparability between different studies poor, and parallel comparisons are difficult. Thus, a unified approach for the study of human well-being is lacking, making future research difficult.

The value of ecosystem services is dependent on time-period data, as embodied in changes in the ecosystem with time and the accounting process, reflecting the different basic parameters of ecosystem services in different periods. For example, the economic value of the food provided per unit area will change in different periods and gradually increase with progress in science and technology. Moreover, this value is also influenced by inflation. In reality, we should compare changes in the value proportion or over all changes under the premise of uniform dimension.

According to our results, the value of the ecosystem services did not improve, but economic income, which was the biggest well-being pursuit of local people, did improve. It seems there is a potential tradeoff between the natural services and economic development. Economic development can improve human well-being, but it may at the same time cause a decrease in ecosystem services, especially regulating services, because the ecosystem and socioeconomic system are interactive. This suggests that some investments (e.g., technological or economic) should be invested in natural capital and may alleviate the situation. For example, ecological projects can contribute to the balance between the ecosystem and economy. Moreover, in the further application of land use policies, the balance between the natural services and economic development should be a precondition.

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