COSTS AND BENEFITS OF ECOSYSTEM-BASED ADAPTATION FOR FLOOD RISK REDUCTION IN FIJI

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Abstract
This paper quantifies the economic impacts of flooding in the Ba River and Penang River catchments in Viti Levu, Fiji. We conducted a detailed assessment of flood damage stemming from two major flooding events in 2012 that severely affected the two important catchments, primarily by using evidence from a novel survey administered in early 2013. We combine these empirical measures of damage with GIS data to estimate total damages from flooding and find that the January 2012 flood caused FJ$36.4 and FJ$12.2 in damages for the Ba River and Penang River catchments, respectively, while the March 2012 flood caused FJ$24.1 and FJ$8.4 in damages for the Ba River and Penang River catchments, respectively. We then estimate the cost of future flooding under moderate and severe climate change projections. Flooding is projected to become more frequent and more severe under both scenarios, with annual losses increasing by 100% with moderate climate change and by 300% with severe climate change. For perspective, damages from a 1-in-50 year flood, which is the estimated return period of the January 2012 event, are projected to cause between FJ$76.5 and FJ$153 million in damages in the Ba River Catchment under these two scenarios.

Keywords
Natural disasters; climate change; flooding; Pacific Islands; economic impacts

1 Introduction

The Pacific is highly vulnerable to natural disasters (Weir and Virani, 2011), which cause average annual direct losses of USFJ$284 million in the Pacific (World Bank, 2012). With a combined population of fewer than 10 million people, these losses are the highest in the world on a per-capita basis (World Bank, 2012). The Fiji Islands is no exception (e.g., Gero *et al*., 2011). For example, in 2012, three natural disasters – one 50-year flood, one 25-year flood, and one Category 4 cyclone – ravaged the northern and western parts of Viti Levu, Fiji's largest island. Early estimates of damage equalled 4.3% of national GDP (Simmons and Mele, 2013).

In this paper, we assess economic vulnerability associated with flooding in Fiji. Specifically, we begin by putting the two flooding events into the context of natural disasters that have impacted Fiji over the last century. We then describe the sites used in this study, namely, the Ba River and Penang River catchments in western and northern Viti Levu, respectively. Next, we provide a detailed assessment of flood damage at the household level in these catchments – including both amounts and types of damage – using evidence from a novel survey conducted in early 2013. Fourth, we combine these empirical measures of damage with GIS data to estimate total damages from flooding in these two areas. Finally, we estimate the cost of future flooding under two climate projections, one moderate and one extreme. We find that flooding is enormously costly in economic terms and that annual losses will increase dramatically with even moderate climate change.

2 Natural disasters in Fiji

Three of the worst natural disasters in Fijian history were prompted by cyclones. In late February 1931, a slow moving hurricane struck Fiji's largest island — Viti Levu — causing estimated 1-in-250 year flooding of the Ba River (McGree *et al.*, 2010). At least 126 people were killed, with a further 99 killed elsewhere in Fiji (Yeo and Blong, 2010). Hurricane Kina caused nine fatalities and resulted in approximately FJ$188 million in damage in 1993 (World Bank, 2000), and Cyclone Ami caused 17 fatalities and resulted in FJ$104 million in damage in 2003 (NDMO, 2003).[1]

However, parts of Fiji are extremely vulnerable to flooding even without cyclonic activity. For example, a persistent monsoon trough triggered record rainfall over five days in January 2009. Severe flooding of the Ba, Nadi, and Sigagtoka rivers ensued, with the Ba River reaching 3m above flood level at the Rarawai mill, eclipsing all previous flood records bar that of 1931 (McGree *et al.*, 2010). 11 lives were lost during the floods and 11,458 people were forced to seek shelter in evacuation centres (Ambroz, 2009). Sugarcane crops were badly damaged, as was infrastructure such as bridges and roads. Public utilities were disrupted for more than a fortnight, and the government declared a 30-day state of natural disaster. In the immediate aftermath, the total costs were estimated at FJ$113 million by the Fijian government (FMS, 2009). This figure was later revised up to FJ$175 million (McGree *et al.*, 2010). Flooding along the Ba River caused FJ$56 million in damage and losses to households and FJ$31 million in damage and losses to businesses Ambroz (2009).

The Ba River flooded catastrophically twice more in early 2012. During January, a broad tropical depression brought over 400mm of rainfall, prompting flooding across western Viti Levu. 1,300 people sought shelter from floods and 11 people were killed

[1] At the time of writing, USFJ$1 = FJ$1.83.

(Molan, 2012). Two months later, another tropical depression caused heavy rainfall across northern and western Viti Levu, which led to additional flooding. In this event, 15,000 people were temporarily displaced and four were killed (Simmons and Mele, 2013). Early estimates of the damages caused by the two floods top FJ$130 million (NDMO, 2012; UN Country Team in Fiji, 2012).

3 Study sites

This study evaluates the impact of flooding in two catchments located on the island of Viti Levu, Fiji (Figure 1). 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.

Located in north-western Viti Levu, Ba is the second largest province in Fiji by area and the largest by population, with 231,762 residents according to the 2007 census (Fiji Bureau of Statistics, 2012b). Two-thirds of the residents in the province are of Indo-Fijian ethnicity and are largely descended from indentured labourers brought to Fiji to work on colonial sugar cane plantations between 1879 and 1916. The remaining one-third of the population is comprised of *iTaukei*, i.e., indigenous Fijians of Melanesian descent. Sugar production, timber harvesting, and fishing are important commercial activities, although the population is largely rural and generally poor: Narsey (2008) reports a 34% poverty rate in Ba Province.

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. Indeed, the Ba River is subject to frequent flooding, with flooding recorded in 1871, 1892, 1918, 1931, 1938, 1939, 1956, 1964, 1965, 1972, 1986, 1993, 1997, 1999, 2009, and 2012 (McGree *et al*. 2010). Recorded flood peak heights and a trend line for the Ba River at the Rarawai sugar mill near Ba Town are shown in Figure 2 (Yeo *et al*., 2007; Yeo, pers. comm, 22 July 2013). As noted above, several of these floods have been catastrophic, leading to significant loss of crops, property, and life.

The Penang river catchment located within neighbouring Ra Province is comparatively small, with just 8,300 residents at the time of the 2007 census (Fiji Bureau of Statistics, 2012b). Approximately 55% of the population lives in Rakiraki Town, its only urban settlement, with the remaining 45% living in scattered rural settlements and villages. Nearly 55% of the population is of Indo-Fijian ethnicity and about 45% is ethnically *iTaukei* . Sugar production is the main economic activity, although tourism and cattle rearing are also locally important industries. Narsey (2008) reports that 53% of the population of Ra Province earns less than the poverty line, suggesting that this population is especially vulnerable to disasters.

The Penang River flows approximately 1 kilometre outside Rakiraki Town. Historical records indicate that he river flooded in 1914, 1939, 1956, 1972, 1986, 1999, 2004, 2009, 2012, and 2014 (McGree *et al*. 2010). Although 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).

4 Methods

To develop empirical estimates of the cost to the 2012 floods along the Ba River, we conducted a detailed socioeconomic survey of catchment residents in early 2013. Specifically, we stratified the potential sample geographically, selecting approximately one-third of the sample from the upper reaches (from the ridge line through Navala), one third from the middle reaches (just downstream of Navala to just upstream of the Rarawai Sugar Mill), and one-third from the lower reaches (from the Rarawai Sugar Mill upstream from Ba Town through the river mouth near Nailaga). See Figure 3.

Within each part of the catchment, we further stratified the sample by ethnicity to ensure that our sample is representative of the region's population, and villages (officially recognized entities that are exclusively *iTaukei*) and settlements (informal clusters of houses that are largely Indo-Fijian) were drawn based on a probability sample. Prior to the start of the survey, enumerators visited each village/settlement (hereafter, “community”) to *sevusevu*, to explain the purpose of the research in broad terms, and to set appointments with 12 heads of households drawn at random from community rosters; in settlements in which fewer than 12 households resided, households from nearby settlements were added, again based on a probability sample.

In this way, 14 villages (58% of all registered villages in the catchment) and 14 settlements[2] were included in the survey. In each community, a separate survey was administered to a community leader who was familiar with local finances and infrastructure. In villages, this questionnaire was answered by the village headman; in settlements, a respected elder was identified to respond to this questionnaire. In addition, separate surveys pertaining to *mataqali* (i.e., clan) land and assets were administered to a representative sample of *mataqali* leaders in each village. Thus, 28 community leaders and 41 mataqali leaders were surveyed throughout the Ba catchment. In addition, 96 households were surveyed in the upper Ba catchment, all of them *iTaukei*. In the middle Ba catchment, 102 households were surveyed, 47% *iTaukei* and 53% Indo-Fijian. In the lower Ba catchment, 97 households were surveyed, 38% *iTaukei* and 62% Indo-Fijian. See Table 1.[3]

The Penang River is smaller than the Ba River in terms of length, volume, elevation drop, and at-risk population. Hence, we stratified this sample only by ethnicity. The 74 households that participated in the survey (49% *iTaukei* and 51% Indo-Fijian) were drawn from three villages and five settlements (Figure 4). Eight community leaders and 12 mataqali leaders were also surveyed. As with the Ba catchment, all communities were visited prior to enumeration. Again, the sample in any settlement comprising fewer than 12 households was augmented by adding households in neighbouring settlements selected via probability sampling.

Approximately 95% of randomly selected household heads kept their appointments with the survey enumerators. In most of the remaining cases, the household head delegated a household member to respond to the survey on his or her behalf. In the eight cases where neither the household head nor a delegate was available at the scheduled time, alternate households were identified in the same communities to serve as replacements. In villages, FJ$30 was donated to the village fund for each survey completed; in settlements, FJ$30 was

[2] Most settlements are not officially recognized, so the percentage of settlements included in the survey is difficult to ascertain. However, the 2007 census registered 3932 rural Indo-Fijian households in the Ba River catchment; the settlements in which we surveyed encompass 1780 households, indicating that 32% of rural Indo-Fijian households are covered by the sample.

[3] Detailed information on the size of each community, the main ethnicity of each community, and the number of households surveyed in each community is available in Table A1 in Supplemental Information.

paid directly to the respondent to acknowledge the time and effort required to participate in the survey.

The community leaders' survey recorded data on community demographics and the value of financial accounts and community assets such as schools, places of worship, halls, dispensaries, canteens/co-ops, lodges, roads, improved footpaths, bridges, vehicles, water storage systems, power lines, generators, communal land, docks, seawalls, boats, monuments, cemeteries, tools, and other durable goods as of 1 January 2012. Respondents were then asked to indicate which assets were damaged and the actual or estimated costs of repair for the two flood events. Finally, community leaders were asked to discuss the causes of natural disasters and to identify possible responses. This survey took 45 minutes to complete, on average.

The *mataqali* leaders' survey covered *mataqali* assets such as crops, livestock, forestry, equipment, and leased land. For each asset, respondents were asked to discuss the extent and value of damage incurred as a result of the two floods. This survey took 30 minutes to complete, on average.

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 pertaining to the socioeconomic impacts of natural disasters. In particular, respondents were asked a series of detailed questions regarding the two major floods of 2012. Specifically, respondents were asked:

- whether they had received warning of each disaster (and how);
- whether they evacuated (and for how long);
- whether there was damage to housing and durable goods (and how much);
- whether they lost electricity or the ability to travel to work (and for how long);
- whether they spent money on food or temporary shelter (and how much);
- whether they lost wages (and how much);
- whether they incurred expenses protecting their homes from disasters and/or cleaning up after them (and the value thereof); and
- whether the disaster caused injury or sickness (and the details thereof)

The surveys were conducted over a four-week period in February and March 2013. The enumeration team included two of the co-authors as well as staff and students from the Fiji campus of the University of the South Pacific. The surveys were enumerated electronically using tablet computers. Computer-assisted data collection enabled very complex logic[4], and up to 2,740 data points were collected for each household. The tablets also allowed the survey to be adaptable, making the questionnaire available in the language preferred by the respondent.[5] On average, the survey took 103 minutes to complete.

The survey results were aggregated to estimate population-level impacts using GIS and 2007 census data that are presented at the level of sub-district enumeration areas. The population by survey site was estimated by creating boundaries that were equidistant from

[4] For example, general data were collected on up to 34 different crops, but detailed production data were only collected for the five crops that were considered to be most important by each household. Similarly, the survey collected different types of information for different fish species depending on habitat and seasonality.

[5] Electronic enumeration also facilitates quality assurance while the enumerators are in the field and eliminates data-entry error.

adjacent sites (i.e., Voroni polygons). The 2007 census data were then overlayed onto polygons containing survey sites to partition the population. Population in census polygons located within more than one survey site polygon were divided by the relative area of each polygon. This method resulted in an average population of 209 iTaukei and 484 Indo-Fijian households per study site in the Ba River catchment and an average population of 280 iTaukei and 212 Indo-Fijian households per study site in the Penang River catchment.

5 Disaster damage in 2012 – empirical survey data

5.1 Demographics and income

Table 2 and shows the average age of respondents to the household survey, their genders, the maximum education obtained by any household member, household income for the 12 months immediately preceding the survey, and total household wealth by ethnicity, averaged across each surveyed community in the Ba and Penang River catchments, respectively.[6] The household income reported here is the net income from cropping, livestock, timber and non-timber forest products, fishing, wage labour, rental of housing and capital, and government transfers, after expenses. Wealth is calculated as the sum of the stated replacement value of the physical house, vehicles and any other durable assets, jewellery, and bank accounts.

Except for a handful of cases in which a surrogate had been nominated, the household survey was administered to self-identified heads of households. The average age of survey respondents is 51 and 90% of survey respondents are male, consistent with headship patterns in Fiji over the last 50 years (Panapasa, 1997). The maximum number of grade levels completed is negatively associated with age, with each successive generation obtaining more education than the one that preceded it. Thus, the average number of grade levels completed is 11.5, higher in households comprising multiple generations and lower in those in which the household head does not reside with his or her children.

The most recent official data on household income comes from the Household Income and Expenditure Survey (Fiji Bureau of Statistics, 2012a). According to these figures, average household income for rural Fiji as a whole was FJ$11,608. For Fiji's Western Division (which includes the Ba and Penang River catchments), average rural household income was FJ$9,960. The average household incomes by community based on our survey results are FJ$7,849 in the Ba River catchment and FJ$10,133 in the Penang River catchment. Given that growth of GDP fluctuated between -1% and 2% between 2009 and 2013 (World Bank, 2014), that these households were exposed to three major natural disasters in 2012, and that 25% of Fiji's poor live in Ba Province (Narsey, 2008), our income figures are consistent with the official figures.

Wealth is not reported in any publically available official documents, but the fact that the demographic and income profiles of our sample so closely matches those reported in both the peer-reviewed literature and official documents suggests that our estimates of wealth will be reliable. The average wealth among households in surveyed communities in the Ba River catchment is FJ$26,366, or 3.3 times annual income. The average wealth among households in surveyed communities in the Penang River catchment is FJ$33,098, also 3.3 times annual income.

[6] These data are broken down by community in Tables A2a and A2b in the Supplemental Information. The community-level analogue of subsequent tables are also presented in the Supplemental Information.

The average income among surveyed households does not differ by ethnicity in the Ba River catchment, although surveyed households in largely Indo-Fijian settlements have higher incomes than surveyed households in *iTaukei* villages in the Penang River catchment (statistically significant at the 5% level using a two-sided *t* test). Narsey (2008) notes that Indo-Fijian households are larger than *iTaukei* households, on average, and that ethnic differences in income at the household level invariably disappear when calculating per-capita income. That being said, Narsey (2008) also reports that Indo-Fijian households tend to be wealthier than *iTaukei* households because *iTaukei* households support more non-working adults than Indo-Fijian households. In addition, rural *iTaukei* households donate or give away 9% of their annual incomes, on average, while rural Indo-Fijian households donate or give away just 1% of their annual incomes (Narsey, 2008). In our sample, the average wealth of households in settlements and *iTaukei* villages in the Ba River catchment are FJ$41,712 and FJ$16,327, respectively. The average wealth of households in settlements and *iTaukei* villages in the Penang River catchment are FJ$47,457 and FJ$17,941, respectively. These differences in wealth by ethnicity are statistically significant at the 1% level.

5.2 Incidence and severity of disasters

Survey respondents were asked whether they had been affected by a variety of natural disasters and ailments "in recent years", including storm surge, declining fish stocks, coastal erosion, coral bleaching, cyclones, heavy rains, flooding, drought, soil erosion, landslides/slips, lack of drinking water, fire, animal/crop disease, and human disease. Respondents were also asked whether they had been affected by invasive species and whether they had faced (or will face) the prospect of un-renewed land leases. [7] Respondents who reported being affected by a given type of disaster were also asked whether the problems associated with each disaster have become better, gotten worse, or remained unchanged.

Table 3 shows the incidence and trend for 15 different disasters, averaged at the community level, for the Ba and Penang River catchments, respectively. Specifically, the number indicates the share of surveyed households in each community that have been adversely affected by each type of disaster. Dashes indicate that none of the surveyed households were adversely affected by that particular type of disaster. Green and red shading indicate that the severity of disasters has diminished and increased over time, respectively. No shading indicates that the trend remains unchanged. Figures shown in the final column are weighted by the number of observations in each community.

Nearly 80% of survey respondents had been adversely affected by cyclones in recent years. Heavy rains also adversely affected the majority of respondents, although fewer respondents reported being personally affected by heavy rains than by cyclones; the adverse impacts of heavy rains are more widespread in the Penang River catchment than in the Ba River catchment. Flooding also widely reported, affecting 56% of respondents in the Ba River catchment and 73% of respondents in the Penang River catchment. Nearly half of survey respondents had been adversely affected by drought while approximately one-

[7] Expiring land leases are a major concern among Indo-Fijian households because *iTaukei* own 87% of the land in Fiji, because the majority of the Indo-Fijians population are tenants of indigenous landowners, and because at least 27,750 leases (the vast majority of them to Indo-Fijian households) were not renewed when they expired between 1999 and 2004 (Narayan, 2008); as such, expiring land leases are classified as "potential disasters" for at least part of the surveyed population.

quarter were adversely affected by lack of drinking water and/or soil erosion. Survey respondents also report being adversely affected by storm surge, declining fish stocks, coastal erosion, landslides/slips, fire, animal/crop disease, human disease, and invasive species, albeit in smaller numbers. No survey respondent reported being adversely affected by coral bleaching (omitted).

Among those who report being adversely affected, a majority of respondents in 19 communities reported that cyclones had become worse over the preceding decade (see Supplemental Information for additional details); respondents only reported that cyclones had become better, on average, in one community in the Ba River catchment. Drought and shortages of drinking water had reportedly become worse in 22 and 19 surveyed communities, respectively, with three communities reporting that droughts had become better and two reporting that problems associated with a lack of drinking water had improved. Flooding reportedly became worse in 13 surveyed communities, improved in one community, and stayed the same in the remaining 21 communities in which at least one respondent reported being adversely affected.

In both the Ba River and Penang River catchments, survey respondents identified flooding as the single most significant challenge facing their communities (Table 4), and the second most common natural disaster after cyclones. Flooding, cyclones, and heavy rains consistently appear among the top three most significant challenges facing communities in both catchments, with droughts being a distant fourth. Soil erosion, lack of drinking water, and/or landslips and landslides were identified as being among the top three challenges for at least 10% of survey respondents in the Ba River catchment. In the Penang River catchment, expiring land leases are the next most important challenge after droughts.

5.2.1 2012 Household Flood Damage

Some 37% of survey respondents were first made aware of pending flooding in January 2012 via storm clouds, high humidity, and rising waters (Figure 5). Approximately 54% of survey respondents were first alerted to the flooding via radio, television, and/or Internet sources; the median affected community was alerted 6.5 hours prior to the floods arriving. Approximately 9% of survey respondents were notified about the January floods via other means, including friends, text messages from mobile phone providers, and indicators based on traditional ecological knowledge. With such short notice, preparations for flooding were generally limited to moving household goods and/or livestock to higher ground and to evacuating.

Table 5 presents detailed data on damages to crops, livestock, housing, durables, and other categories incurred by ethnicity in the Ba and Penang River catchments during the January flooding. Among those that suffered losses, the average value of those crop losses was FJ$3,218 in the Ba River catchment and FJ$2,927 in the Penang River catchment. One surveyed household in Balevutu lost livestock worth FJ$1,700 and one surveyed household incurred property damage that cost FJ$400 to repair. The January flooding was especially severe in Navala, where several households lost kava crops worth several times the average annual household income. Notably, damages to crops greatly exceeded damages to livestock, housing, durables, and other categories in the Ba River catchment during the January floods.

Notification regarding the March floods was more formal, with over 90% of survey respondents first learning of the floods via radio (most common), television, or the Internet (Figure 6). Nevertheless, damages associated with the March flooding follows similar patterns (Table 6), although crop damages are generally lower because many households in flood-prone areas had already lost crops to the January floods. The general pattern of damages for the Penang river catchment closely follows that present in the Ba River catchment, although catastrophic losses to sugarcane (as opposed to kava) underlay the high value of crop losses in some communities. Flooding caused damages totalling up to one-third average annual household income in the Penang River catchment.

5.2.2 2012 Catchment-wide Flood Damages

Scaling the household-level estimates up to the catchment-wide population level reveals that the January and March 2012 floods caused FJ$12.8 million and FJ$8.5 million in household damages to the Ba River catchment, respectively (Table 7). Catchment-wide damage in the Penang River catchment are estimated to be FJ$2.4 million for the January floods and FJ$1.9 million for the March floods (Table 8).

Businesses in the two catchments were also impacted by the two flooding events. We did not explicitly survey local businesses in the Ba and Rakiraki towns about the damages they accrued by the events. Instead, we derive estimates using the valued losses to businesses found from the Ambroz (2009) study of the 2009 Ba flood of FJ$55.9 million for 479 formal businesses in the catchment, or about FJ$116,600 per business. Given that our estimates for Ba household damage for the January 2012 flood was 42% of the estimated household damages from Ambroz (2009), we scale the business damages by the same factor to yield an estimated damage in the January 2012 flood of about FJ$49,000 per business in the Ba River catchment, or a total of FJ$23.5 million. Assuming that the 199 formal businesses in the Penang River catchment faced the same level of damage, the total damage to businesses in that catchment stemming from the January flood are estimated at FJ$9.8 million. Applying the same logic to the March 2012 flood yields estimates of FJ$32,500 per business, i.e., about FJ$15.6 million and FJ$6.5 million in the Ba River and Penang River catchments, respectively, for the March 2012 floods.

Combining damages to households and businesses yields an estimated total damage from the January 2012 flood of FJ$36.3 million for the Ba River catchment and FJ$12.2 million for the Penang River catchment. For the March 2012 flood, total damages were estimated to be FJ$24.1 million in the Ba River catchment and FJ$8.4 million in the Penang River catchment.

6 Climate change and future flood risk in Fiji

6.1 Climate Change Scenarios

The number of recorded disasters globally has increased almost monotonically over the last 70 years, with disproportionately high increases in the incidence of flooding (Munang *et al.,* 2013). While part of the observed increase in number stems from increased exposure as human settlements have expanded, Munang *et al.* (2013) note that the increased incidence of natural disasters has coincided with an increase in temperature, which is widely considered to be anthropogenic in nature (e.g., Preston *et al.*, 2006). As such, the frequency of climate-related disasters is likely to continue to increase.

While patterns in natural hazards related to climate change are observable on a global basis, changes in climate on a regional scale depend highly on atmospheric patterns and oceanic circulation (Bates *et al.*, 2008), making it difficult to isolate localised trends over the historical record. Nevertheless, Australian Bureau of Meteorology and CSIRO (2011) observe that temperatures in the South Pacific have increased by 0.6°C in the last hundred years, and ADB (2011) finds that events such as storm surges, floods, and droughts have increased in the Pacific in recent decades. Thus, climactic trends in the Pacific appear to follow those observed more widely.

To anticipate future trends, PICCAP (2005) developed risk projections for Fiji using two General Circulation Models (GCMs) within the Special Report on Emissions Scenarios. While the A2 scenario is considered to be extreme, the B2 scenario is considered to be "mid-range". Under this mid-range scenario, PICCAP projects that climate change will lead to higher incidence of natural disasters, including flooding, landslides, and coastal erosion. It is also expected that agricultural productivity will decline (Preston *et al.*, 2006), with stronger winds expected to damage crops including sugar, banana, and coconuts and flooding expected to damage crops such as taro and cassava.

Changes in seasonal or annual precipitation often differ from changes in precipitation extremes. Climate change shifts not only average precipitation totals, but also the 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 Solomon *et al*. (2007) and 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. IPCC (2012) suggest that 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. Precipitation intensity may increase even where average precipitation is expected to decrease concurrent with longer periods between rainfall events.

Projections for changes in extreme rainfall in the Pacific region generally reflect global projections. According to Rao *et al.* (2012), while annual rainfall in the region is projected to remain relatively constant, rainfall is likely to be more concentrated in the cyclone season, and extreme rainfall events are likely to increase in magnitude. The maximum five-day rainfall total is expected to increase in the Pacific as a greater proportion of rainfall is projected to occur as heavy rainfall, and thus current 1-in-20 year rainfall events are expected to have a 1-in-5 year probability by 2055 and a 1-in-3 year probability by 2090 under the A2 GCM (Australian Bureau of Meteorology and CSIRO, 2011).

Downscaled projections for Fiji suggest that the number of rainy days is unlikely to change dramatically, although increases in extreme heavy rainfall can be expected, particularly in the northern regions of the country where the Ba and Penang River catchments are located (Australian Bureau of Meteorology and CSIRO, 2011). Hay (2006) modelled future changes in the return period for heavy precipitation events in Viti Levu and concludes that a 400mm 24-hour rainfall total had a 190-year return period between 1946 and 1965, while such rainfall currently has a return period of 50-years today and would likely have a 25-year return period between 2086 and 2100 under a moderate climate change scenario. These projections are likely to be conservative, as GCMs have been found to underestimate both the number of days with extreme heavy rainfall and the intensity of heavy rainfall events in the Pacific Region (Australian Bureau of Meteorology and CSIRO, 2011).

Forming projections for changes in flood frequency and severity is problematic because observational records of floods are often short, sparse, and confounded by influences such as channel constriction and land-use change (IPCC, 2012). Catchments are highly idiosyncratic geographic features; therefore, the relationship between climate and flood risk often needs to be assessed on a case-by-case basis (IPCC, 2012). Based on physical reasoning, there is medium confidence that flooding will increase in areas like Fiji, where the incidence of heavy rainfall is expected to increase (Rao *et al.*, 2012; IPCC, 2012). In the absence of detailed data and hydrological modelling in the region, however, the specifics and magnitude of these changes remain uncertain.

We use the range of projected shifts in extreme heavy rainfall return periods to construct two climate change scenarios to estimate the likely range of future damages from flooding in the Ba and Penang River catchments relative to 'current' climate. The 'moderate' scenario follows projections similar what may occur under the SRES B2 or the relative concentration pathway (RCP) 6.0 scenario, while the 'severe' scenario follows projected changes under the SRES A2 or RCP 8.5 scenario.

Events can be expressed in return periods and/or flood exceedence. For the moderate scenario, we assume that each event under the moderate climate regime shifts one return interval, while the severe scenario assumes a shift of two return intervals. That is, the January flood that was considered a 1-in-50 event under the current climate is assumed to be a 1-in-20 event under the moderate scenario and a 1-in-10 event under the severe scenario. The same method applies to the March 2012 flood, which was estimated to be a 1-in-20 year flood, but which could become a 1-in-10 or 1-in-5 year flood under the moderate and severe climate-change scenarios.

6.2 Climate Change Scenario Flood Damages

The range of average household and business damages estimated for various flood exceedence probabilities for the two catchments under the three climate scenarios are shown in Table 9. Taking a weighted average of the estimated damages that would accrue under the different flood exceedence probabilities yields the expected value of average annual damages. In the Ba River catchment, this is estimated to range from FJ$165 per household per year under the current climate scenario to FJ$686 per household per year under the severe climate scenario. In the Penang River catchment, the expected annual damages range from FJ$225 per household per year for the current climate scenario to FJ$830 per household per year for the severe climate change scenario. Applying the same method to local businesses yields damages to the average business in each catchment of FJ$6,841 per year for the current climate, FJ$12,884 per year for the moderate climate, and FJ$24,170 per year for the severe climate change scenario, respectively.

Scaling the average household and business estimates up to the catchment population level yields significantly higher damage estimates under the two climate change scenarios. In the Ba River catchment, the total expected annual damage accrued by households and businesses range from FJ$4.9 million to FJ$18.2 million (Table 10). Damages from a 1-in-50 year flood under the moderate and severe climate-change scenarios are projected to cause between FJ$F76.5 and FJ$153 million in damages, a 100-300% increase relative to the January 2012 flood that is considered to have same frequency under the current climate scenario. In the Penang River catchment, the total expected annual damage accrued by households and businesses ranges from FJ$1.8 million to FJ$6.4 million (Table 11), and damages from a 1-in-50 year flood under the moderate and severe climate change scenario are estimated to be between FJ$26.2 and FJ$52.4 million.

7 Conclusions

This paper quantifies the economic impacts of flooding in the Ba River and Penang River catchments in Viti Levu, Fiji. To develop empirical estimates of the damages from the

January and March 2012 floods in the two catchments, we conducted a series of detailed socioeconomic surveys for 369 households in 36 communities during early 2013. We found that a majority of the economic value of impacts were to household crops and local businesses. Combining the survey sample measures of damage with GIS data to estimate total damages from flooding, we find that the January 2012 flood caused FJ$36.4 million and FJ$12.2 million in damages for the Ba River and Penang River catchments, respectively. The March 2012 flood caused in FJ$24.1 million and FJ$8.4 million in damages in the Ba River and Penang River catchments. We then use the estimates from the 2012 floods to estimate the cost of future flooding under moderate and severe climate change projections. Flooding is projected to be more frequent and more severe under both scenarios. For example, the January 2012 flood that was estimated to have a 1-in-50 return period could become a 1-in-20 or 1-in-10 year flood under climate change. As a result, we estimate that annual losses will increase by about 100% with moderate climate change and by as much as 300% with severe climate change. Future work will look at cost-effective options for mitigating these damages, including both hard infrastructure and ecosystem-based adaptation.

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References

ADB. (2011). Food Security and Climate Change in the Pacific: Rethinking the Options. Manila: Asian Development Bank.

Ambroz, A. (2009). Ba Floods Economic Costs January 2009 (Vol. Technical Report 425). Suva: Pacific Islands Applied Geoscience Commission (SOPAC).

Australian Bureau of Meteorology & CSIRO. (2011). Climate Change in the Pacific: Scientific Assessment and New Research. *Volume 1: Regional Overview Volume 2: Regional Reports*.

Bates, B., Kundzewich, C., Wu, S. & Palutikof, P. (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Boé, J., Terray, L., Martin, E. & Habets, F. (2009). Projected changes in components of the hydrological cycle in French river basins during the 21st century. *Water Resources Research, 45*.

Botzen W.J.W., Aerts, J.C.J.H. & van den Bergh, J.C.J.M. (2009), Dependence of flood risk perceptions on socioeconomic and objective risk factors. *Water Resources Research*, *45*.

Brody, S. D., Zahran, S., Highfield, W. E., Grover, H. & Vedlitz, A. (2008). Identifying the impact of the built environment on flood damage in Texas. *Disasters, 32*(1).

Davis, R. I., & Brown, J. F. (1999). Kava (Piper methysticum) in the South Pacific. Canberra: ACIAR Technical Reports, 46.

Fiji Bureau of Statistics. (2012a). “Household income and expenditure” http://www.spc.int/prism/fjtest/Key%20Stats/HIES/13.3Average%20Hhold%20Incomes.pdf

Fiji Bureau of Statistics. (2012b). “Population by age, race, and province of enumeration, Fiji: 2007 Census”. http://www.statsfiji.gov.fj/index.php/2007-census-of-population

Fiji Ministry of Information. (2012). “PM Meets Flood Hit”. *Fiji Sun*, 29 January.

FMS. (2009). Preliminary Report on Flooding in Fiji 8-16th January 2009. Meteorological Event Report 01/2009. Suva: Fiji Meteorological Service.

Gero, A., Méheux, K., & Dominey-Howes, D. (2011). Integrating Disaster Risk Reduction and Climate Change Adaptation in the Pacific. Climate and Development 3(4): 310-327.

Hay, J.E., (2006). Preparing the Renewable Power Sector Development Project. ADB TA - 4764 (FIJ), Asian Development Bank, Mandaluyong City, Philippines, 40pp.

IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. In C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, K. J. Plattner, S. K. Allen, M. Tignor & P. M. Midgley (Eds.). Cambridge & New York: IPCC.

McGree, S., Yeo, S. W. & Devi, S. (2010). Flooding in the Fiji Islands between 1840 and 2009. *Risk Frontiers*.

Molan, J. (2012). Fiji Floods January 2012. www.redcross.org.au/fiji-floods-2012-early-2012.aspx. Australian Red Cross.

Munang, R., Thiaw, I., Alverson, K., Liu, J. & Han, Z. (2013). The role of ecosystem services in climate change adaptation and disaster risk reduction. *Current Opinion in Environmental Sustainability, 5*, 1-6.

Murray, W.E. (2000). Neoliberal Globalisaatoin, "Exotic" Agro-exports and Local Change in the Pacific Islands: A Study of the Fijian Kava Sector. *Singapore Journal of Tropical Geography*. 21(3), 355-373.

Narsey, W. (2008). *The Quantitative Analysis of Poverty in Fiji*. Vanuavou Publications: Suva.

NDMO. (2003). Report on Tropical Cyclone Ami. Suva: National Disaster Management Office.

NDMO. (2012). January 2012 Flood Report. Suva: National Disaster Management Office.

Panapasa, S. (1997). Family structure and changes in headship rates in Fiji: 1966-1986. http://www.popline.org/node/269006

PICCAP. (2005). Climate Change: The Fiji Islands Response: Fiji's First National Communication under the Framework Convention on Climate Change. Suva: Pacific Islands Climate Change Assistance Programme.

Preston, B. L., Suppiah, R., Macadam, I. & Bathols, J. (2006). Climate Change in the Asia/Pacific Region - A Consultancy Report Prepared for the Climate Change and Development Roundtable: CSIRO.

Rao, N. S., Carruthers, T. J. B. Anderson, P., Sivo, L., Saxby, T., Durbin, T. & Chape, S. (2012). "A comparative analysis of ecosystem-based adaptation and engineering options for Lami Town, Fiji.: A synthesis report by the Secretariat of the Pacific Regional Environment Programme". Suva: SPREP.

Simmons, M. & Mele, K. (2013). Picking up the pieces. Suva: *Mai Life,* 18-21.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. & Miller, H.L. (eds.) (2007). "Climate Change 2007: The Physical Science Basis - Contribution of

Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge and New York: Intergovernmental Panel on Climate Change.

UN Country Team in Fiji (2012). Humanitarian Action Plan: Strategic Plan for Response to Fiji floods (TD17F) - March/April 2012.

UN News Centre (2012). As floods continue in Fiji, UN stresses need to boost preventative measures. www.un.org/apps/news/story.asp?NewsID=41136&Cr=Fiji&Cr1=. *UN News Centre*.

Weir, T. & Virani, Z. (2011). Three Linked Risks for Development in the Pacific: Climate Change, Disasters, and Conflict. *Climate and Development* 3(3): 193-208.

World Bank. (2000). Economic Implications of Climate Change in Two Pacific Country Locations: Case Study of Tarawa, Kiribati and Viti Levu, Fiji. Washington D.C.: World Bank.

World Bank. (2012). Disaster Risk Reduction and Financing in the Pacific. Washington D.C.: World Bank.

World Bank. (2014). World Bank national accounts data, and OECD National Accounts data files.

Yeo, S. W. & Blong, R. J. (2010). Fiji's worst natural disaster: the 1931 hurricane and flood. *Disasters, 34*(3).

Yeo, S. W, Blong, R. J., & McAneney. (2007). Flooding in Fiji: findings from a 100-year historical series. *Hydrological Sciences, 52*(5).

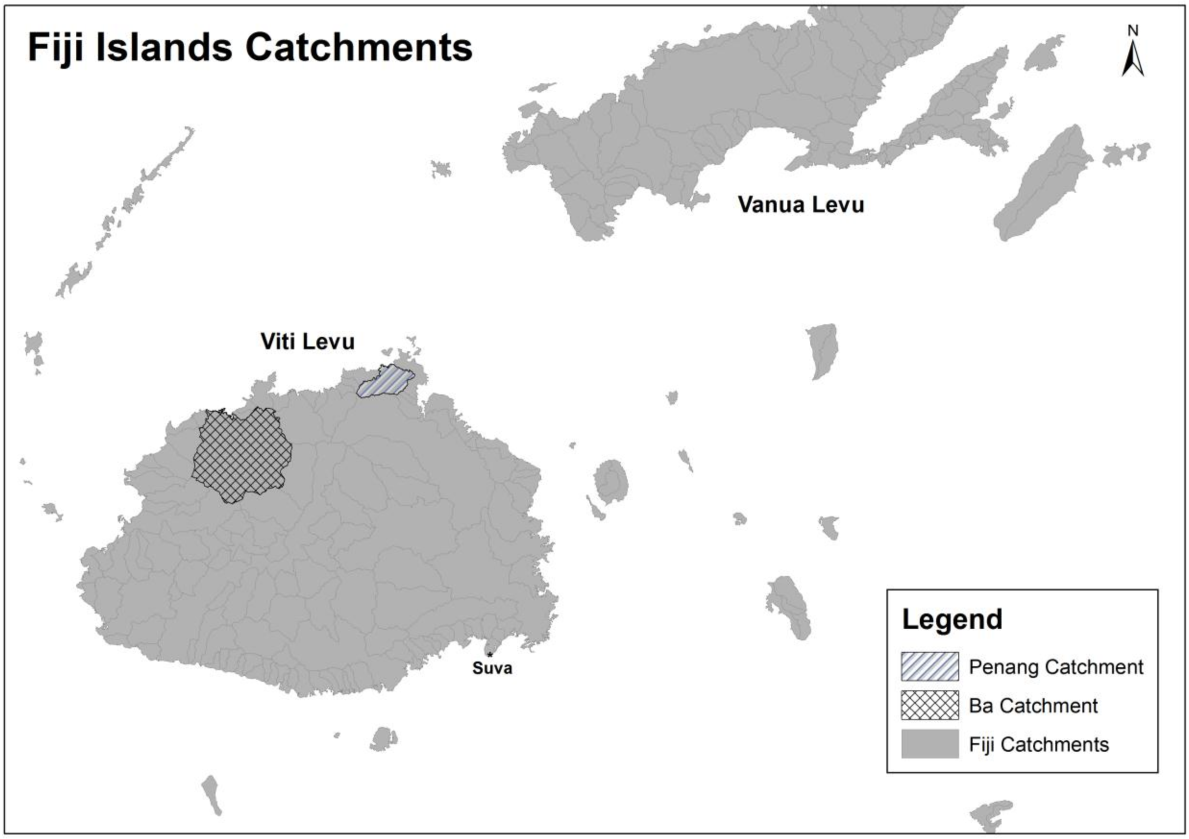

Figure 1. Fiji island catchments

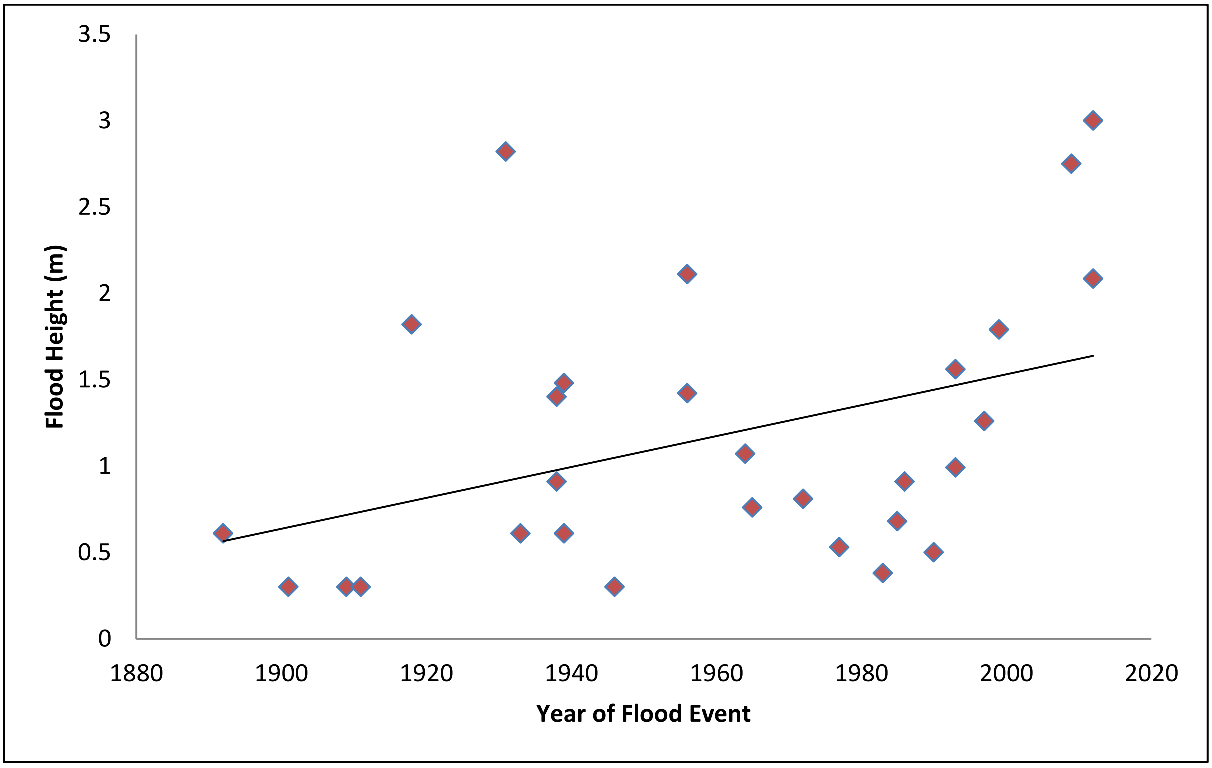

Figure 2. Flood height of the Ba River over time, with trend line

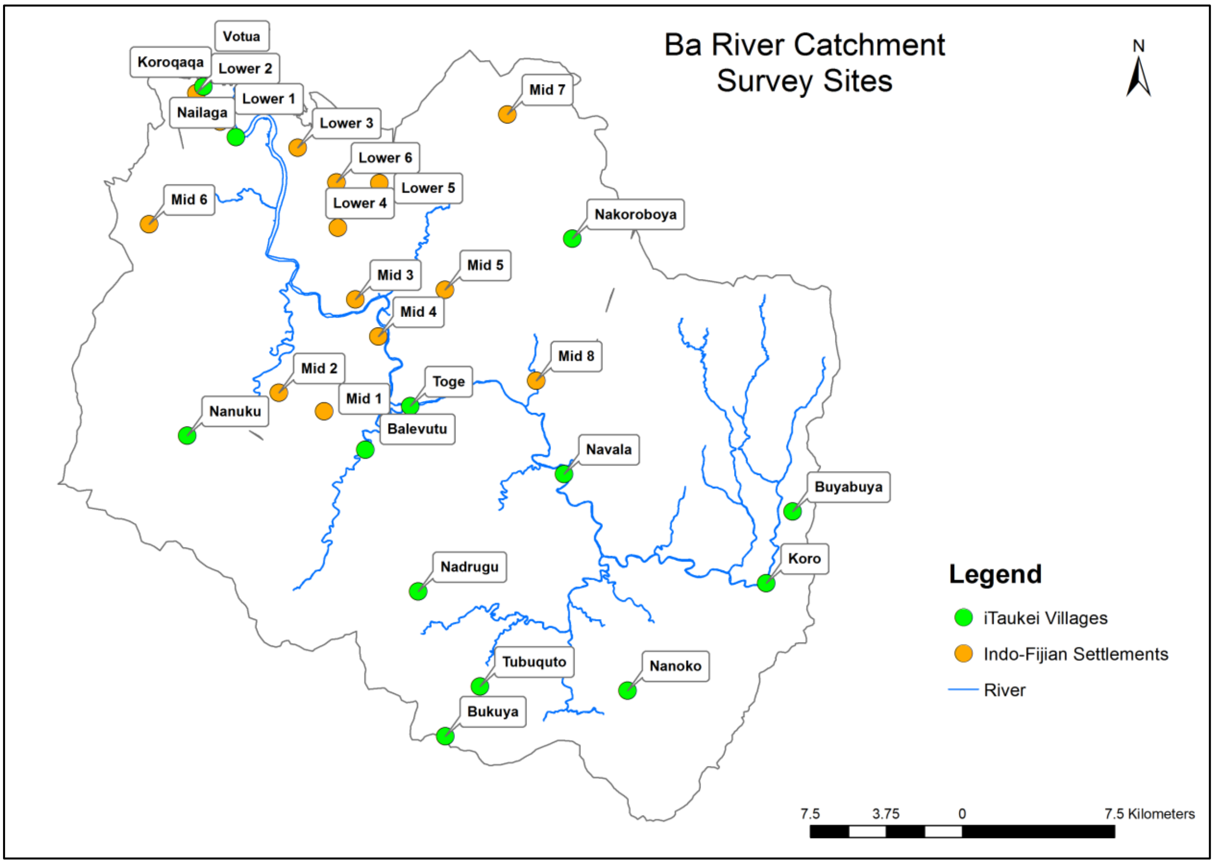

Figure 3. Survey sites in the Ba River catchment

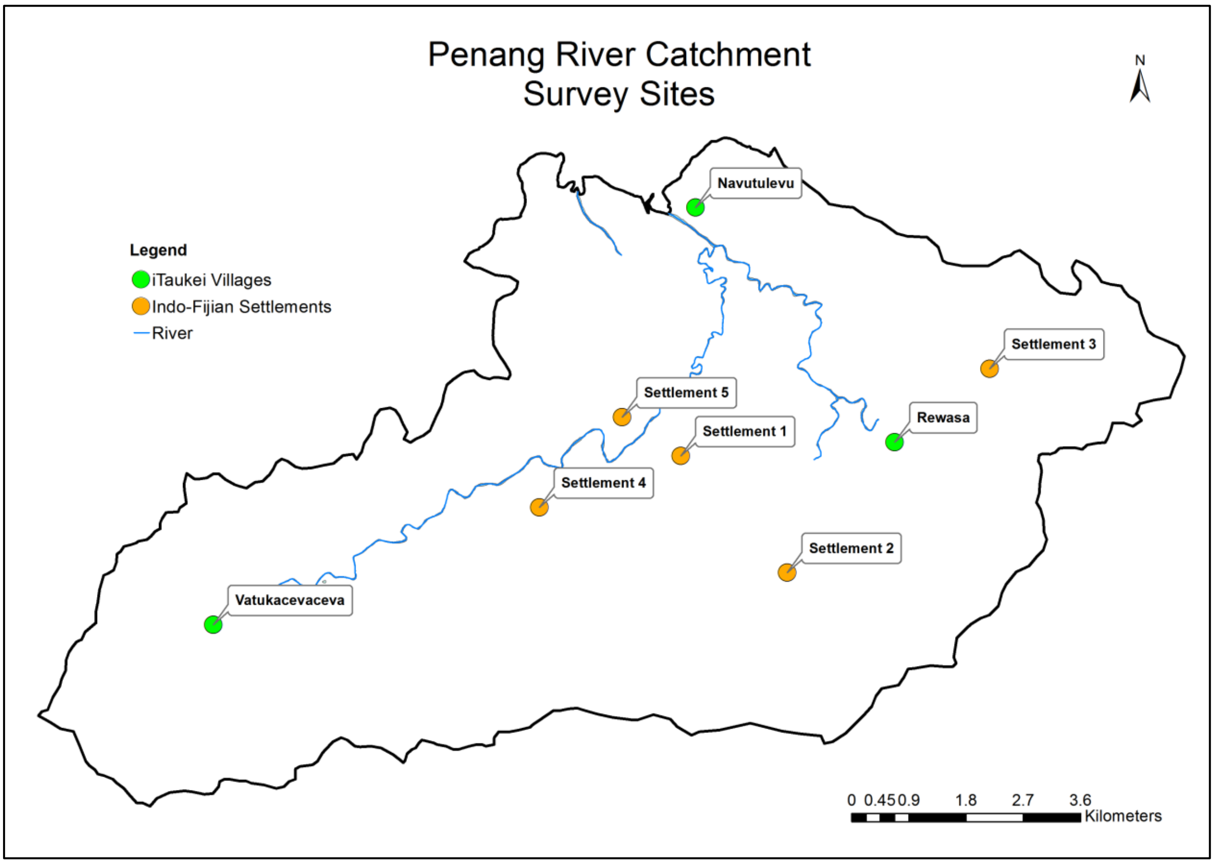

Figure 4. Survey sites in the Penang River catchment

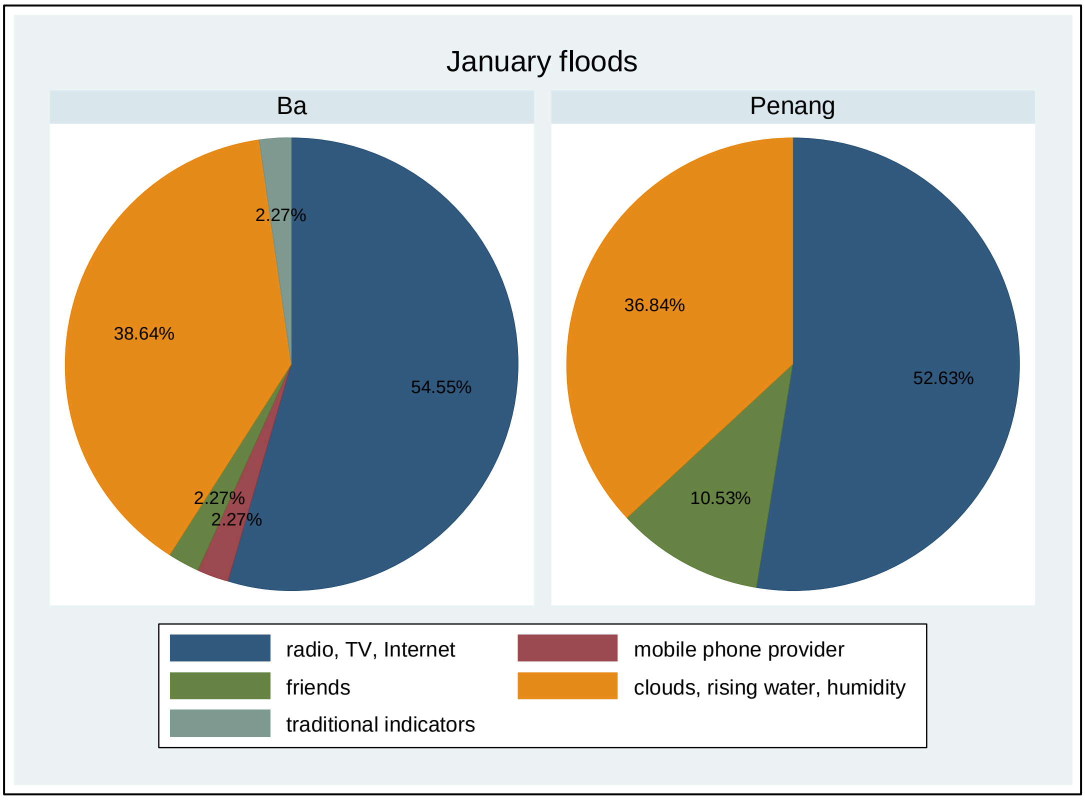

Figure 5. Form of notification, January flooding

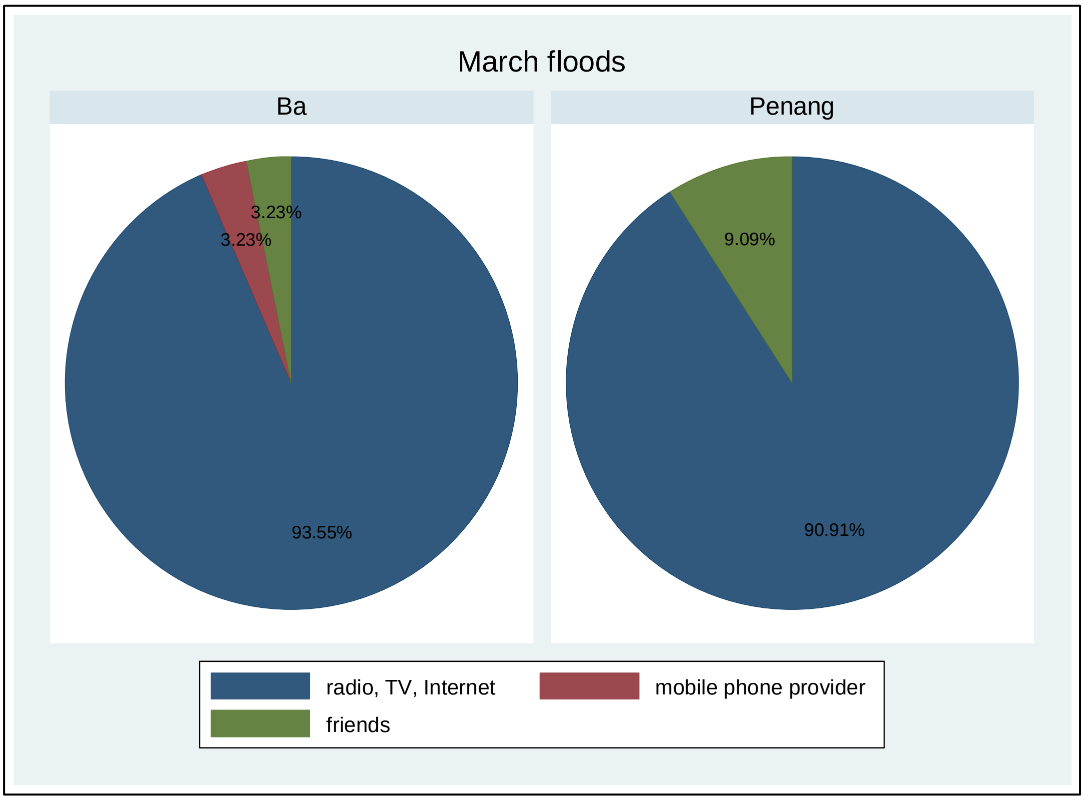

Figure 6. Form of notification, March flooding

Table 1. Survey sample by location and ethnicity

Catchment	iTaukei	Indo-Fijian	Total
Ba lower	37	60	97
Ba middle	48	54	102
Ba upper	96	0	96
Penang	36	38	74
Total	217	152	369

Table 2. Summary statistics, Ba and Penang River catchments

Ethnicity	age *years*	male *share*	max education *years*	total income *FJ$*	total wealth *FJ$*
Ba River Catchment					
iTaukei	51.61	0.89	11.10	7,436	15,761
Indo-Fijian	51.89	0.87	11.54	8,582	41,230
Total	51.69	0.88	11.29	7,849	26,136
Penang River Catchment					
iTaukei	52.28	0.89	11.33	7,917	17,940
Indo-Fijian	48.98	0.97	11.98	12,436	48,189
Total	50.89	0.93	11.69	10,133	33,098

Table 3. Incidence and trend of disasters in communities in the Ba and Penang River catchments

Disaster	*iTaukei*	Indo-Fijian	Total
	Ba River Catchment		
Storm surge	-	0.12	0.02
Declining fish stocks	0.17	0.27	0.04
Coastal erosion	0.08	0.16	0.02
Cyclones	0.80	0.82	0.81
Heavy rains	0.46	0.76	0.59
Flooding	0.48	0.64	0.56
Drought	0.26	0.75	0.45
Soil erosion	0.29	0.26	0.25
Landslides/slips	0.21	0.22	0.17
Lack of drinking water	0.23	0.55	0.29
Fire	0.18	0.16	0.10
Animal/ crop disease	0.08	0.15	0.03
Human disease	0.31	0.23	0.13
Expiring land leases	0.08	0.36	0.13
Invasive species	0.08	0.14	0.06
	Penang River Catchment		
Storm surge	-	-	-
Declining fish stocks	0.17	-	0.05
Coastal erosion	-	-	-
Cyclones	0.83	0.69	0.76
Heavy rains	0.67	0.83	0.76
Flooding	0.61	0.84	0.73
Drought	0.33	0.67	0.49
Soil erosion	0.25	0.40	0.24
Landslides/slips	0.08	0.21	0.12
Lack of drinking water	0.13	0.43	0.24
Fire	0.13	0.24	0.12
Animal/ crop disease	-	0.25	0.03
Human disease	-	0.29	0.15
Expiring land leases	0.08	0.26	0.14
Invasive species	-	0.14	0.07

Note: The number indicates the share of surveyed households in each community that have been affected by each type of disaster "in recent years". Dashes indicate that none of the surveyed households were affected by that particular type of disaster. Green and red shading indicate that the severity of disasters has diminished and increased, respectively. No shading indicates that the severity has not changed.

Table 4. Rankings of most significant disasters affecting households in the Ba and Penang River catchments

Challenge	1st	2nd	3rd	top 3
Ba River Catchment				
Cyclones	0.245	0.344	0.254	0.722
Flooding	0.282	0.170	0.107	0.505
Heavy rains	0.119	0.185	0.239	0.447
Drought	0.065	0.124	0.181	0.298
Soil erosion	0.044	0.039	0.088	0.139
Lack of drinking water	0.095	0.035	-	0.125
Landslips and landslides	0.020	0.058	0.044	0.102
Expiring land leases	0.061	0.012	0.010	0.078
Human disease	0.041	0.015	0.015	0.064
Invasive species	0.010	0.012	0.024	0.037
Fire	0.014	0.008	0.015	0.031
Declining fish and seafood stock	0.003	-	0.015	0.014
Coastal erosion	-	-	0.005	0.003
Animal/crop disease	-	-	0.005	0.003
Penang River Catchment				
Cyclones	0.208	0.235	0.362	0.649
Heavy rains	0.278	0.279	0.170	0.635
Flooding	0.361	0.206	0.149	0.635
Drought	0.028	0.162	0.128	0.257
Expiring land leases	0.042	0.015	0.064	0.095
Declining fish and seafood stock	-	0.044	0.021	0.054
Soil erosion	0.014	0.029	0.021	0.054
Human disease	0.014	-	0.043	0.041
Invasive species	0.014	0.015	0.021	0.041
Lack of drinking water	0.028	-	-	0.027
Fire	0.014	0.015	-	0.027
Landslips and landslides	-	-	0.021	0.014

Note: Each number reflects the share of surveyed households that reported a given disaster as being the first, second, or third biggest challenge facing their communities. Dashes indicate that no households selected that disaster in that order. The final column shows the share of households that reported a given disaster is being among the top three most significant challenges facing their communities.

Table 5. Damages to Ba and Penang catchment households, January floods

Ethnicity	# crop damage	mean crop damage if > 0	# stock damage	mean stock damage if > 0	# house damage	mean house damage if > 0	# durable damage	mean durable damage if > 0	# indirect damage	mean indirect damage if > 0	damage as a share of income
					Ba River Catchment						
iTaukei	81	FJ$4,215	1	FJ$1,700	3	FJ$433	1	FJ$500	4	FJ$119	19.8%
Indo-Fijian	59	FJ$2,221	5	FJ$3,650	7	FJ$791	4	FJ$1,584	33	FJ$170	14.8%
Total	140	FJ$3,218	6	FJ$3,260	10	FJ$657	5	FJ$1,222	37	FJ$156	17.3%
					Penang River Catchment						
iTaukei	27	FJ$1,121	0	FJ$0	0	FJ$0	0	FJ$0	3	FJ$140	11.4%
Indo-Fijian	20	FJ$4,011	0	FJ$0	3	FJ$425	1	FJ$100	10	FJ$127	17.9%
Total	47	FJ$2,927	0	FJ$0	3	FJ$425	1	FJ$100	13	FJ$130	15.4%

Table 6. Damages to Ba and Penang catchment households, March floods

Ethnicity	# crop damage	mean crop damage if > 0	# stock damage	mean stock damage if > 0	# house damage	mean house damage if > 0	# durable damage	mean durable damage if > 0	# indirect damage	mean indirect damage if > 0	damage as a share of income
					Ba River Catchment						
iTaukei	57	FJ$1,999	1	FJ$6,540	0	FJ$0	0	FJ$0	2	FJ$18	5.8%
Indo-Fijian	59	FJ$1,860	5	FJ$1,559	5	FJ$267	5	FJ$1,061	34	FJ$197	11.7%
Total	116	FJ$1,930	6	FJ$2,555	5	FJ$267	5	FJ$1,061	36	FJ$172	8.7%
					Penang River Catchment						
iTaukei	25	FJ$1,045	1	FJ$2,640	0	FJ$0	0	FJ$0	1	FJ$200	11.1%
Indo-Fijian	20	FJ$1,925	2	FJ$3,355	3	FJ$253	1	FJ$250	8	FJ$97	11.2%
Total	45	FJ$1,595	3	FJ$3,117	3	FJ$253	1	FJ$250	9	FJ$114	11.2%

Table 7. Catchment-wide damages to Ba River catchment

Event	Category	Indo-Fijian		*iTaukei*		Total	
Jan 2012 Flood	Crops	FJ$	7,477,044	FJ$	3,072,301	FJ$	10,549,345
	Livestock	FJ$	558,236	FJ$	19,809	FJ$	578,045
	Housing	FJ$	538,580	FJ$	80,831	FJ$	619,411
	Durables	FJ$	693,044	FJ$	11,949	FJ$	704,993
	Indirect	FJ$	383,370	FJ$	4,034	FJ$	387,404
	Business					FJ$	23,504,593
	Total	**FJ$**	**9,650,273**	**FJ$**	**3,188,925**	**FJ$**	**36,343,791**
March 2012 Flood	Crops	FJ$	6,199,696	FJ$	626,810	FJ$	6,826,506
	Livestock	FJ$	441,256	FJ$	126,142	FJ$	567,398
	Housing	FJ$	117,973	FJ$	-	FJ$	117,973
	Durables	FJ$	558,944	FJ$	-	FJ$	558,944
	Indirect	FJ$	438,364	FJ$	557	FJ$	438,921
	Business					FJ$	15,578,702
	Total	**FJ$**	**7,756,233**	**FJ$**	**753,510**	**FJ$**	**24,088,444**

Table 8. Catchment-wide damages to Penang River catchment

Event	Category	Indo-Fijian		*iTaukei*		Total	
Jan 2012 Flood	Crops	FJ$	1,620,904	FJ$	701,651	FJ$	2,322,554
	Livestock	FJ$	-	FJ$	0	FJ$	0
	Housing	FJ$	20,112	FJ$	0	FJ$	20,112
	Durables	FJ$	1,832	FJ$	0	FJ$	1,832
	Indirect	FJ$	25,729	FJ$	15,690	FJ$	41,418
	Business					FJ$	9,764,956
	Total	**FJ$**	**1,668,576**	**FJ$**	**717,340**	**FJ$**	**12,150,872**
March 2012 Flood	Crops	FJ$	1,121,627	FJ$	550,888	FJ$	1,672,515
	Livestock	FJ$	149,148	FJ$	25,087	FJ$	174,235
	Housing	FJ$	13,920	FJ$	0	FJ$	13,920
	Durables	FJ$	4,579	FJ$	0	FJ$	4,579
	Indirect	FJ$	15,634	FJ$	5,792	FJ$	21,426
	Business					FJ$	6,472,154
	Total	**FJ$**	**1,304,908**	**FJ$**	**581,767**	**FJ$**	**8,358,829**

Table 9. Expected damages to average Ba and Penang River catchment households and businesses, 3 climate scenarios

Category	Climate Scenario	Flood Annual Exceedence Probability					Expected Annual Damage
		20%	10%	5%	2%	1%	
Average Ba Household	Current	FJ$173	FJ$346	FJ$693	FJ$1,519	FJ$3,039	FJ$165
	Moderate	FJ$346	FJ$693	FJ$1,519	FJ$3,039	FJ$6,077	FJ$336
	Severe	FJ$693	FJ$1,519	FJ$3,039	FJ$6,077	FJ$12,155	FJ$686
Average Penang Household	Current	FJ$259	FJ$518	FJ$1,036	FJ$1,731	FJ$3,461	FJ$225
	Moderate	FJ$518	FJ$1,036	FJ$1,731	FJ$3,461	FJ$6,923	FJ$432
	Severe	FJ$1,036	FJ$1,731	FJ$3,461	FJ$6,923	FJ$13,846	FJ$830
Average Ba and Penang Business	Current	FJ$8,131	FJ$16,262	FJ$32,523	FJ$49,070	FJ$98,140	FJ$6,841
	Moderate	FJ$16,262	FJ$32,523	FJ$49,070	FJ$98,140	FJ$196,281	FJ$12,884
	Severe	FJ$32,523	FJ$49,070	FJ$98,140	FJ$196,281	FJ$392,561	FJ$24,170

Table 10. Catchment-wide Damages to Ba catchment from flooding, 3 climate scenarios

Climate Scenario	Flood Annual Exceedence Probability 20%	10%	5%	2%	1%	Expected Annual Damage
			Household Damages			
Current	FJ$ 1,681,344.61	FJ$ 3,362,343	FJ$ 6,725,032	FJ$ 14,747,992	FJ$ 29,495,985	FJ$ 1,598,674
Moderate	FJ$ 3,362,343	FJ$ 6,725,032	FJ$ 14,747,992	FJ$ 29,495,985	FJ$ 58,991,969	FJ$ 3,262,211
Severe	FJ$ 6,725,032	FJ$ 14,747,992	FJ$ 29,495,985	FJ$ 58,991,969	FJ$ 117,983,938	FJ$ 6,654,284
			Business Damages			
Current	FJ$ 3,894,675	FJ$ 7,789,351	FJ$ 15,578,702	FJ$ 23,504,593	FJ$ 47,009,186	FJ$ 3,276,989
Moderate	FJ$ 7,789,351	FJ$ 15,578,702	FJ$ 23,504,593	FJ$ 47,009,186	FJ$ 94,018,372	FJ$ 6,171,337
Severe	FJ$ 15,578,702	FJ$ 23,504,593	FJ$ 47,009,186	FJ$ 94,018,372	FJ$ 188,036,745	FJ$ 11,577,394
			Total Damages			
Current	FJ$ 5,576,020	FJ$ 11,151,693	FJ$ 22,303,733	FJ$ 38,252,585	FJ$ 76,505,171	FJ$ 4,875,663
Moderate	FJ$ 11,151,693	FJ$ 22,303,733	FJ$ 38,252,585	FJ$ 76,505,171	FJ$ 153,010,341	FJ$ 9,433,548
Severe	FJ$ 22,303,733	FJ$ 38,252,585	FJ$ 76,505,171	FJ$ 153,010,341	FJ$ 306,020,683	FJ$ 18,231,677

Table 11. Catchment-wide Damages to Penang catchment from flooding, 3 climate scenarios

Climate Scenario	Flood Annual Exceedence Probability					Expected Annual Damage
	20%	10%	5%	2%	1%	
	Household Damages					
Current	FJ$ 497,618	FJ$ 994,996	FJ$ 1,990,712	FJ$ 3,326,664	FJ$ 6,653,567	FJ$ 431,628
Moderate	FJ$ 994,996	FJ$ 1,990,712	FJ$ 3,326,664	FJ$ 6,653,567	FJ$ 13,307,135	FJ$ 830,546
Severe	FJ$ 1,990,712	FJ$ 3,326,664	FJ$ 6,653,567	FJ$ 13,307,135	FJ$ 26,614,270	FJ$ 1,595,773
	Business Damages					
Current	FJ$ 1,618,038	FJ$ 3,236,077	FJ$ 6,472,154	FJ$ 9,764,956	FJ$ 19,529,912	FJ$ 1,361,421
Moderate	FJ$ 3,236,077	FJ$ 6,472,154	FJ$ 9,764,956	FJ$ 19,529,912	FJ$ 39,059,825	FJ$ 2,563,875
Severe	FJ$ 6,472,154	FJ$ 9,764,956	FJ$ 19,529,912	FJ$ 39,059,825	FJ$ 78,119,650	FJ$ 4,809,815
	Total Damages					
Current	FJ$ 2,115,656	FJ$ 4,231,072	FJ$ 8,462,866	FJ$ 13,091,620	FJ$ 26,183,480	FJ$ 1,793,049
Moderate	FJ$ 4,231,072	FJ$ 8,462,866	FJ$ 13,091,620	FJ$ 26,183,480	FJ$ 52,366,960	FJ$ 3,394,421
Severe	FJ$ 8,462,866	FJ$ 13,091,620	FJ$ 26,183,480	FJ$ 52,366,960	FJ$ 104,733,920	FJ$ 6,405,588

Appendix - Supplemental Tables

Note: In this supplement, tables from the manuscript are broken down by community. Table numbers are consistent with those in the main text.

Table A1. Communities and households surveyed

Community	Primary Ethnicity	HH in community	# HH surveyed
Ba River Catchment			
Ba Lower 1	Indo-Fijian	180	13
Ba Lower 2	Indo-Fijian	60	12
Ba Lower 3	Indo-Fijian	35	12
Ba Lower 4	Indo-Fijian	200	12
Ba Lower 5	Indo-Fijian	120	6
Ba Lower 6	Indo-Fijian	100	6
Ba Mid 1	Indo-Fijian	65	8
Ba Mid 2	Indo-Fijian	90	4
Ba Mid 3	Indo-Fijian	210	13
Ba Mid 4	Indo-Fijian	200	12
Ba Mid 5	Indo-Fijian	180	8
Ba Mid 6	Indo-Fijian	75	6
Ba Mid 7	Indo-Fijian	65	10
Ba Mid 8	Indo-Fijian	200	5
Balevutu	iTaukei	305	12
Bukuya	iTaukei	664	12
Buyabuya	iTaukei	167	12
Koro	iTaukei	128	12
Koroqaqa	iTaukei	122	12
Nadrugu	iTaukei	128	12
Nailaga	iTaukei	885	12
Nakoroboya	iTaukei	162	12
Nanoko	iTaukei	319	12
Nanuku	iTaukei	98	12
Navala	iTaukei	526	12
Toge	iTaukei	95	12
Tubuquto	iTaukei	206	12
Votua	iTaukei	691	12
Penang River Catchment			
Navutulevu	iTaukei	378	12
Ra 1	Indo-Fijian	220	12
Ra 2	Indo-Fijian	52	6
Ra 3	Indo-Fijian	375	6
Ra 4	Indo-Fijian	87	6
Ra 5	Indo-Fijian	348	8
Rewasa	iTaukei	348	12
Vatukacevaceva	iTaukei	114	12

Table A2a. Summary statistics, Ba River catchment

Ba Communities	age years	male share	max education years	total income FJ $	total wealth FJ $
Ba Lower 1	49.38	0.85	12.31	7713	50,513
Ba Lower 2	50.17	0.92	11.17	6495	26,304
Ba Lower 3	51.00	0.67	11.50	8373	50,813
Ba Lower 4	50.67	0.92	11.67	7295	39,360
Ba Lower 5	54.83	0.67	12.00	10,155	57,277
Ba Lower 6	54.50	1.00	12.00	11,262	36,288
Ba Mid 1	50.25	0.88	9.88	4293	26,905
Ba Mid 2	48.00	0.75	11.75	8028	41,811
Ba Mid 3	49.31	0.85	11.92	8878	46,116
Ba Mid 4	55.67	0.83	11.42	8757	28,810
Ba Mid 5	54.88	1.00	12.50	6196	27,196
Ba Mid 6	50.83	1.00	9.67	11,950	58,151
Ba Mid 7	55.50	0.90	11.30	11,766	22,815
Ba Mid 8	51.40	1.00	12.40	8983	64,866
Balevutu	56.00	0.75	12.75	4744	12,606
Bukuya	49.25	0.92	11.92	4893	17,611
Buyabuya	49.00	1.00	10.92	6355	12,226
Koro	48.55	0.91	11.36	16,407	18,597
Koroqaqa	48.42	1.00	11.67	6494	11,365
Nadrugu	50.92	0.75	9.75	8113	14,045
Nailaga	55.42	0.67	12.58	4240	27,265
Nakoroboya	47.92	1.00	9.17	5407	10,522
Nanoko	50.33	1.00	11.50	4655	21,941
Nanuku	59.67	0.92	10.92	8174	16,490
Navala	48.08	1.00	10.58	16,397	8810
Toge	55.42	0.75	10.50	4695	13,908
Tubuquto	50.17	1.00	10.92	6193	16,732
Votua	53.33	0.75	10.83	7340	18,536
Total	51.69	0.88	11.29	7,849	26,136

Note: Average income in sampled communities demonstrates high variation: five of the sampled *iTaukei* villages report average household incomes below FJ$5,000 while three report average household incomes above FJ$10,000. Income heterogeneity across *iTaukei* villages is largely driven by production of *piper methysticum*, i.e., kava, (*yaqona* in Fijian). This cash crop plays an important ceremonial role throughout the Pacific; it is slow growing, so producers bear considerable risk in the four or more years of growth between harvest (Davis and Brown 1999), but incomes of between FJ$5,400 and FJ$18,000 per acre have been recorded (Murray 2000).

Table A2b. Summary statistics, Penang River catchment

Penang Communities	age years	male share	max education years	total income FJ $	total wealth FJ $
Navutulevu	47.58	1.00	12.25	10,317	19,933
Ra 1	53.83	1.00	12.00	10,513	43,017
Ra 2	38.17	1.00	12.17	14,316	39,628
Ra 3	54.17	0.83	10.83	7,399	34,603
Ra 4	53.00	1.00	12.17	15,619	73,900
Ra 5	45.75	1.00	12.75	14,332	49,798
Rewasa	58.00	0.83	10.67	6,050	17,679
Vatukacevaceva	51.25	0.83	11.08	7,385	16,209
Total	50.89	0.93	11.69	10,133	33,098

Table A3a. Incidence and trend of disasters in communities in the Ba River catchment

Community	storm surge	declining fish stocks	coastal erosion	cyclones	heavy rains	flooding	drought	soil erosion	land slides/ slips	lack of drinking water	fire	animal/ crop disease	human disease	expiring land leases	invasive species
Ba Lower 1	0.23	0.46	0.23	0.92	1.00	0.85	0.69	0.31	0.15	0.46	0.08	0.08	0.23	0.31	-
Ba Lower 2	-	0.08	-	0.75	0.75	1.00	0.58	-	0.08	0.50	0.08	0.08	0.42	0.50	0.08
Ba Lower 3	0.08	-	-	0.75	0.50	0.67	0.67	0.08	-	0.42	0.08	-	0.17	-	0.08
Ba Lower 4	0.08	-	0.08	1.00	0.75	0.50	0.58	0.25	0.08	0.33	-	0.08	0.25	0.25	0.08
Ba Lower 5	-	-	-	0.67	1.00	0.33	1.00	0.33	0.17	0.33	0.17	0.33	0.33	1.00	0.33
Ba Lower 6	-	-	-	0.83	0.67	0.33	0.83	0.17	0.17	-	-	-	0.17	0.33	0.17
Ba Mid 1	-	-	-	0.63	0.50	0.13	0.75	0.13	0.25	0.75	-	0.13	0.38	0.63	0.13
Ba Mid 2	-	-	-	1.00	1.00	-	0.75	0.25	0.25	0.75	0.50	-	-	-	-
Ba Mid 3	-	-	-	0.85	0.85	0.77	0.77	0.38	0.15	0.38	0.08	-	0.15	0.15	0.15
Ba Mid 4	0.08	-	-	0.83	0.58	0.92	0.75	0.25	-	1.00	0.08	-	0.25	0.17	0.17
Ba Mid 5	-	-	-	1.00	0.88	0.88	0.75	0.13	-	0.50	-	-	0.13	0.38	0.13
Ba Mid 6	-	-	-	1.00	1.00	0.83	0.83	0.50	0.67	0.33	-	0.17	0.17	0.17	0.17
Ba Mid 7	-	-	-	0.60	0.80	0.70	0.80	0.20	0.10	-	0.20	0.20	0.10	0.10	0.10
Ba Mid 8	-	-	-	0.60	0.40	0.40	0.80	0.40	0.40	0.80	-	-	0.20	-	-
Balevutu	-	-	-	0.83	0.67	0.42	0.50	0.25	0.08	0.17	0.17	0.08	0.17	0.08	-
Bukuya	-	-	-	0.83	0.33	0.17	0.33	0.17	0.17	0.17	0.25	-	-	-	0.08
Buyabuya	-	-	-	1.00	0.25	0.08	0.17	0.33	0.08	0.25	-	-	-	-	-
Koro	-	-	-	0.83	0.58	0.08	0.42	0.33	0.08	0.08	0.25	-	-	-	-
Koroqaqa	-	0.17	-	0.58	0.17	0.75	0.25	-	0.08	-	0.25	-	-	0.08	-
Nadrugu	-	-	-	0.92	0.67	0.08	0.42	0.33	0.42	0.17	0.08	-	-	-	0.08
Nailaga	-	0.17	-	0.58	0.33	1.00	0.08	0.33	0.08	-	-	-	-	-	-
Nakoroboya	-	-	-	0.83	0.50	0.17	0.17	0.33	0.42	0.08	0.08	-	0.25	-	-
Nanoko	-	-	-	0.92	0.33	0.25	0.42	0.17	0.25	0.50	0.17	-	0.50	-	-
Nanuku	-	-	0.08	0.83	0.75	0.58	0.08	0.33	0.25	-	0.25	-	-	-	-
Navala	-	-	-	0.92	0.42	0.83	0.17	0.42	0.25	0.33	0.08	-	-	-	-

Toge	-	-	-	0.83	0.50	1.00	-	0.42	0.25	0.17	-	-	-	-	-
Tubuquto	-	-	-	0.75	0.75	0.25	0.25	0.25	0.33	0.33	-	-	-	-	0.08
Votua	-	-	0.08	0.58	0.25	1.00	0.08	0.08	-	-	-	-	-	-	-
Total	0.02	0.04	0.02	0.81	0.59	0.56	0.45	0.25	0.17	0.29	0.10	0.03	0.13	0.13	0.06

Note: The number indicates the share of surveyed households in each community that have been affected by each type of disaster “in recent years”. Dashes indicate that none of the surveyed households were affected by that particular type of disaster. Green and red shading indicate that the severity of disasters has diminished and increased, respectively. No shading indicates that the severity has not changed.

Table A3b. Incidence and trend of disasters in communities in the Penang River catchment

Community	storm surge	declining fish stocks	coastal erosion	cyclones	heavy rains	flooding	drought	soil erosion	land slides/ slides	lack of drinking water	fire	animal/ crop disease	human disease	expiring land leases	invasive species
Navutulevu	-	0.25	-	0.92	0.67	0.75	0.25	-	-	0.08	0.08	-	-	0.08	-
Ra 1	-	-	-	0.67	0.92	0.92	0.50	0.33	0.25	0.25	0.17	-	0.33	0.17	0.08
Ra 2	-	-	-	0.50	0.83	0.83	1.00	0.33	0.33	0.33	0.17	-	0.33	0.33	0.17
Ra 3	-	-	-	1.00	0.67	0.83	0.67	0.67	0.17	0.50	-	-	0.33	0.33	0.17
Ra 4	-	-	-	0.67	0.83	1.00	0.67	0.17	0.17	0.67	-	-	0.33	0.33	0.17
Ra 5	-	-	-	0.63	0.88	0.63	0.50	0.50	0.13	0.38	0.38	0.25	0.13	0.13	0.13
Rewasa	-	-	-	0.83	0.67	0.67	0.25	-	-	0.17	-	-	-	-	-
Vatukacevaceva	-	0.08	-	0.75	0.67	0.42	0.50	0.25	0.08	-	0.17	-	-	-	-
Total	-	0.05	-	0.76	0.76	0.73	0.49	0.24	0.12	0.24	0.12	0.03	0.15	0.14	0.07

Note: The number indicates the share of surveyed households in each community that have been affected by each type of disaster "in recent years". Dashes indicate that none of the surveyed households were affected by that particular type of disaster. Green and red shading indicate that the severity of disasters has diminished and increased, respectively. No shading indicates that the severity has not changed.

Table A5a. Damages to Ba catchment communities, January flood

Community	# crop damage Jan	mean crop damage if > 0	# stock damage Jan	mean stock damage if > 0	# house damage Jan	mean house damage if > 0	# durable damage Jan	mean durable damage if > 0	# indirect damage Jan	mean indirect damage if > 0	damage as a share of income
Ba Lower 1	10	$848	1	$5,700					4	$163	14.79%
Ba Lower 2	3	$2,991	2	$2,890	1	$55			4	$23	19.12%
Ba Lower 3	7	$2,566			2	$2,750	3	$2,667	5	$444	33.52%
Ba Lower 4	2	$604							1	$200	1.61%
Ba Lower 5	2	$1,020			1	$200			3	$133	4.33%
Ba Lower 6	1	$1,051							2	$155	2.01%
Ba Mid 1	1	$2,333									6.79%
Ba Mid 2	1	$389							3	$93	2.08%
Ba Mid 3	9	$2,392			2	$550	1	$500	7	$141	20.89%
Ba Mid 4	7	$1,842	1	$1,850					3	$290	14.86%
Ba Mid 5	4	$2,044	1	$4,160	1	$400			1	$60	25.82%
Ba Mid 6	4	$7,287									40.65%
Ba Mid 7	7	$2,275									13.53%
Ba Mid 8	1	$3,449									7.68%
Balevutu	6	$1,683	1	$1,700	1	$400					21.43%
Bukuya	4	$1,971									13.43%
Buyabuya	2	$4,219									11.06%
Koro	1	$12,693									6.45%
Koroqaqa	9	$2,000							1	$15	23.12%
Nadrugu	5	$6,721									34.52%
Nailaga	8	$892			1	$700					15.40%
Nakoroboya	5	$2,727									21.01%
Nanoko	2	$951									3.40%
Nanuku	9	$2,213									20.30%
Navala	6	$15,903									48.49%

Toge	7	$1,107	1	$200			1	$30	14.16%
Tubuquto	5	$5,347					1	$400	36.51%
Votua	12	$585			1	$500	1	$30	8.57%

Table A5b. Damages to Penang catchment communities, January flood

Community	# crop damage Jan	mean crop damage if > 0	# stock damage Jan	mean stock damage if > 0	# house damage Jan	mean house damage if > 0	# durable damage Jan	mean durable damage if > 0	# indirect damage Jan	mean indirect damage if > 0	damage as a share of income
Navutulevu	9	$1,058							1	$20	7.71%
Ra 1	7	$1,789			2	$350	1	$100	5	$168	11.23%
Ra 2	3	$9,307							1	$200	32.74%
Ra 3	4	$2,835							2	$35	25.70%
Ra 4	4	$3,280			1	$500			1	$200	14.75%
Ra 5	2	$2,844							1	$30	4.99%
Rewasa	8	$1,335							2	$260	15.43%
Vatukacevaceva	10	$970									10.95%

Table A6a. Damages to Ba catchment communities, March flood

Community	# crop damage March	mean crop damage if > 0	# stock damage March	mean stock damage if > 0	# house damage March	mean house damage if > 0	# durable damage March	mean durable damage if > 0	# indirect damage March	mean indirect damage if > 0	damage as a share of income
Ba Lower 1	9	$738	2	$3,675			1	$1,000	4	$224	15.85%
Ba Lower 2	3	$2,863							3	$17	11.08%
Ba Lower 3	6	$3,394	1	$710	3	$433	3	$2,033	4	$479	30.25%
Ba Lower 4	3	$3,933							2	$200	13.94%
Ba Lower 5	2	$1,017							3	$142	4.04%
Ba Lower 6	1	$1,051							1	$500	2.29%
Ba Mid 1	2	$1,834									10.68%
Ba Mid 2	1	$389							3	$105	2.19%
Ba Mid 3	8	$1,925			2	$100			7	$166	14.53%
Ba Mid 4	7	$1,827	1	$860			1	$150	4	$255	14.10%
Ba Mid 5	4	$1,622	1	$990					1	$60	15.20%
Ba Mid 6	4	$1,858							1	$100	10.50%
Ba Mid 7	7	$1,566							1	$120	9.42%
Ba Mid 8	2	$2,028									9.03%
Balevutu	4	$511									3.59%
Bukuya	2	$700									2.38%
Buyabuya	4	$1,515									7.95%
Koro	1	$12,693									6.45%
Koroqaqa	5	$1,213							1	$15	7.80%
Nadrugu	5	$2,660									13.66%
Nailaga	4	$68									0.53%
Nakoroboya	5	$145	1	$6,540							11.20%
Nanoko	1	$1,046									1.87%
Nanuku	2	$39									0.08%
Navala	5	$5,564									14.14%

Toge	6	$239			2.55%
Tubuquto	4	$1,415			7.61%
Votua	9	$183	1	$20	1.90%

Table A6b. Damages to Penang catchment communities, March flood

Community	# crop damage March	mean crop damage if > 0	# stock damage March	mean stock damage if > 0	# house damage March	mean house damage if > 0	# durable damage March	mean durable damage if > 0	# indirect damage March	mean indirect damage if > 0	damage as a share of income
Navutulevu	7	$892									5.04%
Ra 1	7	$1,910			3	$253	1	$250	4	$126	11.80%
Ra 2	3	$2,238							1	$200	8.05%
Ra 3	4	$1,961	1	$1,070					1	$30	20.15%
Ra 4	3	$1,513	1	$5,640					1	$100	10.97%
Ra 5	3	$2,004							1	$30	5.27%
Rewasa	8	$1,032							1	$200	11.65%
Vatukacevaceva	10	$1,210	1	$2,640							16.63%