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Diagnosis of Flood Events in Brisbane (Australia) using a Flood Index based on Daily Effective Precipitation

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INTRODUCTION

Like the case of drought, flood events are considered major detrimental hazards for our community (Yeo 2002; Coates 1996). In eastern region of Australia, the 2010–2011 Summer saw significant flooding that appeared to be exacerbated by a strong La Nina event with damages of a magnitude similar to previous floods in 1974 and the mid-1950s (Seqwater 2011). A plethora of flood events in eastern Australia raises questions about how best to address the increasing vulnerability and economic and societal costs of flood events (van den Honert & McAneney 2011). On the same viewpoint, several studies have documented the particularly vulnerable geographic setting of the Capital city, Brisbane, which is known to be situated on a flood plain area (e.g. (van den Honert & McAneney 2011; Box, Thomalla & Van Den Honert 2013; Inquiry 2011; Keogh et al. 2011)). Consequently, flood events have been common in the past that resulted in serious environmental degradation and economic costs. To name a few such events, the worst flood event occurred in January 1974 and of s similar magnitude in December 2010 – January 2011 which inundated most of the local dwellings around the Brisbane River catchment and quite severely in the Toowoomba and the Lockyer Creek catchments causing 23 deaths. In the 2010-2011 flood event, property insurers received some 56,200 claims with payouts totaling $2.55 billion, due to estimated inundations of 18,000 properties (Seqwater 2011; van den Honert & McAneney 2011). Clearly, flood events have left a clear footprint of damage and suffering over the past many decades.

It is well understood that crucial to any flood mitigation or adaptation to the disaster is the requirement to monitor closely to help predict or forecast such events. For flood monitoring, a real-time system that is able to detect precisely the onset and end dates of flood, the elevating danger of flood based on how the event will unfold according to its water-intensive properties, is a useful tool. In general, any flood event is dependent on how the abundance of water resources due to heavy rainfall varies over time, and how the water is dissipated over the passage of time. With such a system, it may be possible to determine the elevating danger of a flood event well in advance, thus increasing the ability for contingency planning.

In this study we explore the utility of a daily flood monitoring index for detecting flood danger and measurement of flood properties in Brisbane (Australia). Here, we consider the index based on the remaining effective precipitation on daily basis which is the summed rainfall due to heavy rain over a given period of time. The proposed Flood Index (*FI*) used in this study was initially developed by Byun & Wilhite (1999) based on the concept of daily Effective Precipitation (*EP*) and Available Water Resources Index (*AWRI*) (Kim, Byun & Choi 2009; Byun & Lee 2002).The purpose of this study was as follows: (1) To test the applicability of FI as an objective flood diagnostic tool following earlier studies (Byun & Jung 1998; Nosrati, Saravi & Shahbazi 2011) and (2) verify the ability of the FI for quantifying the duration and peak danger of flood. This paper is organised as follows. In Data and Methods section, we show the study region, the rainfall data used to compute the Flood Index and the methodology involved in computations. In Results and Discussion section the main findings are presented and in Conclusions, final remarks for closing the paper are made.

DATA AND METHODS

In this study, we have applied the FI to the region of Brisbane City, which is the State capital of Queensland (Australia) located at longitude 153.0°E and latitude 27.50°S. In order to compute the FI, we used the pre-processed daily rainfall data acquired from the Australian Bureau of Meteorology's high quality archives (http://www.bom.gov.au/climate/data-services/). The data for the period 1915–2012 were extracted for the local station, Harrisville, which was closest to the Brisbane City located at longitude 152.67°E and latitude 27.81°S. Further analysis was undertaken using supplementary rainfall data for the local station Ambooya Post Office located at longitude 151.87°E and latitude 27.71°S and UQ Gatton located at longitude 152.34°E and latitude 27.55°S as both stations were close to Toowoomba and Lockyer Valley where the 2010-11 flood event was extremely catastrophic (Box, Thomalla & Van Den Honert 2013; Seqwater 2011; van den Honert & McAneney 2011).
In order to demonstrate the suitability of FI for diagnosis of flood events, the mathematical process required the calculation of daily Effective Precipitation *EP*. This was the accumulated value of the daily precipitation using a suitable time-reduction function that allowed a reasonable estimate of the decay in water resources due to hydrological processes such as evaporation, surface run-off and seepage (e.g. (Byun & Jung 1998; Byun & Wilhite 1999)). Following the basic equations, if P_m was the daily rainfall and N was the duration of the preceding period, then *EP* for current day could be calculated as

$$\begin{aligned} EP &= \sum_{N=1}^{D}\left(\left(\sum_{m=1}^{N} P_m\right)/N\right) \\ &= P_1 + \frac{(P_1+P_2)}{2} + \frac{(P_1+P_2+P_3)}{3} + \ldots + \frac{(P_1+P_2+\ldots+P_{365})}{365} \\ &= P_1\left(1+\frac{1}{2}+\frac{1}{3}+\ldots+\frac{1}{365}\right) + P_2\left(\frac{1}{2}+\frac{1}{3}+\ldots+\frac{1}{365}\right) + \ldots + P_{365}\left(\frac{1}{365}\right) \end{aligned} \quad (1)$$

The daily Available Water Resources Index (*AWRI*) was calculated as

$$W = \sum_{N=1}^{D}(1/N) \quad (2)$$

$$AWRI = \frac{EP}{W} \quad (3)$$

Note that *AWRI* is a supplementary property that accounts for available water resources. It is logical to perceive that if the abundance of the available water resources is a pertinent factor for the danger of flood event. Therefore, the daily Flood Index (FI) was computed as follows:

$$FI = \frac{AWRI - \langle AWRI_{y\max} \rangle}{ST(AWRI_{y\max})} \quad (4)$$

where $\langle AWRI_{y\max} \rangle$ and *ST*(*AWRI* $_{y\ \max}$) are the mean and the standard deviation of yearly maximum *AWRI* over the climatology period. Indeed, equation (4) determines the standardized value of *FI* by comparing the water resources for any Julian date to the yearly maximum. To detect flood events and their properties, the following classifications were used: (1) Danger of the onset of a flood event at any given station when the FI > 0 (i.e. water resources were larger than the normal period), (2) severity of the flood event denoted by the accumulated value of the Flood Index (AFI) for all days with FI > 0, (3) peak flood danger (*PFI*) as maximum value of FI after the onset date in any identified flood period.

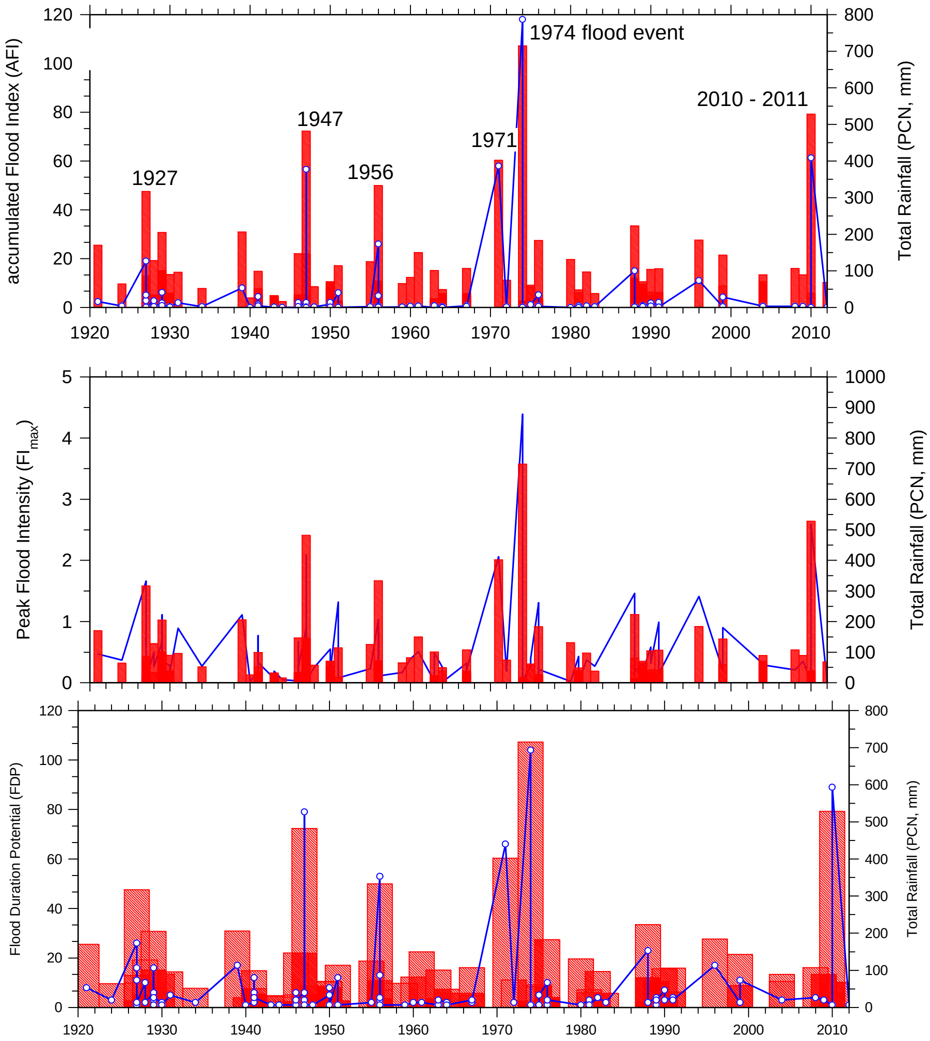

Figure 1. Diagnosis of flood events using Flood Index based on daily effective precipitation. (a) Accumulated flood index (AFI), (b) Peak Flood Intensity (FI_{max}), (c) Flood duration potential (FDP) for

the period 1915-2012 in Brisbane (Australia). The bar graph represents rainfall and the line graph represents the flood properties.

RESULTS AND DISCUSSION

Figure 1 displays the practical usage of equation (4) for the diagnosis of flood events. Here, the identified periods of flood were quantified by the Accumulated Flood Index (AFI), Peak Flood Intensity (FI_{max}) and the Flood Duration Potential (*FDP*). The time-series of the FI makes it immediately obvious that the FI has good ability for identifying historical floods for the years 1974, 2010-2011, 1947, 1971, 1956 and 1927. Note that these were the major years of flood events in Brisbane (Australia). The years of minor flooding were also identified although the magnitude of the flood properties was substantially smaller. Three properties of flood events (severity, intensity and potential duration) appear to be well captured by the *AFI*, FI_{max} and *FDP*, which indeed concur with the total precipitation value during these years.

Table 1. The top ten catastrophic flood events ranked for Brisbane (Australia) based on their water-intensive properties. The approximate onset dates were detected for all days with FI > 0.

Approximate Onset Dates	Accumulated Flood Index, AFI	Max Flood Index, FI_{max}	Maximum Available Water Resources Index, $AWRI_{max}$ (mm)	Total Rainfall, PCN_{tot} (mm)	Potential Duration of Flood, FDI (days)
26-Sep-1974	118.1	4.4	530	715	104
29-Dec-2010	61.3	2.6	415	528	89
26-Jan-1971	58.3	2.1	381	402	66
13-Feb-1947	56.6	2.1	383	482	79
09-Feb-1956	25.7	1.0	315	333	53
23-Jan-1927	18.6	1.7	355	317	26
04-Apr-1988	15.1	1.5	342	223	23
03-May-1996	11.1	1.4	339	184	17
10 Mar-1939	8.0	1.1	320	206	17
31-Jan-1951	6.2	1.3	334	114	12

Another practical utility of FI is demonstrated in Table 1. Here we show the properties of all flood events detected over the past 98 years of investigated dataset. In this table the top ten flood events were ranked in accordance with their water-intensive properties and the maximum value of AWRI. Note that the AWRI has been used to indicate the danger of flood event in terms of the surplus of water resources that could trigger inundations. Undoubtedly, the results depicted the flood events of 1974, 2010 and 1971 as the most severe episodes. For these cases, the impact was potentially very damaging where the highest value of the AFI was realized after the flood onset date. Interestingly, the magnitude of the flood severity appeared to be nearly twice of the 2010 – 2011 event and the 'potential duration of this flood' was 108 days.

It must be realised that potential duration of the flood event does not mean the inundations where sustained for this period of time, but rather the index is used to show the approximate number of days when flood danger remained in place due to elevated water resources. Based on the results in Table 1, the properties of flood events are consistent in terms of their magnitude. For example, the AFI was the highest for the 1974 flood event, and the lowest for the 1951 flood event. Accordingly, the maximum of the Flood Index and total precipitation during the flood event followed a similar trend. This demonstrates consistent results when flood events are analysed based on equation (1) – (4).

CONCLUSION

In this study the practical utility of the Flood Index based on daily effective precipitation, originally designed by Byun & Jung (1998) was used to quantify flood in Brisbane (Australia). The analysis performed over 98-year period demonstrated the efficacy of the index for quantification of flood severity, peak danger and potential durations. Additionally the method allowed estimation of available water resources for each flood period. Based on the Flood Index, the onset date of the infamous 1974 flood event was 26-January-1974 and the November 2010 – January 2011 flood event was 29-December-2010.

In agreement with the published data, we showed that the 1974 flood event was the most severe episode. This event yielded an accumulated value of the FI =118, maximum FI = 4.4 and a potential duration of 104 days. By comparison the most severe flood in Lockyer Valley and Toowoomba was the 2010-2011 floods with accumulated FI of about 65.96, maximum FI of about 3.05 and potential duration of about 57 days and accumulated FI of about 62.05, maximum FI of about 2.81 and potential duration of about 81 days, respectively. Accordingly we conclude that the Flood Index allows measurement of flood properties and comparison of various events. The method is novel for quantifying flood events on daily basis, and appears promising for the forecasting of flood events using time-series approach. As flood events can also inundate in a flash style over hourly timescales, the use of hourly rainfall data should be included in the analysis of floods to quantify their danger over short-term timescales. Our research on the hourly detection and diagnosis of flood events is currently in progress.

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