Science of the Total Environment 642 (2018) 979–987

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Assessment of the ecosystem services provided by ponds in hilly areas

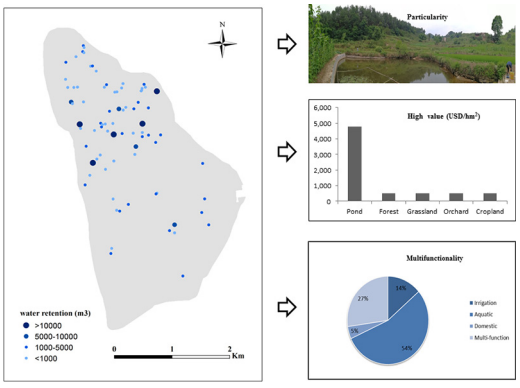
Bin Fu *, Pei Xu, Yukuan Wang *, Kun Yan, Suresh Chaudhary

Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu, Sichuan 610041, China
Wanzhou Key Regional Ecology and Environment Monitoring Station of Three Gorges Project Ecological Environmental Monitoring System, Wanzhou Chongqing 404020, China

HIGHLIGHTS

- Ponds are broadly distributed in mountainous regions.
- Water retention is the primary ecosystem service with 10 times than forest.
- Ponds have prominently been used for fish farming and leisure services.
- Ecological management of ponds in accordance with societal changes is necessary.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 March 2018
Received in revised form 11 June 2018
Accepted 11 June 2018
Available online xxxx

Editor: P. Kassomenos

Keywords:
Pond
Ecosystem services
Multi-function
Mountain areas
Three Gorges area
InVEST model

ABSTRACT

Ponds are an important ecosystem in rural landscapes. They play an important role in water retention, aquatic products supply and biodiversity conservation. By using a questionnaire-based survey of rural households in a small watershed in the Three Gorges Reservoir area, we analyzed the distribution of ponds, their size and current status. The Integrated Valuation of Environmental Services and Tradeoffs (InVEST) model was used to evaluate the regulation, provision and culture services of the ponds. We found that pond density was high throughout hilly areas. About 20 ponds were within an area of 1 km^2. They were mainly distributed in the middle and lower parts of the basin. The presence of such a large number of ponds was considered remarkable. Water retention was the primary ecosystem service. On average, each pond contained about 4500 mm depth of water, which was 10 times that of the surrounding forest. However, with the transformation of agriculture in mountainous areas, the irrigation and domestic water services provided by ponds have declined. In recent years, ponds have been used predominantly for fish farming and leisure services. Aquaculture and multi-function ponds accounted for 54.55% and 27.7% of the surveyed ponds, respectively. Multi-function ponds consumed more water, but fish farming ponds were the most economically valuable. Due to weak environmental management and the decreasing economic value of ponds, it is necessary to conduct ecological management of ponds in accordance with societal changes in mountainous areas and to promote the protection and use of ponds.

1. Introduction

Wetland ecosystems provide a range of services, including water retention, flood regulation, biodiversity conservation, and the mitigation of climate change (Zedler and Kercher, 2005; McLaughlin and Cohen,

* Corresponding authors at: Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu, Sichuan 610041, China.
E-mail addresses: fubin@imde.ac.cn (B. Fu), wangyukuan@imde.ac.cn (Y. Wang).

https://doi.org/10.1016/j.scitotenv.2018.06.138
0048-9697/

2013). Throughout the world, 2193 major wetlands are recognized, with a combined area of about 209 million m^2 (https://rsis.ramsar.org/). China has 46 of these important wetlands. In recent years, the patterns, changes, and driving forces of wetland ecosystem services have become a major global concern (Corrigan and Nieuwenhuis, 2016; Hu et al., 2017; Li et al., 2016; Li and Gao, 2016). Previous studies of wetland ecosystem services focused on natural wetlands with large areas (Wang et al., 2004; Lai et al., 2013; Guimaraes and Lowe, 2016; Howard et al., 2016). However, the impact of human activities, such as agricultural development, urban development, and road construction has seriously degraded wetland areas (Choi and Bury, 2003; Na et al., 2008; Van Dam et al., 2015).

In the Ramsey Convention, wetlands are divided into three major categories; coastal wetlands, inland wetlands, and constructed wetlands (Ramsar, 1971). These categories can be further divided into 42 sub-categories (Ramsar, 1971). Ponds are generally small areas of still water. They are one of the most important types of constructed wetlands and they are prevalent mainly in agricultural landscapes (Son et al., 2014; Natsumeda et al., 2015). In 1989, at the beginning of a conservation program in the UK in 1989, an assessment was conducted to clarify the number of ponds, including their distribution, variation, and biological diversity (Jeffries, 2010; Williams et al., 2010; Munns et al., 2016). Prach and Tolvanen (2016) reviewed the program's implementation and noted the challenges of pond conservation. The study addressed the fact that simple indicators cannot reflect the complexities of biodiversity. Ponds are commonly distributed throughout farmland areas in South Korea. Some studies have found that ponds provide multiple ecosystem services such as water retention, vegetation diversity, and education (Son et al., 2014). The vegetation type and pond size have a significant impact on the biodiversity of agricultural ponds (Natsumeda et al., 2015). Several ponds have been artificially created in the central United States to meet the needs of agricultural irrigation. Hydrological processes in ponds have been integrated into agricultural management systems such as the Farm Pond Water Irrigation Management System (FPWIMS) and the Structural Thinking and Experiential Learning Laboratory with Animation (STELLA) model (Feng et al., 2015; Ouyang et al., 2017).

The protection and use of ponds have not been given much attention in most areas where there is a scattered distribution of small ponds. The abandonment, demise, and pollution of ponds have become increasingly prominent (Cirovic et al., 2016; Mupepele et al., 2016). For example, in Scotland, 50% of small ponds have disappeared as a result of agriculture and urban development (SEPA, 2000). In China, eutrophication is widespread in agricultural ponds (Martinez et al., 2016). Thus, there is a significant knowledge gap regarding the role of ponds or natural wetlands on ecosystem services (Son et al., 2014; Prach and Tolvanen, 2016). Ponds are highly susceptible to changes in human activities; thus, a better understanding of patterns, trends, better protection, and utilization are necessary.

Southwest China is dominated by mountain landforms. The increasing demand for agricultural management and irrigation has resulted in the construction of many ponds. This has a significant impact on the hydrological cycle. Pond ecosystem services are also important for sustaining rural production and livelihoods. Although rapid urbanization has changed the structure and function of ponds, there have been few reports of the ecosystem services they provide. We conducted an integrated survey in a small watershed in the Three Gorges Reservoir area in order to: (1) identify the distribution and characteristics of mountain ponds; (2) evaluate the ecosystem services of ponds, and (3) analyze the trends in the use, challenges, and protection of ponds.

2. Materials and methods

2.1. Study area

The Three Gorges Reservoir Area is located in southwest China. The terrain is mainly dominated by hills and low altitude mountains. A large number of paddy fields have been constructed for grain production throughout the area. The government and rural households have actively developed different sized ponds for irrigation and it was found that the number of ponds has increased since the 1960s. We conducted our survey in the Chengjiagou watershed in the central Three Gorges Reservoir area. This small watershed is 20 km from downtown Wanzhou City. The watershed covers an area of 8.1 km^2, with more than 80% of the area occupied by forests and cropland. The Wanzhou ecological environment monitoring station, which services the Three Gorges ecological and environmental monitoring network is located in this watershed and monitors land use changes and hydrological conditions (Fang, 2017). A climate recording system, with five rainfall observation points and five hydrological observation points has been established for automatic observation (Fig. 1).

2.2. Land use survey using an unmanned aerial vehicle (UAV)

The study area was located in the Three Gorges parallel ridge-and-valley area where there is a mountain canopy that experiences a high incidence of fog. We used a quad rotor UAV (unmanned aerial vehicle) to conduct remote sensing surveys and obtained the land use conditions and location of ponds throughout the area. UAVs have been widely used for surveying and mapping in recent years (Christensen, 2015; Pedras et al., 2015). We used the Phantom 3 professional quadrotor UAV to conduct two aerial surveys. We divided the study area into 500 m grids. There were 38 takeoff points and flights were performed at a height of 300 m from the ground. The captured aerial images were processed by PhotoScan software and image data were acquired with a resolution of 0.2×0.2 m. Cognition analysis was used to stitch images to interpret land use in the study area (Ding, 2005). The density of ponds in the study area was very high and the ponds and paddy fields were inlaid and arranged to form a complete irrigation system (Fig. 2).

2.3. Household survey

We conducted a household survey in typical pond landscape in February 2015 (Fig. 3), and a participatory rural appraisal was used to conduct structured face-to-face interviews with pond managers (Chambers, 1994). We interviewed the managers of 66 ponds to obtain data on topics such as regulation services and storage capacity. The factors relating to water supply services were irrigation area, population, and numbers of people using the pond water. Data collected covered the provision of aquatic products including fish species, quantity, weight, harvest and sales revenue. Data relating to recreational services included the numbers of people who fished, time spent fishing and income. Other considerations included crop acreage, crop yield and income in order to compare income differences between fish farming and arable farming.

2.4. Assessment of the ecosystem services of ponds

According to the classification of the Millennium Ecosystem Assessment, ponds provide various ecosystem services, including provision, regulation, and cultural services (Mace, 2008). The services provided by ponds are determined by the demand generated from the surrounding households. Ponds are normally used for irrigation, aquaculture, and domestic water supply, but they also provide regulation services, such as water retention, sediment control, and water purification, as well as fishing, sightseeing and other leisure activities. We assessed aquatic products, water retention, and fishing as representative types of provision, regulation and recreation services (Table 1). Other services such as soil conservation and flood mitigation were not considered in this study.

Methods commonly used to assess ecosystem service include models, matrix scores, and questionnaires (Turner et al., 2016). Various evaluation models have been used, such as InVEST, Soil and Water