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Evaluation of ecosystem services: A case study in the middle reach of the Heihe River Basin, Northwest China

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ABSTRACT

Ecosystem services evaluation aims at understanding the status of ecosystem services on different spatial and temporal scale. In this paper, we selected the middle reach of the Heihe River Basin (HRB), which is the second largest inland river basin in China, as one of the typical area to estimate the ecosystem services values (ESVs) corresponding to the land use changes. Based on the land use data and ecosystem service value coefficients, the total ecosystem services values (TESVs) of the middle reach of the HBR are quantitatively calculated, which were 9.244×108, 9.099×108, 9.131×108 and 9.146×108 USD in 1988, 2000, 2005 and 2008 respectively. During 1988–2008, the decrease of grassland, forest land, water area and unused land contributed 148.94%, 57.85%, 87.87% and 16.42% respectively to the net loss of TESVs, while the dramatic increase of cultivated land improved the TESVs with contribution of −211.08% to the net loss of TESVs. Expansion of cultivated land, which especially caused the loss of grassland and forest land, directly exerted negative impacts on the provision of ecosystem services in the study area. The findings of this research indicated that land use change was an important form of human activities, which had a strong impact on ecosystem services.

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1. Introduction

Ecosystem services are critical to humans being's life, which directly and indirectly provide essential materials and benefits to the sustainable development of human society and environment (Costanza et al., 1997). There have many researches been conducted in the classification and evaluation of ecosystem services, and the analyses of the relationship between ecosystem services and land use changes (Deng et al. 2013; Li et al., 2013). Since the concept of ecological system being put forward by Tansley (1935), relevant studies of ecological systems have gradually formed a scientific system, and further been strengthened since the end of 20th century. Among those studies, Daily (1997) carried out research of ecosystem services classification and evaluation. Costanza et al. (1997) mainly focused on the global ecosystem services classification and evaluation and summarized 17 types of the ecosystem services according to the estimation of 16 kinds of biome in monetary form. Bockstael et al. (2000) conducted researches on measurement method of the economic valuation of ecosystem services and the analysis and generalization of the system. Groot et al. (2002) presented a conceptual framework and typology for describing, classifying and assessing ecosystem functions, goods and services in a clear and consistent manner. Farber et al. (2002) illustrated the concept of ecosystem service value and evaluation methods, which provided a theoretical basis for government decision-making. Howarth and Farber (2002) examined the role of the value of ecosystem services (VES) concept in measuring trends in human well-being. Chee (2004) conducted a critical review on the framework, tools and approaches that can be applied to estimate the economic value of ecosystem services, comprehensive management decision-making in social and economic benefits, etc., from an ecological perspective.

As the concept of ecosystem services being acknowledged, many methodological frameworks have been put forward to analyze and evaluate the ecosystem services, which make ecosystem services have become a popular scientific topic, especially in the last two decades. However, considering spatial and temporal scales, the links between ecosystem services and human activities

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are more complicated (Pereira et al., 2005). According to the report of Millennium Ecosystem Assessment (MEA), it showed that human activities had induced more rapid and extensive changes in ecosystems over the past 50 years compared to other period, which mainly due to the rapidly growing demands of humans for food, fresh water, timer, fiber and fuel etc. This has resulted in a substantial and largely irreversible loss in the diversity of life on the earth. The future capability of ecosystems to provide these services is determined by changes in socioeconomic characteristics, land use, biodiversity, atmospheric composition and climate (Metzger et al., 2006). Among these factors, land use conversions were identified as the most significant factors driving the changes in ecosystem services, affecting human well-being and threatening the survival of other species (Geneletti, 2013). It was also identified that the changes in the extent and composition of different land use type had large impacts on the provision of ecosystem services, biodiversity conservation and returns to landowners (Polasky et al., 2011). Land use changes typically impact on the capacity of ecosystems to provide goods and services to the human society, thus resulted in large changes in ecosystem service supply (Schroter et al., 2005).

It has been identified that ecosystem services were declining over the previous decades, while there is no common method to evaluate the impacts of land use change on ecosystem services. However, the method that links spatial land cover information derived from remote sensing (RS), land survey and Geographic Information System (GIS), with data from monitoring, statistics, modeling or interviews, was mostly applied to asses and transfer ecosystem service supply to different spatial and temporal scales (Burkhard et al., 2012). Thus, regarding the depicting of ecosystem services, many researchers used different methods to spatially analyze and map the changes of ecosystem services. For example, Haines-Young et al. (2012) developed an approach, which is mainly expert- and literature-driven method, to map indicators of the potential of ecosystems to supply ecosystem services, and to analyze the impact of land cover changes on ecosystem services. Troy and Wilson (2006) designed a decision framework to estimate ecosystem service flow values based on the query of relevant economic valuation studies and to spatially explicitly map the results based on GIS. Egoh et al. (2008) evaluated and mapped the production of five ecosystem services, and further tested the correlation between primary production and these five services to check whether the primary production can act as a whole representative measurement of ecosystem services. Naidoo (2008) reviewed the theory and available data to quantify imperfect global proxies for only four ecosystem services. Ayanu et al. (2012) used different remote sensing systems, sensor types, and methods that can be applied to quantify provisioning and regulatory services. Jackson et al. (2013) introduced a GIS framework (Polyscape), which was designed to explore spatially explicit synergies and trade-offs among ecosystem services to support landscape management. Leh et al. (2013) presented a methodology to quantify and assess the changes in multiple ecosystems services induced by land use changes using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model. The studies mentioned above can be divided to two types, one mostly focused on the evaluation and mapping of the economic values of ecosystem services, while the other tried to apply models to quantify the provision of physical ecosystem services.

Further, recent studies of ecosystem services mainly focus on the large scale comprehensive systematic analyses of ecosystem service function and value assessment, while quantitative research on ecosystem services on small scale is relatively less. In this paper, taking the middle reach of the Heihe River Basin as study area, combining land use datasets with the information on ecosystem service value coefficients derived from literature review, we aimed to evaluate the ecosystem services values (ESVs) and further to analyze the impacts of land use changes on ecosystem services. As Heihe River Basin is an ecological fragile area, where water resource plays a key role in sustaining ecosystem services, and in return, the improvement of ecosystem services will help alleviate the water scarcity pressures (Deng and Zhao, 2015; Wu et al., 2015; Li et al., 2015), thus the comprehensive analyses can support the exploration of sustainable land use management for mitigating the impacts on water scarcity and ecosystem services.

2. Data and method

2.1. Study area

The Heihe River Basin (HRB) is the second largest inland river basin located in the arid zone of Northwest China, with annual rainfall of 100–200 mm. The total length of the main stream river is more than 800 km, and the river basin covers an area of 130,000 km^2 (Xiao et al., 2014). The HRB can be divided into three parts, the upper reach region, which is the main source area of water resources, the supply of water mainly comes from the Qilian Mountains in the upper reach; the middle reach region, which is the irrigation agriculture economic zone and main water consumption area; and the lower reach region, which is mainly dominated by desert animal husbandry (Xiao et al., 2015). We select the middle reach of the HRB as study area, it covers Ganzhou district, Minle, Shandan, Linze and Gaotai county (Fig. 1). The land development in the middle reach is the most intensive in the HRB, and industrial and agricultural production are mainly concentrated in the oasis area within the middle reach. While, due to agricultural irrigation water diversion and intensive water consumption of industrial production, water problems have become an important restriction factor of the ecological and socio-economic sustainable development, leading to serious ecological environmental problems, such as degradation of natural oasis, soil erosion, and desertification.

2.2. Data

Two types of data sets were collected. On the one hand, the land-use data in 1998, 2000, 2005 and 2008 used in this study were derived from the Resources and Environment Scientific Data Center, Chinese Academy of Sciences, which were processed based on the remotely sensed digital imagines (Deng et al., 2010; Liu et al., 2010; Wu et al., 2013; Deng et al., 2014). The land use was classified into six types, including cultivated land, forest land, grassland, water area, built-up land and unused land (Fig. 2).

On the other hand, different ecosystems have different functions and therefore different capacities to provide ecosystem services. According to the theory of ecosystem service values (ESVs) put forwarded by Costanza et al. (1997), an ecosystem is composed of sub-ecosystems including cropland ecosystem, forest ecosystem, grassland ecosystem, water body ecosystem, wetland ecosystem and urban ecosystem. Based on the ecological characteristics of land use in the middle reach of the HRB, each type of land was matched with one type of sub-ecosystem. Ecosystem services supply capacities were assessed for the five major different land-use types in the study area. We choose the expert- and literature-driven method to get the information about the capabilities of different land use types to provide ecosystem services and the values of different ecosystem services, during which we collected relevant empirical studies which have the similar research context (Ausseil et al., 2013; Burkhard, 2009; Müller, 2007), and further we analyzed and extracted ecosystem service value coefficients associated with each land-use type. Table 1 shows the ecosystem service

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