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Stationarity of major flood frequencies and heights on the Ba River, Fiji, over a 122-year record

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ABSTRACT: The economic impact of natural disasters on developing economies can be severe with the recovery diverting scarce funds that might otherwise be targeted at development projects and stimulating the need for international aid. In view of the likely sensitivity of low-lying Pacific Islands to anticipated changes in climate, a 122-year record of major flooding depths at the Rarawai Sugar Mill on the Ba River in the northwest of the Fijian Island of Viti Levu is analysed. Reconstructed largely from archived correspondence of the Colonial Sugar Refining Company, the time series comprises simple measurements of height above the Mill floor. It exhibits no statistically significant trends in either frequency or flood heights, once the latter have been adjusted for average relative sea-level rise. This is despite persistent warming of air temperatures as characterized in other studies. There is a strong dependence of frequency (but not magnitude) upon El Niño-Southern Oscillation (ENSO) phase, with many more floods in La Niña phases. The analysis of this long-term data series illustrates the difficulty of detecting a global climate change signal from hazard data, even given a consistent measurement methodology (*cf* HURDAT2 record of North Atlantic hurricanes) and warns of the strong dependence of any statistical significance upon choices of start and end dates of the analysis.

KEY WORDS climate change; flooding; flood frequency; flood heights; time series analysis; Small Island Developing States

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1. Introduction

Low-lying islands of the Pacific Ocean are considered particularly vulnerable to the impacts of global climate change. Potential impacts may arise from changes in weather patterns, including the frequency and intensity of El Niño-Southern Oscillation (ENSO) events and extreme weather, in addition to sea-level rise. These islands occupy an important region in respect of the geopolitics of global climate change and at the 2015 World Climate Change Conference in Paris, France, Small Island Developing States (SIDS) (UNFCCC, 2005) together with other vulnerable nations sought and were ultimately successful in obtaining, a political commitment to limit global warming to below 1.5 °C (Mabey, 2015). In terms of assessing the risk facing SIDS in the particular case of flooding, there is a general paucity of gauge-data suitable for long-term trend analysis; while this is a worldwide problem (Kundzewicz *et al.*, 2014), the Pacific Islands occupy a particularly data-poor region of the globe. In their discussion of flood risk and climate change in Oceania, for example, Kundzewicz *et al.* (2014) refer *onl*y to floods in Australia and New Zealand; there is no mention of the Pacific Islands.

With this in mind, this study examines a long-term flood series from the Fiji Islands in the southwestern Pacific Ocean for the influence of global climate change. Two properties of this data set make it *a priori* propitious for this task: first its time span of 122 years is unusually long (Rodier and Roche, 1984) and secondly, it comprises measurements largely undertaken with one simple and unchanging technology: in short, the use of rulers to measure flood heights above surveyed benchmarks. As discussed below, the data set brings us one step closer to the hazard as compared with analyses of economic or insurance losses caused by extreme weather, which are modulated by changes in exposure over time, and, in some cases, by changes in the vulnerability of assets at risk [e.g. Crompton and McAneney (2008) and McAneney *et al.* (2007)].

The likely impact of global climate change on SIDS such as Fiji due to extreme weather is not just a local concern with post-event economic recovery diverting scarce funds that might otherwise be targeted at development projects and stimulating the need for international aid. Data sets from developed countries suggest that, to this juncture at least, the rising economic costs of natural disasters [e.g. Swiss Re (2013)] are more closely linked to growing concentrations of population and wealth in disaster-prone regions than the impacts of global climate change *per se* (IPCC, 2012, 2014). This has been established now for many different perils and across jurisdictions [e.g. Pielke and Landsea (1998), Pielke *et al.* (2008), Crompton and McAneney (2008), Barredo (2009, 2010), Di Baldassarre *et al.* (2010), Crompton *et al.* (2010, 2011a) and others

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reviewed by Bouwer (2011), Barredo *et al.* (2012), Barthel and Neumayer (2012), Visser *et al.* (2014) and Pielke (2014)]. However little information exists to extend this understanding to the threats faced by small island states like Fiji.

Economic and insured losses from natural disasters are expected to continue to increase in the future, and, while an anthropogenic climate change contribution may well exacerbate this trend, the time scales for this attribution to be established with statistical certainty may be long. In the case of North Atlantic hurricanes, for example, time scales of some hundreds of years are possible (Crompton *et al.*, 2011b; Emanuel, 2011). This time frame arises because both the raw and normalized losses are characterized by large inter-annual variance and longer-term influences. Trying to find a climate change contribution in these noisy signals poses, in the parlance of physics and engineering, a severe signal-to-noise challenge. Because of this, Crompton *et al.* (2011b) suggest it more sensible to search for climate change signals in time series of hazard attributes – tropical cyclone numbers, hailstone sizes, rainfall extremes or as in the case of the current study, floodwater heights. Bender *et al.* (2010) has done this for climate model projections of North Atlantic basin-wide hurricane activity and found a timescale of roughly 60 years is needed to be able to detect a statistically significant change in the frequency of Category 4 and 5 hurricanes.

With that in mind, this study explores a long-term series of major flood height observations from the Rarawai Sugar Mill on the Ba River on the main island of Fiji in the southwestern Pacific Ocean (Yeo *et al.*, 2007; Yeo 2015). Our interest here is to explore whether the data set can reveal the degree to which islands in the Pacific are already seeing the impact of global climate change on the risk of severe flooding. By way of comparison with these data, the North Atlantic hurricane record (HURDAT2 database) is unavoidably complicated by changes in observation platforms – shipborne, aircraft and satellites (Landsea *et al.*, 2006; Chen *et al.*, 2009; Landsea and Franklin, 2013) – and even within the satellite era by improvements in coverage, resolution and signal processing (Klotzbach 2006; Landsea *et al.*, 2006). Attempts to draw unequivocal conclusions about the possible contribution of anthropogenic climate change in past North Atlantic hurricane activity inevitably founder on these inhomogeneities [e.g. Webster *et al.* (2005)]. By contrast the self-consistency of the Fijian flood measurements is appealing, especially as the catchment has been relatively exempt from other confounding influences such as expanding urbanization and large land use changes over the time period of interest.

2. Climate and flooding in Fiji

Viti Levu (18°S 178°E), the largest of the Fijian Islands (Figure 1(a)), experiences highly variable rainfall (Kumar *et al.*, 2014a). Rainfall seasonality is strongly influenced by movements of the South Pacific Convergence Zone (SPCZ) (Mataki *et al.*, 2006), one of the globe's most expansive and persistent cloud bands (Trenberth, 1976; Folland *et al.*, 2002). The position of the SPCZ is in turn modulated at inter-annual time scales by ENSO phases. In an El Niño event the SPCZ is displaced to the north-east away from Fiji, leading to drier than normal conditions, particularly on the north-western side of the main islands that is shielded from rain-bearing south-easterly trade winds. In a La Niña event, the SPCZ moves south-west towards Fiji, giving rise to wetter than normal conditions (Folland *et al.*, 2002; Kumar *et al.*, 2014a).

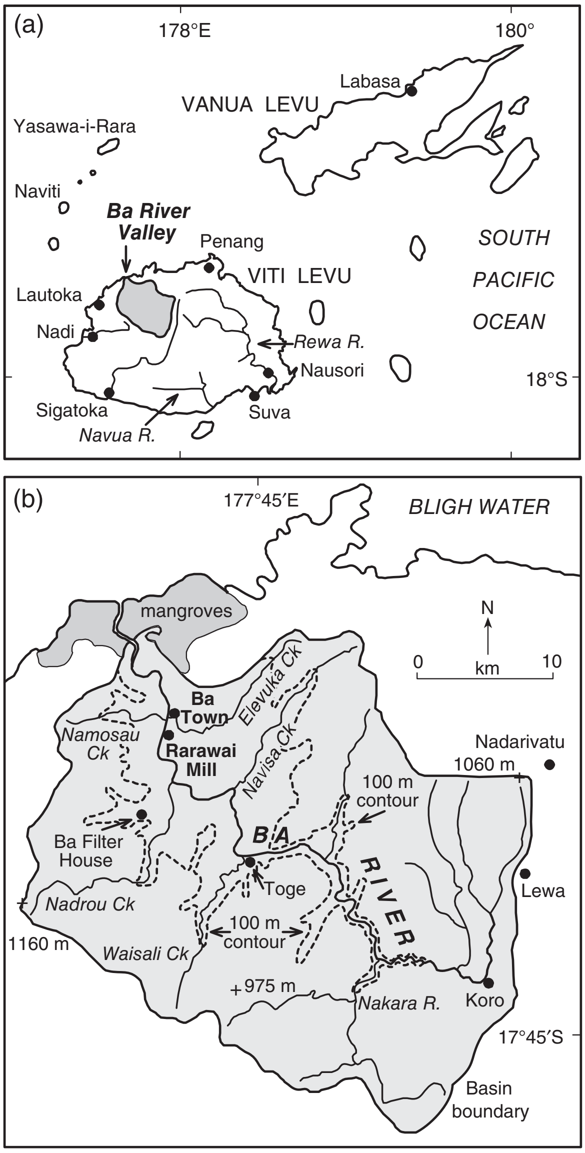

Figure 1. Ba River Valley. (Source: Yeo *et al.*, 2007.)

In both El Niño and La Niña phases, however, Fiji may be impacted by tropical cyclones (Chand and Walsh, 2009), which often produce intense rain and flooding. For example, 1133 mm of rainfall was recorded in 2 days during the slow-moving 1931 cyclone at Nadarivatu station (Figure 1(b)) at an elevation of 835 m (Yeo and Blong, 2010). This led to record flooding of three river systems whose headwaters originate near Nadarivatu: the Rewa, Sigatoka and Ba Rivers. Downstream flooding in the Ba

Figure 2. View of the December 1938 flood looking towards the Mill. (Source: CSR Company – Deposit No. 171/239, photo no. 31.2.)

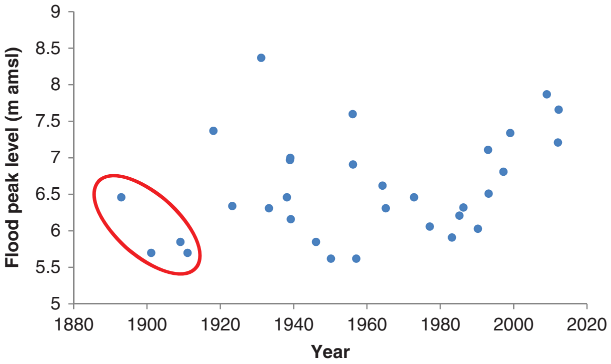

Figure 3. Peak heights of major floods since 1892 at the Rarawai Mill site ($n = 32$). The four encircled points are of lower accuracy than the remainder of the data.

River at the Rarawai Sugar Mill (Figure 2) is the subject of our study here.

3. A 122-year history of major flooding in Ba River, Fiji

Yeo *et al.* (2007) developed a historical flood series for the Ba River that was based largely on correspondence between the Rarawai Sugar Mill and the headquarters of its former owner, the Colonial Sugar Refining (CSR) Company in Sydney, Australia. The archives of the CSR Company are held at the Noel Butlin Archives Centre at the Australian National University in Canberra.

The sugar mill at Rarawai, meaning *Field of Water* in the local language, operated since 1886 under the ownership of CSR until the Fiji Sugar Corporation (FSC) took over the factory in 1973. Located some 15 km from the river mouth, the river is tidal at the Mill site.

Yeo (2015) has extended this flood series and undertaken further validation against other sources such as newspaper and meteorological reports and interviews with local identities. The time series comprises 32 events designated as ‘major’ floods between 1892 and 2013 that have attained or overtopped the Mill floor (Table A1); peak levels of these floods are plotted in Figure 3. This data series is considered complete. Many lesser Ba River floods are also known (McGree *et al.*, 2010; Yeo, 2015) but this record is not complete and thus unsuitable for the analyses undertaken here.

Landmarks such as the Mill floor were surveyed so that reported peak depths above this height [5.55 m above mean sea-level (amsl)] and other landmarks could be converted to the National Datum. Since the change of Mill ownership in 1973, fewer records of flood heights are available at the Mill, but these have been supplemented from records at Ba town located 1 km downstream. Flood levels for seven recent events were estimated using a linear regression ($R^2 = 0.97$) between flood heights at the Mill and the town where data at both sites were available. In a similar vein, another two flood levels were estimated using a second linear regression ($R^2 = 0.99$) between an upstream railway bridge and the Mill.

Of the 32 floods, Yeo (2015) considers 18 depths to be of high accuracy (<±0.10 m); 11 of medium-high or medium accuracy (~±0.15 m), a category that includes those derived by regression analysis as described above; and three early events of low accuracy (~±0.4 m) (Tables A1 and A2). The higher uncertainty in these latter cases arises where the primary correspondence is missing and thus we are dependent on references in subsequent correspondence, or where depths of inundation are not explicitly reported.

No flood discharges are available and the homogeneity of the flood level series cannot be confirmed definitively given some changes to catchment land use including the area under sugar cane cultivation, changes to river channel morphology and floodplain development over the period of record (Yeo, 2015). None of these, however, are likely to have had an important influence on the major floods under consideration here. At the 2007 Census, the Ba township had a population of 18 526 persons, including the peri-urban population (FIBS, 2008); the township occupies only a tiny fraction of the catchment that drains an area of about 950 km^2.

4. Statistical analyses of major floods

In what follows we report the results of statistical analyses of the data set, comprising temporal analyses of:

- major flood frequencies across non-overlapping time intervals of approximately equal duration,
- major flood heights,
- the influence of coupled ocean–atmosphere phases of the ENSO on the above and
- the role of sea-level rise and global warming.

4.1. Flood frequencies

Figure 4 displays the frequency of occurrence of the observed major floods by month. The period of maximum flood risk extends from January through March with 28 out of 32 floods (88%) occurring within this period. This corresponds to what is generally referred to as the ‘wet’ or ‘tropical cyclone’ season.

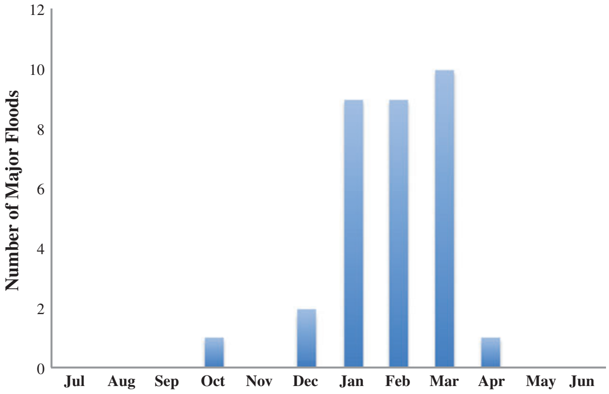

Figure 4. Monthly frequency of occurrence of major floods.

Table 1. Mean and standard deviation of the number of major floods occurring per year in each 30 (or 31)-year period at the Rarawai Mill.

	1892–1921	1922–1951	1952–1982	1983–2013
n (years)	30	30	31	31
Mean (major floods per year)	0.17	0.30	0.23	0.35
Standard deviation (major floods per year)	0.38	0.60	0.50	0.61
Coefficient of variation	2.27	1.99	2.20	1.71

Table 2. Observed frequencies of the number of years with 0, 1 or 2 major floods.

Number of years with	1892–1921	1922–1951	1952–1982	1983–2013	Total
0 floods	25	23	25	22	95
1 flood	5	5	5	7	22
2 floods	0	2	1	2	5
Total	30	30	31	31	122

To identify whether flood frequencies have been increasing across time, the data set was divided into four periods of approximately equal length (30 or 31 years) and the mean and standard deviation of the frequency of major floods occurring per year in each period calculated. These are shown in Table 1.

The frequency of floods in the period 1892–1921 is less than half that of 1983–2013, a result that at first blush might suggest flood frequency is increasing. However a formal analysis of variance (ANOVA) test shows no statistically significant difference in mean frequency between the four groups ($F = 0.74$, $p > 0.5$). This arises because the variance in frequencies within each group is large (coefficient of variation ~ 2). On this basis, we conclude that the average frequency of major floods on this river has *not significantly* increased across time.

To further scrutinize this conclusion, we also examined the trend in annual flood frequencies by comparing the observed *frequency of years having n floods* in each of the four periods, where n is the number of major floods (0, 1 or 2). A chi-squared test is appropriate and shows no statistically significant association between the annual frequency of floods and the time periods considered ($\chi_2^2 = 1.54$, $p > 0.4$) (Table 2). In other words the results confirm that the frequency of major floods is *not significantly* increasing across time.

We further examined the dependence of the above result on the number of time periods (each having roughly the same number of observations) and confirmed that there is no statistical change in the mean frequency of major floods across time (data not shown).

4.2. Peak flood heights

Peak flood levels and the year of occurrence of the 32 major floods are depicted in Figure 3. The data are quite scattered and the correlation between these two variables is 0.31. A formal hypothesis test reveals a nearly statistically significant correlation between depth and time ($t_{30} = 1.78$, $0.05 < p < 0.10$). The slope of the regression line is positive and statistically significantly different from zero at the 10% level, but not at the 5% level. While the multiple R^2 is 0.095, meaning that the regression explains only 9.5% of the variance in the flood depths, we might cautiously conclude that flood depths are gradually increasing over time. The implications of rising sea levels (Church *et al.*, 2006) for this conclusion will be dealt with in later discussion.

The flood heights of three of the four earliest data points [i.e. those prior to 1912 (Figure 3)] are considered to be of relatively low accuracy (Tables A1 and A2). Because, observations at the extreme ends of the range of the explanatory or determinant variable, in this case, time, have relatively greater influence on the slope of the regression line, it could be argued that these points be omitted from further analysis so not to sully confidence in the otherwise more accurate data points. If these data are omitted from consideration, the correlation between the two variables reduces to 0.13 and the regression now explains only 1.8% of the variation in the flood height over the reduced range of observations. A formal hypothesis test is not statistically significant, even at the 40% level ($t_{26} = 0.6908$, $p > 0.4$) and neither is the slope of the regression line statistically significantly different from zero ($F_{1,26} = 0.4772$, $p > 0.4$).

The (reduced) data set implies there is no significant increase in flood heights across time, at least from a statistical viewpoint. Note that this result does not put in question our earlier analysis of flood frequencies because despite our low confidence as to the exact height of some of the earliest data points, there is no question that all events in the database did actually flood above the Mill floor level and thus constitute, in the context of this study, major floods.

The above discussion illustrates simply that varying the starting point of a time series can lead to quite different conclusions about trends in the data, even if the statistical

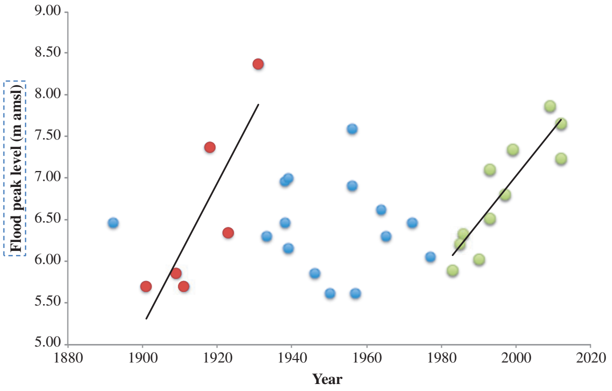

Figure 5. Peak heights of major floods during periods experiencing similar rises in peak flood depths.

analysis is consistent. As one further example of this, Figures 3 and 5 show that flood heights have been steeply increasing since around 1980. In point of fact, many other studies seeking to explore the likely role of climate change in natural disaster statistics have chosen to begin their analyses around 1970–1980 [e.g. Webster *et al.* (2005) and Klotzbach and Landsea (2015)] on data quality grounds.

To further demonstrate this point, a regression analysis of the flood height data post-1980 yields an R^2 of 0.79 (i.e. 79% explanation of the variability in the data) and a correlation of 0.89 (Figure 5). The slope of the regression line is highly statistically significant ($p < 0.0003$). We do not contend that this subdivision of the data is justified in any unique manner given the quasi-oscillatory character of the time series, and, in fact, an almost identical result can be obtained for the years 1900–1931 (Figure 5). Rather it serves to emphasize that arbitrary data selections can support equally arbitrary hypotheses with respect to the role of anthropogenic climate change, or any other phenomena for that matter.

4.3. Influence of ENSO phases

ENSO impact analyses categorize events as belonging to one of three phases: El Niño, La Niña or neutral, based on an index derived from sea surface temperature (SST) anomalies. The index employed here comes from the Japan Meteorological Agency (JMA): it is a 5-month running mean of spatially averaged SST anomalies over the tropical Pacific: 4°S–4°N, 150°W–90°W. If index values are 0.5 °C (−0.5 °C) or greater (less) for six consecutive months including October, November and December, the ENSO year of October through to the following September is categorized as El Niño (La Niña). All other years are classified as neutral. For the period 1949 to the present, the JMA-index is based on observed data; pre-1949, the index is based on reconstructed monthly mean SST fields using an orthogonal projection technique (Meyers *et al.* 1999). Table 3 shows a categorization of the flood events in our series into the three ENSO phases.

Table 3. The distribution of observed and (statistically) expected number of major flood events by ENSO phase.

Phase	Number of years per phase	Expected number of major floods if independent of ENSO phase	Observed number of major floods
La Niña	29	7.61	14
Neutral	66	17.31	13
El Niño	27	7.08	5

Differences between the last two columns of Table 3 point to a statistically significant differences in frequencies ($\chi_2^2 = 7.06$, $p < 0.05$) in La Niña years. Put simply, more floods are observed in La Niña phases than expected under a hypothesis that major floods are equally distributed amongst ENSO phases. If we also consider floods not reaching the Mill floor level (McGree *et al.*, 2010; Yeo, 2015), we find that flooding of the Ba River was observed in 25 of the 29 La Niña years but in only 12 of the 27 El Niño years, a difference that is statistically highly significant. Thus it appears that the ENSO phase plays a significant role in influencing flood frequency. On the other hand, the observed correlation between the height of major floods and ENSO phase is very low (−0.02). In summary, it appears that whether or not a flood occurs in a given year is strongly related to the ENSO phase, but the actual height of major floods on the Ba River is not.

These results are unsurprising. A greater frequency of floods during the La Niña phase of ENSO is expected given the closer proximity to Fiji of the SPCZ in this ENSO phase (Folland *et al.*, 2002; Mataki *et al.*, 2006), which tends to generate markedly wetter conditions in north-west Viti Levu [e.g. Kumar *et al.* (2014a)]. In addition to the higher likelihood of tropical disturbances from the convergence zone affecting the Fiji Group, soil moisture levels and baseflow are likely to be higher, promoting runoff and flooding when subsequent storms cross the islands.

Two factors may account for the absence of a correlation between flood height and ENSO phase. First, tropical cyclones are important (but not the only) meteorological systems responsible for bringing flooding rains to Fiji and these can occur in both El Niño and La Niña years (Chand and Walsh, 2009). With reference to Fiji Meteorological Service's database of tropical cyclones, eight of the 13 major Ba river floods recorded in La Niña years, and four of the five major Ba river floods recorded in El Niño years, were associated with tropical cyclones. Particularly large tropical cyclone floods have occurred in both phases – February 1931 in an El Niño and January 1956 in a La Niña, for example. Second, flood magnitude is strongly influenced by the particular characteristics of each storm, notably its rate of movement. The record flood in February 1931 was attributed to a hurricane almost 'stalling' northwest of Viti Levu, causing continuous heavy rain on the same catchment (Yeo *et al.*, 2007; Yeo and Blong, 2010). Similarly, stationary tropical depressions were responsible for severe flooding in January and March 2012 (a neutral, or, by other measures, a weak La Niña year; Kuleshov *et al.*, 2014).

5. The impacts of sea-level rise and global warming

Our analyses find no statistically significant trends in the frequency of major floods since 1892 and in terms of the peak heights, the degree of significance is highly conditional to the choices of start and finish dates. This is also true of the confidence we might place in any mechanistic hypotheses we might pose based on that degree of significance, although clearly statistical significance cannot in itself prove such a mechanism exists.

In terms of flood heights, one obvious variable that has not featured in our analyses to this juncture is correction for the average sea-level rise relative to land over the period of interest. Global averaged sea-level rise is estimated at about $1.7 \pm 0.2\,\text{mm year}^{-1}$ (Rhein *et al.* 2013), however, this global average rise ignores any local land movements. Church *et al.* (2006) and J. A. Church (2016; personal communication) suggest a long-term average rate of relative (ocean relative to land) sea-level rise of $\sim 1.3\,\text{mm year}^{-1}$ might be applicable to Fiji. This figure corrects for glacial isostatic adjustment but ignores any vertical motion of the land from tectonic effects or subsidence of estuarine sediments for which no correction is possible over the twentieth century, or any acceleration in the rate of rise in more recent times.

Taking this average figure into account, we find that the regression with the full data set [32 points (Figure 3)] is now no longer significant ($p > 0.15$, whereas before it was <0.1) and when we leave out the first 4 points, the regression is even less significant than before ($p > 0.65$, whereas before it was $p > 0.4$). When we only look at data post-1980 things are hardly changed and the 1900–1931 regression has almost identical significance. This being the case, our conclusion is that the frequency and magnitudes of riverine flooding in the Ba River has remained unchanged since 1892, except for the impact of sea-level rise on the latter.

This conclusion emerges despite such flooding events taking place against a background of consistent warming, with the homogenized air temperature data from the Nadi airport – some 40 km distant from the Rarawai Mill – showing an increase of ~0.18 °C per decade over the last 68 years (Kumar *et al.*, 2014b). This warming is in line with other Pacific Island climatological stations examined by Jones *et al.* (2013) as part of the Pacific Climate Change Science Program (http://www.pacificclimatechangescience.org/).

On the other hand, contemporaneous annual rainfall totals measured at the Rarawai Sugar Mill itself exhibit no significant trend since 1910 when measurements began (Kumar *et al.* 2014a). This does not in itself rule out a possible change in flooding for a number of reasons: first, because the relationship between rainfall and flood response in a catchment is complex (Kundzewicz *et al.*, 2014); second, the Rarawai rainfall series is unlikely to include contemporaneous rainfall during many of the major floods considered here as the rain gauge would likely have been overtopped by a metre or more of water; third, even if correctly measured, such daily rainfall figures would only be loosely correlated with the annual totals and finally, because riverine flooding is not necessarily a response to local rainfall.

6. Conclusions

A long-term flood height series reconstructed largely from archival searches of correspondence between the Rarawai Sugar Mill situated on the lower reaches of the Ba River in Fiji and CSR's Head Offices in Sydney, Australia, is scrutinized using simple and well-known statistical tests. The data show no consistent trend in the frequency of flooding over the 122-year duration of observations despite persistent warming of air temperatures characterized in other studies [e.g. Kumar *et al.* (2014b)]. On the other hand, flood frequencies are strongly influenced by ENSO phases with many more floods of any height occurring in La Niña years.

In terms of flood heights, a marginal statistically significant upward trend is observed over the entire sequence of measurements. However, once the data have been adjusted for average sea-level rise of $1.3\,\text{mm year}^{-1}$ over the entire length of the record, no statistically significance remains, either for the entire record, or for the shortened series based on higher quality data. The analysis of the uncorrected data shows how the choice of starting points in a time series can lead to quite different conclusions about trends in the data, even if the statistical analysis is consistent.

In short, we have been unable to detect any influence of global warming at this tropical location on either the frequency, or the height of major flooding other than that due to its influence on sea-level rise. We note that our study was not undertaken with a view to generalizing these results in respect to the significance of the impacts of man-made global warming on other manifestations of extreme weather, or even to flooding in other jurisdictions. Rather it sought to demonstrate the difficulty of achieving statistical significance in terms of attribution of extreme weather even with relatively long data sets, consistent measurement techniques and without the complications of having to account for changing exposure and building vulnerability that collectively influence disaster loss histories.

Acknowledgement

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Appendix

Table A1. Historical major flood peak levels for major floods at Rarawai Mill, Ba, 1892–2013: 'major floods' are those reaching or exceeding Mill floor level.

Date of flood	Assessed level	Accuracy
15 December 1892	6.46	Low
16–17 February 1901	5.70	Low
7 February 1909	5.85	High
16 January 1911	5.70	Low
7 February 1918	7.37	High
30 March 1923	6.34[a]	Medium
21–22 February 1931	8.37	High
27 March 1933	6.31	High
27 February 1938	6.46	High
22 December 1938	6.97	High
21 January 1939	7.00	Medium-high
16 March 1939	6.16	High
30 January 1946	5.85	High
27 February 1950	5.62	High
31 January 1956	7.60	High
6 March 1956	6.91	High
16 January 1957	5.62[a]	Medium
22 March 1964	6.62	High
9 February 1965	6.31	High
24 October 1972	6.46	High
4 February 1977	6.06[b]	Medium
2 March 1983	5.90[b]	Medium
6 March 1985	6.21[b]	Medium
11 April 1986	6.33[b]	Medium
21 March 1990	6.03[b]	Medium
3 January 1993	7.11	High
27 February 1993	6.52[b]	Medium
8 March 1997	6.81	High
19 January 1999	7.34	High
10 January 2009	7.87	Medium-high
24 January 2012	7.24[b]	Medium
30 March 2012	7.66	High

[a] Level for Rarawai Mill was estimated using a level recorded at the railway bridge upstream. [b] Level for Rarawai Mill was estimated using a level recorded at Ba Town downstream.

Table A2. Summary of methods used to assess historical flood peak levels at Rarawai Mill, Ba.

Method	Flood (year, month)	Source quality
Estimation based on general description of magnitude/consequences	1892, 1901, 1911	Low
Transfer from measurements at the Rarawai Railway Bridge	1923, 1957	Medium
Transfer from unofficial measurements in Ba Town	1977, 1986, January 2012	
Transfer from official measure at old Ba Road Bridge	1983, 1985, 1990, February 1993	
Flood observation relative to other floods at Rarawai Mill	1918, 1933, January 1939, January 1956, March 1956, 1965, 1997, 2009, March 2012	High
Flood observation relative to a surveyed level at Rarawai Mill	1909, 1931, February 1938, December 1938, March 1939, 1946, 1950, 1964, 1972, January 1993, 2009, March 2012	
Flood mark surveyed at Rarawai Mill	1999	

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