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Original Article

Long-term Changes in Precipitation Characteristics at Sturt Meadows, Western Australia

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Long-term changes in the precipitation data at Sturt Meadows were analyzed by the Mann-Kendall statistics and the Lepage test. Yearly and spring precipitation increased significantly from 1910 to 2008, and the significance levels were $p < 0.10$ and 0.01, respectively. The data of daily precipitation were classified into two groups (class 1-4 and 5) separated by the distribution of the data, and class 1-4 precipitation increased significantly. There were 4 significant-climatic jumps (1925-27, 1963, 1979-1982 and 1993) by results of the Lepage test. The averages of yearly precipitation during whole years and the latest period are 215.0 and 280.9 mm/year, respectively. The averages of monthly precipitation in February, October and November during the latest period (1993-2008) is higher than those in the previous periods. That in February during the latest period was especially heavy, when the mean precipitation in February was six times higher than that in the previous period. This change was attributed to the increase in the frequency of storm events in February during the latest period. Monthly precipitation exceeding 100 mm/month in February was recorded three times (1995, 2001 and 2006), and this occurred only 2 times in previous periods (1925 and 1975).

Key Words: Western Australia, Sturt Meadows, arid land, precipitation, long-term changes

1. Introduction

Rainfall is the single most limiting-climatic factor affecting afforestation in dry areas[1]. Managers of afforestation projects in arid lands are required to have a thorough understanding of the precipitation patterns, trends and magnitudes within their sites.

Afforestation experiments in the arid lands of Western Australia for the sequestration of Atmospheric carbon dioxide have progressed since 1998[2]. Most of the afforestation sites are designed to catch water from precipitation and surface run-off for planted trees.

Periodic fluctuation of yearly precipitation was determined with yearly precipitation data at Sturt Meadows[3]. However, long-term changes in precipitation at Sturt Meadows have not been analyzed. While the contribution of net primary production in humid regions is controlled by various factors (average temperature, change of climate, nutrient concentrations and any other factors) than

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yearly precipitation, the net primary production rate by plants in dry regions increase linearly relative to yearly precipitation[4]. If managers of dry land afforestation projects understand that there is an increasing trend of yearly precipitation, they will be able to predict an increase in the growth rate of trees.

Managers should be able to understand whether or not present years are pluvial years. In general, pluvial or non-pluvial years last for several or dozens years, and those years are separated by climatic jumps[5].

Karl et al. (1995)[6] classified daily precipitation into five levels of intensity and analyzed long-term trends. While light-rain water tends to evaporate before seeping into the ground, heavy-rain water tends to penetrate into the soil. Therefore, managers of afforestation projects in arid lands are better able to understand trends of heavy rain in their respective sites.

The purpose of this study is to analyze the long-term changes of precipitation at Sturt Meadows.

2. Materials and Methods

2.1 Study Site and Data Analysis

The study site is Sturt Meadows, Western Australia (28°40'S, 128°58'E; **Fig. 1**). The precipitation data have been recorded by settlers since 1899, and the record is maintained by the Bureau of Meteorology (BOM) of Australia. In this study, contiguous data from December 1909 to November 2008 are used for the analysis of long-term changes in the precipitation characteristics. The data from December 1909 to May 2006 were received from the Bureau of Meteorology. The data after May 2006 were obtained from present settlers at Sturt Meadows.

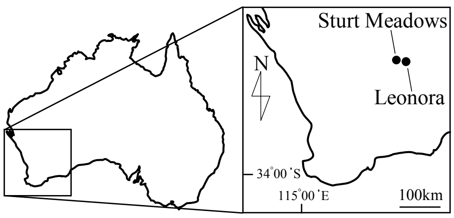

Fig. 1 Location of Sturt Meadows and Leonora

The data are recorded as daily precipitation [mm/day], and the minimum unit of the data is 0.2 mm/day. To determine seasonal precipitation, climate data at Lenora (28°52'S, 121°19'E; **Fig. 1**), the site of the nearest BOM weather station to Sturt Meadows, were applied. **Fig. 2** shows the mean minimum and maximum temperature at Leonora measured by BOM. By the distribution of the average temperature, a year is defined from 1st December of the prior year to 30th November of the year in this study, and the seasons are as follows; summer: December of the prior year to February; autumn: March to May; winter: June to August; spring: September to November. We defined each season according to following assumption: each season is 3 months; the thermal characteristics of each season require that the summer temperature be the hottest of the year; for autumn, that the peak temperature decrease; for winter, that the temperature be the lowest; and for spring, that the temperature increase. The analysis of the climate data using the start time of the coverage period from December of the prior year has been used in other scientific studies (Takeshima et al. 2005[7]).

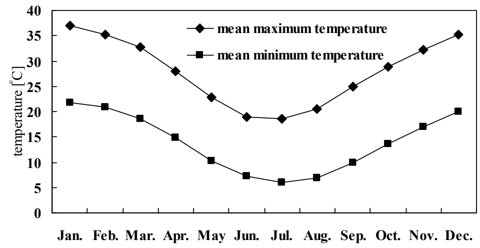

Fig. 2 Mean maximum and minimum temperature at Leonora observed by BOM

2.2 The Mann-Kendall Rank Statistics Test

To estimate the long-term trend of yearly and monthly precipitation, the Mann-Kendall rank statistics test was used[8]. The test is a non-parametric method of analysis and is regarded as more robust than linear least square fitting[9][10]. The significance levels of this test are adopted to be 0.10, 0.05 and 0.01 according to an analysis of long-term precipitation data using the same method[7].

2.3 The Lepage Test

To detect any climatic jumps in yearly precipitation, the Lepage test was employed[5]. This method is used as a non-parametric test to investigate significant differences in a given year between precipitation data during the previous *n* years and those after *n* years, even if the distributions of the parent populations are unknown. The Lepage statistic is a sum of the squares of the standardized Wilcoxon's and Ansari-Bradley statistics. The Lepage test has an optimal sample size for detecting step-like changes for any series[10], and an applicable period depends on the predominant and low-frequency variability[9]. Currle and Vines (1996)[11] and Yasuda *et al.* (2001)[3] showed a cycle of approximately 11 years was detected by analyzing of precipitation data of Australia and Sturt Meadows, respectively. Therefore, the *n* value in the Lepage test is used for 11 years in this study. The significance levels of this test are 10, 5 and 1 % according to the CSIRO Atmospheric Research Technical Paper in which the results of a Lepage test were applied to precipitation data of Australia[12].

2.4 Long-Term Changes of Intensity of Daily Precipitation

To observe a long-term changes of intensity of daily rainfall during the objective period, the data of daily precipitation were sorted in ascending order and divided into 5 categories (- <20th, 20 - <40th, 40 - <60th, 60 – <80th and 80 – 100th percentile), and they were summed as the yearly precipitation of each class[6]. However, it was not necessary to make a distinction in class 1-4 because many values of daily precipitation are the same around the borders of those classes. Therefore, the precipitation data were separated into 2 groups (class 1-4 and 5) for the analysis in this study.

3. Results

3.1 Long-Term Trend of Precipitation

The yearly precipitation at Sturt Meadows is shown in **Fig. 3**. Yearly precipitation ranged from 52.6 and 563.4 mm/year, and the average and median are 215.0 and 192.4 mm/year, respectively. Variability was estimated to be 0.515, and that value was much higher than those in Japan (0.05-0.10)[13].

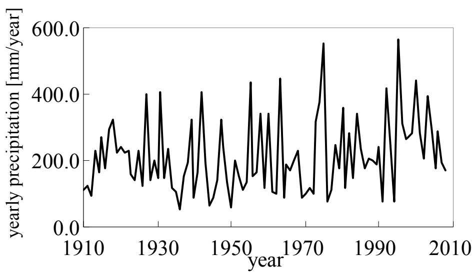

Fig. 3 Time series of yearly precipitation at Sturt Meadows

The time series of seasonal precipitation are shown in **Fig. 4**. Seasonal precipitation ranged from 0.0 to 470.2 mm, and the average and median were 53.0 and 41.0 mm, respectively. The average precipitation for each season is following: summer: 67.0 mm; autumn: 69.9 mm; winter: 50.3 mm; spring: 25.3 mm. The average precipitation value in spring was lower than that in the other season, however, it is of the same order as that in the other seasons. Gentilli (1981)[14] describes the internal region belt from west to south-east Australia, including Sturt Meadows, as the "median annual rainfall" in a distribution map of precipitation. The average precipitation for each season calculated in this study is roughly in accordance with that reported by Gentilli (1981)[14]. The average variability for each season is 0.69-1.06, and that of summer is higher than that of winter.

Results of the application of the Mann-Kendall rank statistics test to yearly and seasonal precipitation are shown in **Table 1**. Three significance levels are detected in yearly, seasonal and spring precipitation, and the p values to those in this test are <0.10, <0.05 and <0.01, respectively. The significance results of a decreasing trend have never been detected in those data.

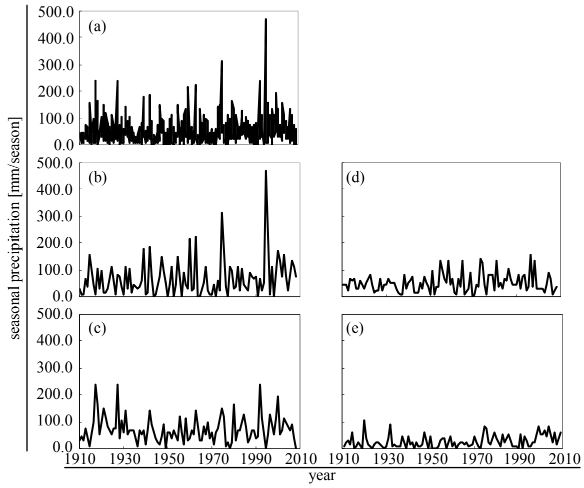

Fig. 4 Time series of seasonal precipitation at Sturt Meadows. (a) whole seasons, (b) summer, (c) autumn, (d) winter, (e) spring.

3.2 Climatic Jumps

Results of the application of the Lepage test to yearly precipitation at Sturt Meadows are shown in **Fig. 5**. Significant-climatic jumps are detected in 1925-1927, 1963, 1979-1982 and 1993. The p values in 1925, 1927 and 1979-1982 in the Lepage test are <0.05, and the others are <0.10. The longest period separated by climatic jumps is 35 years from 1928 to 1962. After 1963, those periods separated by climatic jumps tended to be shorter (1964-1978: 15 years, 1983-1992: 10 years).

Table 1 Results of application of the Mann-Kendall rank statistics test to yearly and seasonal precipitation

	τ value	significance level
yearly precipitation	0.128	$p < 0.10$
seasonal precipitation	0.068	$p < 0.05$
Summer precipitation	0.104	$p > 0.10$
Autumn precipitation	-0.016	$p > 0.10$
Winter precipitation	0.054	$p > 0.10$
Spring precipitation	0.209	$p < 0.01$

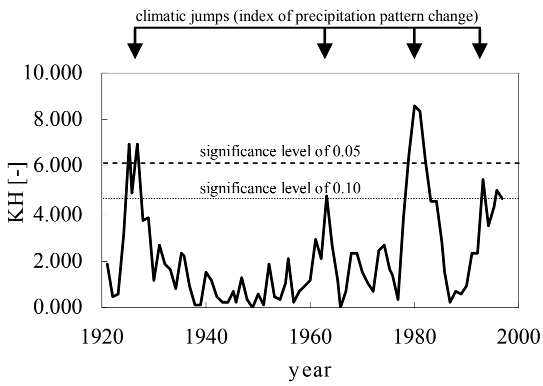

Fig. 5 Result of application of The Lepage test to yearly precipitation at Sturt Meadows

3.3 Long-Term Changes of Intensity of Daily Precipitation

The time series of yearly precipitation classified into class 1-4 and 5 are shown in **Fig. 6**. The threshold value is 11.2 mm/day, and the daily precipitation of class 1-4 and 5 are <11.2 mm/day and ≥11.2 mm/day, respectively. The yearly precipitations defined as class 1-4 and 5 ranged from 21.8 to 173.3 and from 0 to 440.2 mm/year, respectively. The average and median of class 1-4 yearly precipitation are 86.3 and 82.8 mm/year, respectively. Those of class 5 are 129.6 and 111.3 mm/year, respectively. In 1936, yearly precipitation classified as class 5 was 0.0 mm/year, and yearly precipitation was 52.6 mm/year. This value of yearly precipitation is the minimum recorded at Sturt Meadows. Results of the application of the Mann-Kendall rank statistics test to the yearly precipitation of class 1-4 and 5 are shown in **Table 2**. The result indicates that there is significance in the yearly precipitation of class 1-4 and the p value is <0.05. The result of class 5 indicates an increasing trend because the value is positive, however, the value does not reach the significance level.

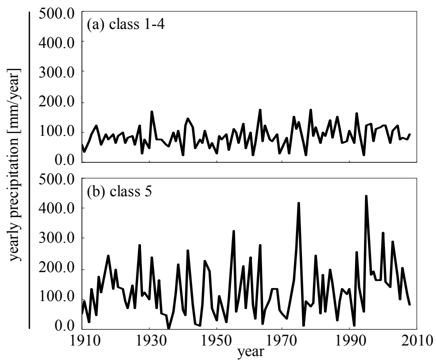

Fig. 6 Time series of yearly precipitation classified as class 1-4 and 5 at Sturt Meadows

Table 2 Results of the application of the Mann-Kendall rank statistics to yearly precipitation classified as class 1-4 and 5

	τ value	significance level
class 1-4	0.147	$p < 0.05$
class 5	0.106	$p > 0.10$

4. Discussion

The average values of yearly precipitation for each period separated by the results of the Lepage test (**Fig. 5**) are shown in **Fig. 7**. The average in 1910-2008 of yearly precipitation is 215.0 mm/year, and the mean precipitation during the latest period (1994-2008) is 280.9 mm/year. The average of yearly precipitation during the latest period is the most pluvial. The mean monthly precipitation for each period separated by the results of the Lepage test is shown in **Fig. 8**. The average-monthly precipitation in October and November during the latest period is about two or three times higher than that in the previous period. The mean value of February precipitation (63.1 mm) is about six times higher than that in the previous period (10.9 mm). The heavy rain event during February may increase after 1994. After 1994, data of monthly precipitation over 100 mm/month in February were recorded 3 times in 1995, 2001 and 2006, however only two occurrences (1925, 1975) were recorded before 1994. These results show that heavy rain sometimes contributed greatly to the monthly precipitation, while precipitation in class 5 did not significantly increase.

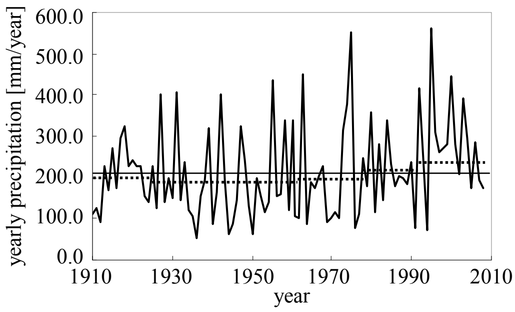

Fig. 7 Average of yearly precipitation for each period separated by the results of the Lepage test. The solid line indicates the average value from 1910 to 2008. The dotted lines show the averages for each periods

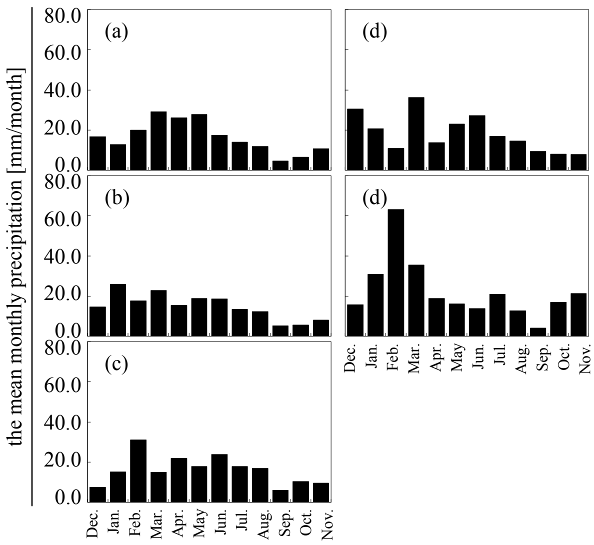

Fig. 8 Mean monthly precipitation for each period separated by the Lepage test. (a) 1910-1025, (b) 1928-1962, (c) 1964-1978, (d) 1993-2008.

Conclusion

In this study, we determined the long-term trend of precipitation by analysis of precipitation data over 99 years at Sturt Meadows. Yearly precipitation increased significantly, and the latest period (1994-2008) separated by climatic jumps was the most pluvial. Data of daily precipitation at Sturt Meadows is classified as class 1-4 and 5. There was a significant increase in class 1-4 precipitation. In the present period (after 1994), monthly precipitation data over 100 mm/month in February were recorded 3 times, while this occurred only twice before 1994. These results show that precipitation conditions are improving for afforestation trees, and heavy-rain water contributes significantly more to the water supply than light-rain water for afforestation.

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