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Trends in Extreme Rainfall Events in Tasmania, Australia

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***Abstract*—**Climate change will affect various aspects of hydrological cycle such as rainfall. A change in rainfall will affect flood magnitude and frequency in future which will affect the design and operation of hydraulic structures. In this paper, trends in sub-hourly, sub-daily, and daily extreme rainfall events from 18 rainfall stations located in Tasmania, Australia are examined. Two non-parametric tests (Mann-Kendall and Spearman's Rho) are applied to detect trends at 10%, 5%, and 1% significance levels. Sub-hourly (6, 12, 18, and 30 minutes) annual maximum rainfall events have been found to experience statistically significant upward trends at 10% level of significance. However, sub-daily durations (1 hour, 3 and 12 hours) exhibit decreasing trends and no trends exists for longer duration rainfall events (e.g. 24 and 72 hours). Some of the durations (e.g. 6 minutes and 6 hours) show similar results (with upward trends) for both the tests. For 12, 18, 60 minutes and 3 hours durations both the tests show similar downward trends. This finding has important implication for Tasmania in the design of urban infrastructure where shorter duration rainfall events are more relevant for smaller urban catchments such as parking lots, roof catchments and smaller sub-divisions.

***Keywords*—**Climate change, design rainfall, Mann-Kendall test, trends, Spearman's Rho, Tasmania.

I. Introduction

IMPACTS of climate change on rainfall has important implication in water resources management since a change in rainfall will impact droughts, floods and catchment hydrological processes, which will in turn affect various aspects of agriculture, ecology, infrastructure and environment [1]-[8]. The future rainfall at many locations will be changed significantly due to climate change [9]. Warming of the climate system has potential impacts to intensify the global hydrological cycle, causing exacerbation of extremes such as floods and droughts [10]. It has become an important research question to investigate trends in historical rainfall data. However, due to irregular topography and complex atmospheric circulation rainfall intensity shows notable spatial variability [11]. Although increase in global temperature leads to increase rate of precipitation, it has been found that for some regions there is no trends in the annual rainfall [12], [13].

To characterize possible changes in climatic extremes and assess the knock on effects, trends analysis has extensively been used on hydrological time series data at different parts of the world [14], [15]. Some studies on the trends analysis of rainfall can be found in [16]-[25]. Most of these studies observed increasing trends in short duration storms and not any significant increasing trends for medium to long duration storms.

Due to the high rainfall variability in Australia, the number of hydrological impact studies due to climate change has increased in recent years. In order to improve water management, researchers attempted to evaluate changes in the spatial and temporal patterns of rainfall. The majority of research has examined changes in annual, seasonal, monthly and daily rainfall data, whereas studies for sub daily rainfall are limited. The main findings are that there is an increase in annual rainfall in the northern parts of Australia whereas eastern and southwest regions exhibit decreasing trends in annual rainfall [26]-[32].

Tasmania has complex spatial rainfall patterns [33]. Consequently, understanding and making future projections of Tasmanian rainfall are challenging. Rainfall variability is influenced by various remote drivers [e.g. El Nino–Southern Oscillation (ENSO), Southern Hemisphere Annular Mode (SAM), Indian Ocean Dipole (IOD)] [34]. There have been limited studies on Tasmanian rainfalls as compared with mainland Australia.

Many researchers have highlighted the role of the westerly airstream in conveying air across Tasmania's west coast where it undergoes lifting over the rugged topography resulting in higher annual rainfall over the western highlands. However, there is a significant 'rain shadow' over parts of eastern Tasmania and the midlands [35]-[37].

In regards to the projections for changes to rainfall in Tasmania, the increase in precipitation may be confined to the west coast with stronger winds contributing to greater evaporation [38].

Godfred-Spenning and Gibson [39] have conducted an analysis of the synoptic weather systems which produce rainfall over the 'Hydro' catchments and concluded that over the period of the study, there were no significant trends in the data; however, the frequency of occurrence of 'northerly depressions' had increased.

Tasmania has experienced two wet periods in the 1950s and in the 1970s, and a dry decade in the 1940s. According to Srikanthan & Stewart [40] in the period 1910 to 1990, there were no statistically significant trends in the mean annual rainfall in Tasmania. Downward trends in rainfall over the period 1970 to 1990 was present, and this has continued from 1990 to 2007 [37].

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Rainfall distributions differ significantly across Tasmania, i.e. north and east (excluding some around Ben Lomond) experience lower rainfall, which affects the bushfire regimes as well as vulnerability of the vegetation to fire [41]; however, the wetter regions of the southwest rarely experience fire. In Tasmania water is a very valuable resource in producing electricity [42]. Some regions in Tasmania are more prone to intense rainfall than others, and have greater flood risk. The highest one-day rainfall is 352 mm, recorded at Cullenswood in Tasmania's north-east. The proportion of rainfall that reaches storages and the timing of any runoff are greatly influenced by the nature of the catchment and catchment management practices. Runoff variability is caused by the natural variability of rainfall and rainfall - runoff processes.

It has been assessed that large catchments (such as the Derwent catchment below Meadowbank) characterized by upstream storage, durations of 72 hours or greater will have significant impact on flooding [43].

Although many studies have been conducted for Tasmania's rainfall, extreme precipitation events of short durations have not been fully investigated in relation to the trends. Hence, this paper investigates the trends of short and long duration extreme rainfall events for Tasmania.

II. Methods

Two non-parametric rank-based trends tests Mann-Kendall (MK) and Spearman's Rho (SR) are used in this study to assess the trends of extreme rainfall events of shorter and longer durations. Non parametric tests are more suitable for non-normally, nonlinearly and censored data which are frequently found in hydro-metrological time series. The null hypothesis in the MK test states that the data ($X_1, X_2, ...,X_n$) are a sample of n independent and identically distributed random variables. The MK test statistic is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i-1}^{n} sign(X_j - X_i) \tag{1}$$

where X represents a univariate time-series, i and j denote the time indices associated with individual values, n is the number of data points and sign is determined as follows:

$$sign(X_j - X_i) = \begin{cases} +1 & (X_j - X_i) > 0 \\ 0 \quad if & (X_j - X_i) = 0 \\ -1 & (X_j - X_i) < 0 \end{cases} \tag{2}$$

The statistic S under the null hypothesis is approximately normally distributed for $n \geq 8$ with mean and variance as follows:

$$E(S) = 0 \tag{3}$$

$$Var\,(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{L} t_l\,(l)(l-1)(2i+5)}{18} = \sigma^2 \tag{4}$$

where t_l indicates the number of ties of extent l, and L is the number of tied groups [44], [45]. Under the null hypothesis, the standardized test statistic (Z) defined in (5) and its corresponding p-value are approximately normally distributed:

$$Z_s = \begin{cases} \frac{S-1}{\sigma} & S > 0 \\ \frac{S+1}{\sigma} \quad for & S < 0 \\ 0 & S = 0 \end{cases} \tag{5}$$

The null hypothesis is rejected at a significance level α if $|Z_S| > Z_{crit}$, where Z_{crit} is the value of the standard normal distribution with an exceedance probability of α/2. In the analysis, the statistically significant trends are evaluated generally at the 10% significance level (α = 0.1, two-tailed test).

In the SR test, the null hypothesis (H_0) is that all the data X_i in the time series are independent and identically distributed, while the alternative hypothesis (H_i) is that X_i increases or decreases with i, that is trends exists [46]. The SR test statistic D is given by:

$$D = 1 - \frac{6\sum_{i=1}^{n}(R_i - i)^2}{n(n^2-1)} \tag{6}$$

$$Z_{SR} = D\sqrt{\frac{n-2}{1-D^2}} \tag{7}$$

where, R_i is the rank of i-th observation X_i in the time series and n is the length of the time series. A positive value of Z_{SR} indicates an upward trends; while a negative Z_{SR} indicates a downward trends in the time series. When $Z_{SR} > t_{(n-2,1-\alpha/2)}$, the null hypothesis is rejected indicating significant trends in the time series. Here, $t_{(n-2,1-\alpha/2)}$ is the critical value of t distribution.

III. Study Area and Data

This paper uses rainfall data from Tasmania. Tasmania is an island located in the south of mainland Australia. Rainfall in Tasmania is governed by the combination of prevailing westerly winds and locations of mountains. The west coast in Tasmania is found to be the wettest, with a total annual rainfall exceeding 3000 mm; the midlands being the driest with less than 600 mm annual rainfall; and the mountainous areas of the north-east has a moderate mean annual rainfall of about 1000 mm.

A total of 41 pluviograph stations were selected from Tasmania; however, 23 stations were rejected as they had more than 20% missing values in the annual maximum rainfall series. The selected 18 pluviograph stations are listed in Table I along with record lengths and elevations. The pluviograph data were obtained from the Australian Bureau of Meteorology. The geographical locations of the stations are shown in Fig. 1. The record length of the selected 18 stations ranges from 9 to 94 years (average: 26 years). The elevations of the selected pluviograph stations range from 4 m to 665 m (average: 230 m). Rainfall events for sub-hourly durations (6, 12, 18, and 30 minutes), sub-daily durations (60 minutes, 2, 3, 6, and 12 hours) and daily durations (24, 48, and 72 hours) were extracted from the selected pluviograph stations.

TABLE I
SELECTED PLUVIOGRAPH STATIONS, RECORD LENGTHS AND ELEVATIONS

Station ID	Data Period	Data Length (years)	Latitude (Degree)	Longitude (Degree)	Elevation (m)
91049	1931-1963	33	-41.5000	147.2000	24.4
91104	1939-2005	67	-41.5397	147.2033	166.0
91186	1977-2008	32	-41.2039	146.265	127.0
91219	1988-2010	23	-41.1708	147.4883	197.5
91237	1981-2010	30	-41.4194	147.1222	5.0
91290	1997-2009	13	-41.6308	146.7000	487.0
92079	1958-1975	18	-42.2133	147.7831	468.5
92042	1958-1983	26	-41.5333	147.8667	427.0
92099	1998-2010	13	-42.7153	147.7525	318.0
93053	1997-2010	14	-42.0250	147.4953	186.0
94008	1961-2005	45	-42.8339	147.5033	4.0
94029	1912-2005	94	-42.8897	147.3278	50.5
94145	1997-2009	13	-42.8831	147.3022	231.6
94163	1999-2010	12	-43.0156	147.3275	36.0
94204	1998-2006	9	-42.6525	147.3578	335.0
95048	1997-2008	12	-42.4842	146.7106	90.0
97006	1997-2010	14	-41.9933	145.5725	665.0
97053	1997-2009	13	-42.7681	146.0461	322.0

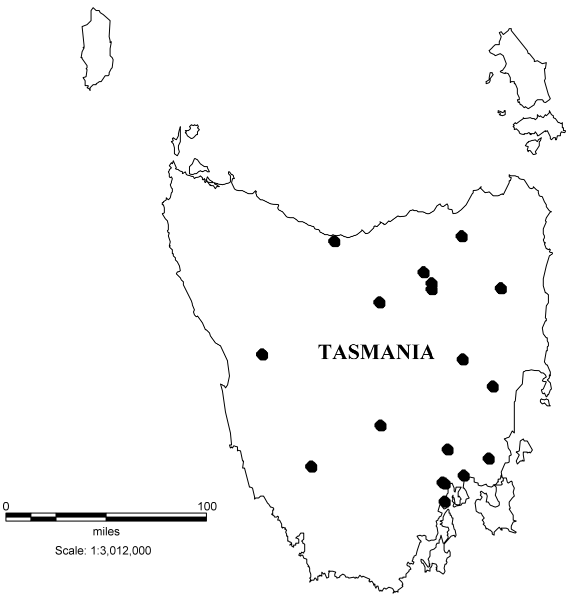


Fig. 1 Locations of the selected 18 pluviograph stations in Tasmania

IV. RESULTS

The percentages of stations with statistically significant upward or downward trends (at 10% level of significance) are shown in Figs. 2 (a) and (b) for the MK and SR tests, respectively. These figures reveal that most of the stations exhibit upward trends for sub-hourly durations (6, 12, 18 and 30 minutes) compared to downward trends. Downward trends are more evident for the sub-daily durations (60 minutes, 3, and 12 hours). Interestingly, 6 hours duration shows more upward trends than downward trends. Almost no trends exist for daily durations (24 and 72 hours). The results from SR and MK tests are found to be very similar in some of the durations (e.g. 6 minutes and 6 hours) showing more positive trends and (12, 18 and 60 minutes, and 3 hours) showing more negative trends in Fig. 3.

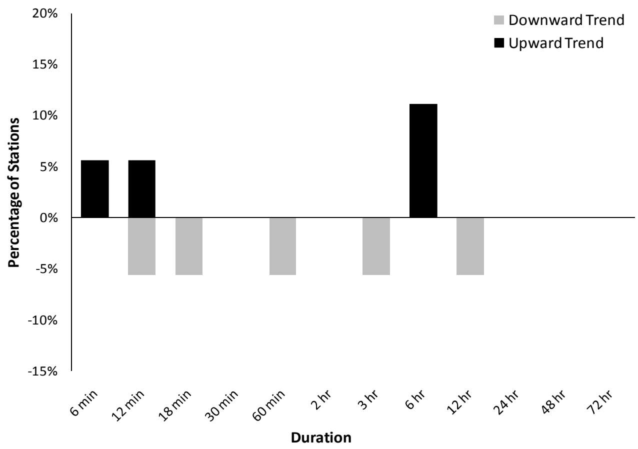


Fig. 2 (a) Percentage of stations with upward and downward trends (at 10% level) for MK test

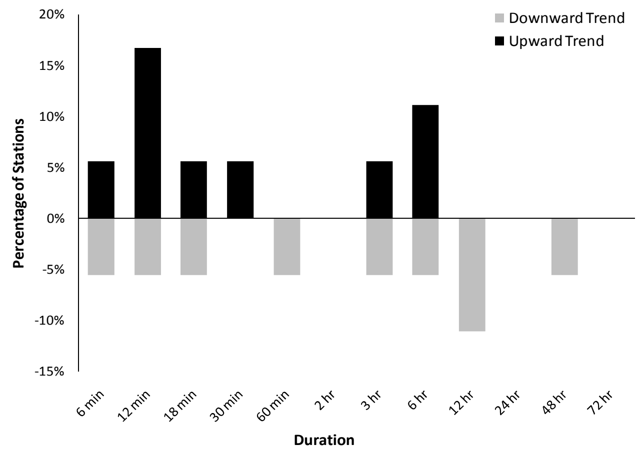


Fig. 2 (b) Percentage of stations with upward and downward trends (at 10% level) for SR test

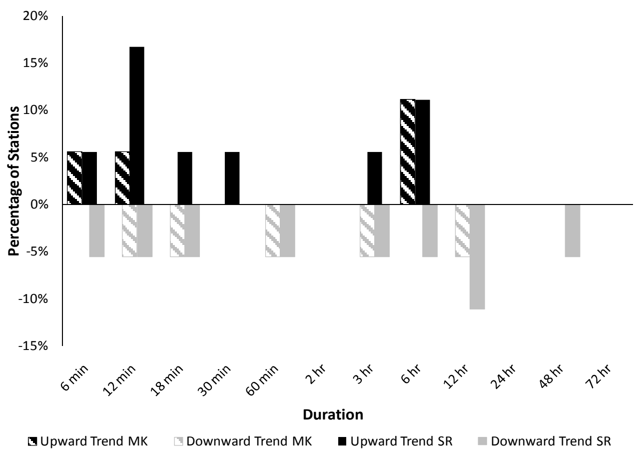
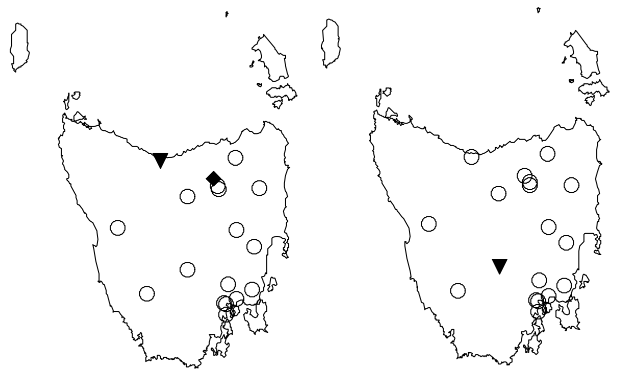


Fig. 3 Comparison of trends test results by SR and MK tests (10% level of significance)

For 5% level of significance, the percentage of stations showing positive trends varies from 0% to 5.6% for both the tests. Similar range can be seen for negative trends in SR test whereas in MK test the negative trends are absent. In SR test most of the stations indicate positive trends for sub-hourly durations i.e., (6, 12, and 18 minutes), negative trends can be seen for longer duration i.e. 12 hours. In the MK test, positive trends can be seen for the 12 minutes duration and rest of the durations has no significant trends as shown in Table II.

In the case of 1% level of significance, no significant trends was observed for both the tests which is not surprising as 1% test is the stringiest among the three levels of significance adopted in this study.

Fig. 4 shows the spatial distributions of the pluviograph stations for 12 min and 12 hour durations for the MK test. The hollow black circles represent no trends, diamond represents upward trends and triangle represents downward trends respectively. Figs. 4 (a) and (b) show upward and downward trends for shorter duration whereas only negative trends for the longer duration.



(a) (b)

Fig. 4 Spatial distribution of stations showing upward (represented by diamond), downward (triangle) and no trends (circle) (at the 10% level of significance) for 12 min (a) and 12 hours (b) durations using MK test

TABLE II
PERCENTAGE OF STATIONS SHOWING UPWARD AND (DOWNWARD) TREND AT 5% SIGNIFICANCE LEVEL

Duration	SR test	MK test
6 min	5.6(0)	0(0)
12 min	5.6(5.6)	5.6(0)
18 min	5.6(5.6)	0(0)
30 min	0(0)	0(0)
60 min	0(5.6)	0(0)
2 hr	0(0)	0(0)
3 hr	0(0)	0(0)
6 hr	0(0)	0(0)
12 hr	0(5.6)	0(0)
24 hr	0(0)	0(0)
48 hr	0(0)	0(0)
72 hr	0(0)	0(0)

V. CONCLUSIONS

This paper examined trends of extreme rainfall events for Tasmania. For this purpose, data from 18 pluviograph stations were used. Two nonparametric trends tests (Mann-Kendall and Spearman's Rho) were applied at 10%, 5% and 1% significance levels. Sub-hourly (6, 12, 18, and 30 minutes) annual maximum rainfall events have been found to experience statistically significant upward trends at 10% level of significance. However, sub-daily durations (1 hour, 3 and 12 hours) exhibit decreasing trends and no trends exists for longer duration rainfall events (24 and 72 hours). Some of the durations (e.g. 6 minutes and 6 hours) show similar results (with upward trends) by both the tests. For 12, 18, 60 minutes and 3 hours durations both the tests show similar downward trends. This finding has important implication for Tasmania in the design of urban infrastructure where shorter duration rainfall events are more relevant for smaller urban catchments such as parking lots, roof catchments and smaller sub-divisions.

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