Ecological Economics 122 (2016) 25–35

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Dredging versus hedging: Comparing hard infrastructure to ecosystem-based adaptation to flooding

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ARTICLE INFO

Article history:
Received 18 March 2015
Received in revised form 19 November 2015
Accepted 27 November 2015
Available online 17 December 2015

Keywords:
Disaster risk reduction
Cost–benefit analysis
Floods
Ecosystem-based adaptation

ABSTRACT

Efforts to ameliorate flooding have historically centred on engineered solutions such as dredging rivers, building levees, and constructing spillways. The potential for ecosystem-based adaptation (EbA) options is becoming increasingly apparent; however, implementation is often limited by a poor understanding of their costs and benefits.

This study compares the costs and benefits of a range of hard infrastructure and ecosystem-based adaptation options to mitigate flooding under climate change using data from two catchments in Fiji. We employ unique survey data to document the costs of flooding under various climate change scenarios. We then use a hydrological model to simulate the potential benefits of a range of hard infrastructure and EbA options and conduct a comprehensive cost–benefit analysis.

We find that under reasonable economic assumptions, planting riparian buffers is the most cost-effective option, yielding benefit–cost ratios between 2.8 and 21.6. However, the absolute level of protection provided by this strategy is low. Afforestation provides greater overall benefits, yielding net present values between 12.7 and 101.8 million Fijian dollars, although implementation costs would be substantial. Planting floodplains and reinforcing riverbanks provide some monetary benefits that are lower than riparian and upland planting. Elevating houses is not economically viable under any climate scenario.

1. Introduction

Flooding is the most common, widely experienced, and deadliest form of natural disaster (UNISDR, 2015). In 2012, flooding disasters affected 53% of all global disaster victims and caused 42% of all disaster fatalities (Guha-Sapir et al., 2013). Over the last 70 years, the number of weather-related natural disasters increased globally, with disproportionately large increases in the incidence of flooding (Munang et al., 2013). Hydrological disasters are closely linked to climate and are expected to increase in frequency and severity under climate change (PICCAP, 2005; Bates et al., 2008). Climate change shifts not only the average precipitation totals but also their statistical distributions such that extremes of high, low, heavy, and light precipitation become more common in both absolute and relative terms (Boé et al., 2009). According to the IPCC (2012), it is likely that the ratio of heavy rainfall to total rainfall will increase over the 21st century, particularly in regions affected by tropical cyclones. In many parts of the world, annual maximum daily precipitation amounts that have a probability of 1-in-20 years today are likely to have a probability of between 1-in-5 and 1-in-15 years by 2100 (IPCC, 2012).

Historically, efforts to mitigate flooding have centred on engineered solutions such as constructing levees, dredging rivers, and strengthening buildings (Hills et al., 2013; Yeo et al., 2007; Ambroz, 2009; Chaudhary, 2012; Brown et al., 2014). Recently, however, interest in ecosystem-based adaptation (EbA) strategies such as replanting of headwaters and riparian zones has been prominent (Shreve and Kelman, 2014). While EbA strategies often provide less protection than engineered flood defences overall, they are generally far cheaper and easier to maintain, and they may provide substantial co-benefits (Hills et al., 2013; Naumann et al., 2011; Rao et al., 2013).

Despite this potential, EbA implementation remains uncommon. A lack of technical capacities within government planning agencies has limited the uptake of EbA in a number of regions (Hills et al., 2013; Hay and Mimura, 2013) because decision makers often allocate funds to high-profile, post-disaster response measures rather than to prevention strategies (Benson and Twigg, 2004). Furthermore, social and economic conditions in at-risk communities are not well understood, and decision makers are often sceptical of the ability of EbA to reduce disaster risk (Lal, 2011; SPREP, 2011). Hills et al. (2013) point out that there is a paucity of literature describing the costs and benefits of alternative adaptation options and further suggest that this lack of information has contributed to a gap between the conceptual rationale for EbA and its application in practice.

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http://dx.doi.org/10.1016/j.ecolecon.2015.11.023
0921-8009/

Without additional evidence on the effectiveness and costs a variety of adaptation approaches, decision makers may allocate resources suboptimally when planning for climate-related disasters (UNEP, 2013; Jones et al., 2012). Hence, there is a need to evaluate the potential effectiveness of various adaptation approaches to mitigating flood risk. In this paper, we assess the potential for EbA to protect against flooding in Fiji. The Pacific Islands suffer the highest per capita natural disaster losses of any region (World Bank, 2012), and Fiji is particularly susceptible to extreme weather events. For example, major natural disasters caused damages amounting to at least 4.3% of the nation's GDP in 2012 (Brown et al., 2014).

This paper uses survey data from 2013 to assess the costs and benefits of a range of hard infrastructure and ecosystem-based adaptation options to mitigate flooding. We combine the survey data and a hydrological model to simulate the potential benefits of a range of hard infrastructure and EbA options and conduct a comprehensive cost–benefit analysis (CBA). The case study area includes the Ba and Penang catchments on Viti Levu, Fiji, which were impacted by significant flooding events in January and March 2012 and are expected to experience more frequent flooding events in the future as a result of climate change. In line with best practice, we model costs and benefits under a range of climate change scenarios and test the sensitivity of the analysis to alterations of its major assumptions, including the severity of climate change on flood events in the region (Reed et al., 2013; Shreve and Kelman, 2014).

2. Methods

The foundation of this study is an extensive socioeconomic survey that quantifies the direct and indirect impacts of flooding in the Ba River and Penang River catchments. Hydrological models of the two river catchments were developed to simulate flood damages and to evaluate the effect of infrastructure development and ecosystem-based adaptation on future flood damage. We then employ cost–benefit analysis (CBA) – a systematic approach to identifying, valuing, and comparing options – to assess and rank the economic viability of several adaptation strategies. Our approach is similar to previous research on catastrophic natural disaster risk management (e.g., Grossi and Kunreuther, 2005) and damage assessment modelling (e.g., Merz et al., 2010), which we extend by using detailed survey data to estimate a wide range of benefits and costs for a several conventional and EbA-focused flood mitigation options.

2.1. Study Sites

This study evaluates options to adapt to climate-related hazards in the Ba and Penang River catchments located on the island of Viti Levu (Fig. 1). Both river catchments have been susceptible to flooding in the past (McGree et al., 2010), including large flood events in January and March 2012.

The Ba River runs north from its headwaters in the central, mountainous parts of Viti Levu, spilling into the Pacific near the village of Nailaga. "Ba" is also the name given to the province, a *tikina* (an administrative area comprising several towns and/or villages), and a prominent town. The population of the Ba district is predominantly rural and generally poor, with 34% of residents below the poverty line (Narsey, 2008). Some 45,879 people live within the boundaries of the Ba River catchment, most of them in Ba Town and downstream, where flooding is a particular risk.

Bordering Ba Province on the east, the Penang River catchment located in Ra Province is comparatively small, with just 29,464 residents at the time of the 2007 census. Approximately 15% of the population lives in Rakiraki Town, its only urban settlement, with the remaining 85% living in scattered rural settlements and villages. Overall, 53% of the population of Ra Province live below the poverty line (Narsey, 2008), suggesting that this population is especially vulnerable to natural disasters. The Penang River is the district's main waterway and flows approximately 1 km outside Rakiraki Town. While the Penang River is considerably smaller than the Ba River, significant flooding and forced evacuations in recent years have prompted the Rakiraki provincial administrator to call for proposals to divert the river and/or to relocate Rakiraki Town (Fiji Ministry of Information, 2012).

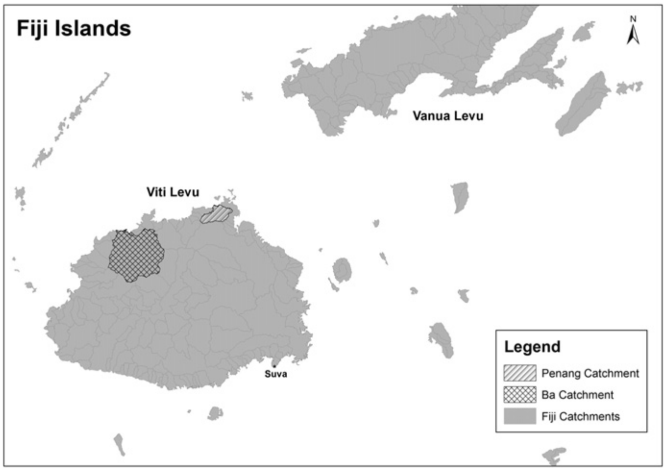

Fig. 1. Fiji Islands, with location of Ba and Penang River catchments.

2.2. Household and Community Surveys

A detailed socioeconomic survey of residents in the Ba and Penang River catchments was conducted in early 2013. To draw the sample for the Ba River catchment, the population was stratified geographically, with one-third selected from the upper catchment area, one-third from the mid-catchment area, and one-third from the lower catchment area (see Fig. 2). The population in each area was further stratified by ethnicity to ensure both geographic and ethnic representativeness in the sample. Villages (officially recognised entities that are the exclusive domain of indigenous Fijians, or *iTaukei*) and settlements (informal clusters of houses that are dominated by Indo-Fijian) were drawn based on probability sampling. In this way, 14 villages (58% of those registered in the catchment) and 14 settlements (representing approximately 32% of the Indo-Fijian population) were surveyed in the Ba River catchment. In each community, a separate survey was administered to a community leader who was familiar with local finances and infrastructure. In addition, surveys pertaining to *mataqali* (i.e., clan) land and assets were administered to a representative sample of *mataqali* leaders in each village. In total, 295 households, 28 community leaders, and 41 *mataqali* leaders were surveyed in the Ba River catchment.

The Penang River is smaller than the Ba River in terms of length, elevation drop, and at-risk population. Therefore, the population was stratified only by ethnicity. A total of 74 households, eight community leaders, and 12 *mataqali* leaders participated in the survey, drawn from three villages and five settlements (see Fig. 3).

The household survey consisted of questions on demographics, education, and health; cropping, livestock, fishing, and forestry; labour income, remittances, durable goods, and housing; and time allocation. The survey also included several novel elements applicable to the social and economic impacts of natural disasters. For example, respondents were asked to reflect on environmental challenges ranging from flooding and cyclones to expiring land leases and invasive species, noting which had adversely affected them in recent years and whether the problem had increased, decreased, or been unchanged over the preceding decade. Respondents were also asked to identify and rank the