Land Use Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Land Use Policy

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

Transforming flash floods into resources in arid China

Junze Zhang[a,b], Zhongqi Yu[c], Tengfei Yu[d], Jianhua Si[d], Qi Feng[d], Shixiong Cao[a,*]

[a] School of Economics, Minzu University of China, No. 27, Zhongguancun South Street, Haidian District, Beijing, 100081, PR China
[b] Faculty of Geographical Science, Beijing Normal University, No. 19, Xinjiekouwai Street, Haidian District, Beijing, 100875, PR China
[c] College of Economic Management, Beijing Forestry University, No. 35, Qinghuadong Road, Haidian District, Beijing, 100083, PR China
[d] Cold and Arid Regions Environmental Engineering Research Institute, CAS, No. 320, Donggang West Road, Lanzhou, Gansu 730000, PR China

ARTICLE INFO

Keywords:
Flash floods
Flood resources management
Sustainability
Private enterprise

ABSTRACT

Flooding causes huge economic losses, yet the flood water is an important resource, especially in arid and semi-arid areas. Because rivers flood annually, most flooding research has focused on river management. Researchers have largely ignored the resource potential of flash floods, as they are less predictable. Here, we describe an innovative project in which disaster management planners in a dryland community in northwestern China treated flash floods as a resource rather than as a threat, and helped the community to benefit from this resource. The project produced ecological benefits (combating desertification), social benefits (flood control), and economic benefits (harvesting water for future use) that improved the community's adaptive capacity and facilitated sustainable development. This example should inspire risk managers to seek ways to transform natural disasters into resources, thereby improving hazard management and promoting community survival and development.

1. Introduction

Flooding is a recurring phenomenon around the world, particularly in river basins, which frequently experience annual flooding. Management of rivers to prevent or minimize flood damage has been an important research topic around the world, as it threatens both human structures, natural systems (e.g., riparian vegetation), and the coupling between human and natural systems (Hering and Ingold, 2012; Kiedrzyńska et al., 2014; Gain et al., 2016). Floods have been defined as hydrological phenomena that result in a sharp increase in water flow or a rising water level that exceeds the capacity of rivers, lakes, and reservoirs to accept the water (Burrel et al., 2007). Flooding is a natural process that often has significant ecological benefits, such as the deposition of rich and fertile sediments in the land adjoining the river and replenishing groundwater. However, when floods cause economic losses or threaten human survival and social development, they are considered to be "disastrous" (Shrestha, 2008; Shrestha et al., 2008). Floods fall into different categories, including open floods, urban floods, flash floods, channel-jam floods, and riverine surges, with the category depending on the cause and location of the flooding (Burrel et al., 2007). Floods killed an estimated 100 000 persons annually and affected 1.4 billion people worldwide during the 1990s, with significantly higher mortality and number of people affected per event in Asia (Shrestha, 2008; Shrestha et al., 2008).

Humans are endangered by flooding because water is an essential resource for survival, leading to the establishment of cities and other structures close to bodies of water. To prevent flood disasters, reduce the losses caused by floods, and make more efficient and rational use of the water provided by floods, researchers have studied the phenomenon around the world, including Bangladesh (James, 1994), Canada (Yin, 2001), Nepal (Shrestha, 2008; Shrestha et al., 2008), Africa (Di Baldassarre et al., 2010), the United States (Calil et al., 2015), England (Howarth, 2017), and South Korea (Lee and Brody, 2018). A review of these studies suggests that there are two main kinds of measures to deal with flooding. The first involves structural measures, and represents action to reduce the effects of floods by means of physical interventions (the creation of structures) such as retention basins, embankments, dredging, diversions, dams, levees, floodwalls, elevated buildings, and flood-proofing of property. The second involves non-structural measures, such as land-use planning, floodplain zoning, early warning systems, and flood insurance (Burrel et al., 2007; Shrestha, 2008; Shrestha et al., 2008). Although both structural and non-structural measures can reduce the economic losses caused by floods, they generally cannot make full use of flood resources such as water and sediment deposition. As a result, integrated water resources management (IWRM) is receiving increasing attention (Gain et al., 2017; Howarth, 2017).

IWRM currently lacks a unified definition, but generally refers to a system of management processes that aim to achieve coordinated development and management of water, land, and related resources, with

* Corresponding author.
E-mail address: shixiongcao@126.com (S. Cao).

https://doi.org/10.1016/j.landusepol.2018.03.002
Received 1 November 2017; Received in revised form 14 January 2018; Accepted 1 March 2018

the goal of equitably maximizing the overall economic and social welfare without compromising the sustainability of vital ecosystems (Shrestha, 2008; Howarth, 2017). Gain et al. (2017) suggested seven dimensions that could be used to evaluate IWRM implementation in a country: (i) integrated management; (ii) using whole river basins as the spatial scale; (iii) development of a water governance policy and institutions to administer that policy; (iv) a multi-stakeholder approach; (v) valuation of the resources; (vi) gender equity and social good; and (vii) ecology and environment.

Despite the laudable goals of IWRM, its application is difficult because of these many dimensions, leading to a need to take full account of a range of social and natural conditions and to work together across sectors with many stakeholders (Gain et al., 2017). An additional problem is that flood management research has traditionally focused on riverine floods, which tend to be predictable and follow annual cycles such as prolonged heavy rain during the monsoon season and which tend to affect whole managed watersheds, where they can be monitored and predicted. These approaches may not be relevant for flash floods, which are caused by short but intense rainfall in mountainous or arid regions. These floods cannot be easily converted into water resources due to the difficulty of predicting them soon enough to take the necessary action when they occur (Shrestha, 2008; Shrestha et al., 2008). Therefore, flash floods remain a potentially important resource in mountains and semi-arid to arid regions, but one that is difficult to safely exploit.

Floods are potentially the most serious natural disasters in China. From 1991 to 2008, the direct economic losses caused by floods in China totalled 2.2×10^{12} RMB (an annual average of 0.12×10^{12} RMB), accounting for 48% of the total economic losses caused by natural disasters (Wan and Wang, 2011). China's arid and semi-arid regions suffer from a serious shortage of freshwater resources, as the precipitation is extremely variable, leading to high variation in surface runoff. Therefore, flash floods are precious freshwater resources, but are resources that have rarely been exploited. In this paper, we describe the results of nearly 20 years of hard work in an arid region of northwestern China, where governments, private industry, and residents of the study area have cooperated to provide a successful example of how to utilize the flash flood resource. We highlight the important roles of enterprises and consultation among all stakeholders in reducing flood disasters and driving local economic development. The results of our study will provide an important new example of IWRM that can potentially be applied in China and other parts of the world where flash floods are both a problem and a potentially important resource.

2. Methods

2.1. Study area

Our study took place in Yangguan Town, which is located in a region of northwestern China's Kumtag Desert, in Dunhuang County of Gansu Province (Fig. 1). This area has suffered from a combination of flash floods and desertification. According to the Koeppen-Geiger Climate Classification, the arid desert area corresponds to the BWk climate type (Kottek et al., 2006). The annual temperature averages 9.3 °C, with mean monthly temperatures ranging from 24.7 °C in July to −9.3 °C in January. Due to the low mean annual precipitation (39 mm yr^{-1}) and high potential evapotranspiration (2480 mm yr^{-1}), there is little near-surface water, and meltwater from the Altun Mountains is the region's main water source. Both natural ecosystems and human communities rely on this water for their survival. Like the many impoverished regions in drylands around the world, poverty is the most significant problem for residents due to the low soil fertility and the remoteness from markets (Reynolds et al., 2007).

Historically, desertification caused by expansion of the Kumtag Desert has posed serious threats to Yangguan Town. From 1982 to 2005, Yangguan Town experienced an unusually severe drought, with evaporation reaching 80–100 times annual precipitation and the groundwater table declining to depths below 20 m, causing the death of large numbers of sheltering trees and leading to serious expansion of desertification. A similar problem occurred due to changes in land cover in arid areas of Ethiopia (Alemayehu et al., 2009; Demissie et al., 2015). Despite the aridity of the region surrounding Yangguan, flash floods during the summer have become one of the biggest threats to local residents. For instance, the annual flood frequency from 2005 to 2007, before implementation of the project described in this paper, averaged 12 times, and the floods caused serious damage to buildings and infrastructure. Based on observations at regional meteorological stations, the region's climate is becoming wetter. Precipitation during the rainy season has increased from an average of 32.4 mm during the 1960s to 54.8 mm during the 2000s (Chen et al., 2017). This suggests that flash floods may increase in frequency. Meltwater in the spring and heavy rainfall events during the spring and summer cause water to flow from the eastern slopes of the Qilian Mountains and the western slopes of the Altun Mountains into our study area, often leading to flash floods (Chen et al., 2017).

Yangguan Town has been facing an environmental poverty trap: the community's vulnerability to natural hazards exacerbates its poverty and its poverty prevents it from responding adequately to these hazards. To protect itself against flooding, the community has constructed simple flood-defence structures such as barriers and drainage ditches and has planted shelter forests. However, these measures have proven to be ineffective. To take advantage of the region's abundant solar radiation and dramatic daily temperature swings, the community has attempted to develop a fruit industry. Unfortunately, these efforts were compromised by flash floods that destroyed the flood-defence structures and a lack of sufficient water to irrigate the orchards or sufficient fertilizer to ensure good crops when water was sufficient. In addition, the lack of warning of potential flooding means that flash floods emerging from the Kumtag desert could not be predicted, leading to a serious threat to lives and farmland (mainly orchards), and often destroying infrastructure such as roads and buildings. Before the flood-management project described in this paper was implemented, damage from flooding averaged more than 70×10^6 RMB annually (Cao and Zheng, 2016). Under these conditions, it has been impossible for the community to simultaneously create effective flood protection and alleviate their poverty.

2.2. A strategy for utilization of flash floods

China has no experience transforming flash floods in its drylands into a resource to mitigate the regional water scarcity. To provide such experience, China's Ministry of Science and Technology and the Chinese Academy of Sciences collaborated with an aquaculture firm to explore the possibility of converting flash floods into a resource that would help local people to escape their environmental poverty trap. The project was planned in 2000 and implementation was conducted from 2005 to 2007, covering 21.3 km^2 of desert near Yangguan Town. The Chinese Academy of Sciences provided scientific support, China's Ministry of Science and Technology provided financial support, and a local aquaculture firm implemented and managed the project. The investment in the project has been 190×10^6 RMB: 180×10^6 RMB from the aquaculture company and 10×10^6 RMB from the government. (For readers who are interested in learning the value of the RMB in their own currency, we recommend the following Web site: http://www.bankofcanada.ca/rates/exchange/currency-converter/).

In any such project, there will inevitably be trade-offs, and the stakeholders must collectively determine which values (e.g., ecosystem services) should be prioritized (Lankford et al., 2011). In the present study, developing a strategy to utilize flash floods required the involvement of governments, scientists and other researchers, a private-sector company, and the community affected by the project to identify the optimal combination of economic development, risk management,