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Climate Variable Trends in South Australia

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Abstract

It is general knowledge that rainfall and temperature are experiencing changes over time in South Australia. What is less well known is exactly by how much, whether there are regions where it is rising and others where it is falling. Understanding the climate variable trends are necessary and important for the further investigation, specifically finding what the influencing factors are. This project explores the historical trends of rainfall and mean maximum and minimum temperature for the two major regions, Eyre Peninsula and Monarto Plateau, in South Australia since 1960 until now. Most places on Eyre Peninsula show an decreasing trend, in contrast, the rainfall in the places close to the Monarto Plateau with substantial plantings increases significantly over years. Temperature does not behave the same in different selected towns on Eyre Peninsula, however, almost all places at Monarto have a significantly increasing temperature. In addition, for those locations with significant changes in either rainfall or temperature, the amount of increase or decrease after certain years is estimated for understanding how much the impact of changes might have over time.

1 Introduction

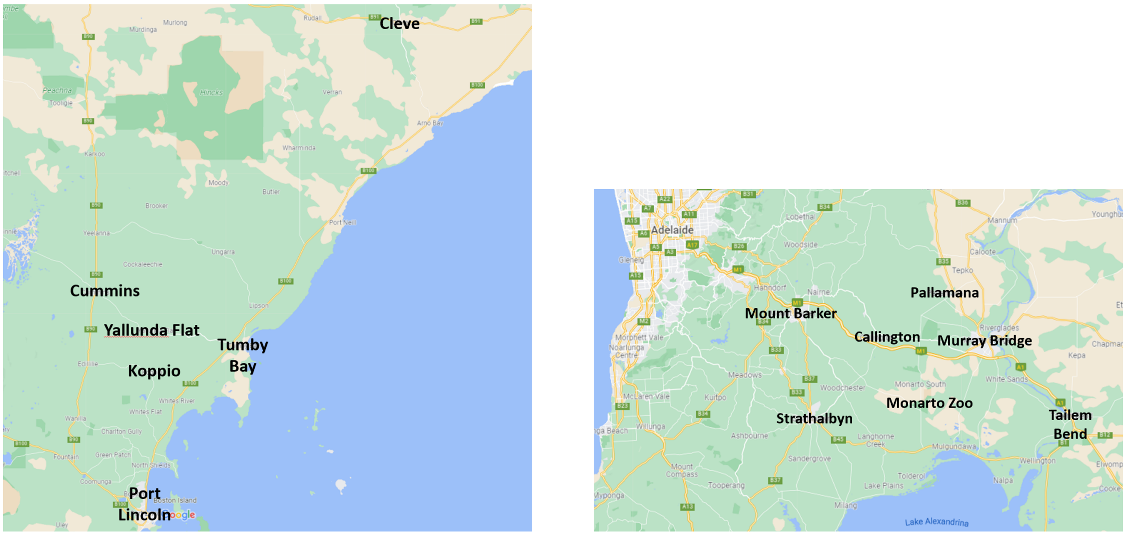
Rainfall and temperature are the two main climate variables, and their changes are closely related to our daily life. Excess rainfall can cause flooding and that will damage property and crops. In the other extreme cases, a deficiency of rainfall can result in drought and crop failure. Rainfall also plays a important role in the regional water management policies [3]. Temperature can guide the life cycle of various organisms and maintain ocean levels. A change of a couple of degrees may throw an entire ecosystem into chaos. That is why it is necessary to explore whether the climate variables (that is, rainfall and temperature) change over time by a significant amount. In addition, understanding the climate trends is the foundation of the further investigation on potential influencing factors.

In this project, we focus on the changes of climate variables that have happened in two major regions of South Australia, Eyre Peninsula and Monarto Plateau. Figure 1 presents the target towns used for trend analysis. There are two main reasons why these towns are chosen for investigation. Firstly, these towns have stations for collecting rainfall and/or temperature data regularly. Secondly, it is inspired by John Boland's paper in which he stated the changes of annual rainfall happened in these two areas [2]. We aim to extend his work and explore how the rainfall and temperature change over years.

In Eyre Peninsula, we selected Cleve, Cummins, Yallunda Flat, Koppio, Tumby Bay, and Port Lincoln. In Monarto Plateau, we selected Monarto Zoo, Callington and Murray Bridge, which are closest to the Monarto Plateau. Also, we included other four towns further away from the plateau. They are Mount Barker, Strathalbyn, Pallamana, and Tailem Bend.

1.1 Statement of authorship

I wish to acknowledge John for his supervision in this project and AMSI for funding this project.



(a) Selected towns in Eyre Peninsula

(b) Selected towns in Monarto Plateau

Figure 1: Map of selected towns for investigation of climate variable trends.

John formulated the project idea, selected proper locations for exploring and suggested the appropriate analysis methods in this project. The programming was written by Shurui, analysis and interpretation of results was performed by Shurui with guidance and supervision given by John.

2 Method

2.1 Data preparation

In this project, all data are downloaded from the Bureau of Meteorology (BOM). Climate variables used for analysis involved rainfall and mean minimum and maximum temperatures measured by month. The annual value of rainfall is the sum of monthly rainfalls. The annual mean minimum and maximum temperatures are the average of the monthly mean minimum and maximum temperatures.

The dates starting to record the climate variables are different. Therefore, the scale of time is different by locations. The first year of records is not the same and differs by locations. Some towns started recording data in 1800s, however, others may start later. In the project, we decided to use the data since 1960 only. One of the reasons is that it is generally thought that climate change effects started to become apparent from then. The other reason is the records in 1800s are too long ago from now. The data might not be reliable since the equipment for measurements were possibly not of the highest standard.

The starting year, ending years and the number of available years used for rainfall and temperature analysis in selected locations are shown in Table 1 and 2. Although we set the same time interval for all datasets, not all data are consistent and available from 1960 and 2021. Given that some stations were built or enabled to measure climate variables after 1960, so their initial years of available data are later than 1960. Similarly, some stations may stop collecting data at an early date, for example the temperature data in Tailem Bend. In addition, some datasets contain missing years. As such, Koppio missed data of 5 whole years (see Table 1).

Region	Location	Initial year	End year	Years
Eyre Peninsila	Cleve	1960	2021	62
	Cummins	1960	2021	62
	Yallunda Flat	1960	2021	62
	Tumby Bay	1960	2021	62
	Koppio	1960	2021	57
	Port Lincoln	2004	2021	18
Monarto Plateau	Monarto Zoo	1998	2020	23
	Callington	1960	2021	62
	Murray Bridge	1960	2021	62
	Mount Barker	1960	2021	62
	Pallamana	2007	2021	15
	Strathalbyn	1960	2021	62
	Tailem Bend	1960	2021	62

Table 1: Data for rainfall trend analysis.

Region	Location	Initial year	End year	Years
Eyre Peninsila	Cleve	1960	2021	61
	Cummins	2008	2021	14
	Port Lincoln	1996	2021	26
Monarto Plateau	Murray Bridge	1967	2021	55
	Mount Barker	1960	2021	61
	Strathalbyn	1960	2001	42
	Tailem Bend	1960	1975	15

Table 2: Data for mean maximum and minimum temperature trend analysis.

2.2 Infilling missing data

The data of climate variables for analysis are incomplete in some target locations. In other words, they missed the whole years or months in certain years. The annual total rainfall and mean temperature are the sum or average of the values collected in each month from January to December. If there are no values for the entire year, then we ignore this year. However, if there are missing values in specific months, we deal with missing data based on these two situations:

- if there are null values in the first year (ie, first row) of available data, then remove the whole row,

- if months missed in the years are not at the beginning, then fill them based on the available value collected on the closest first or second location.

If the closest place is also missing data for that month, then the second closest location is chosen. If unfortunately the data of the same month and year is not found in these two places either, the year will be excluded from analysis.

The built-in search function of BOM website returns a list of towns according to the distance from them to the target location. They are displayed in order of the increasing distance. If the location contains the data on the same month and year as the missing data, we select the month without null value as X_m in the following equation.

$$Y_m = a \times X_m + b$$

$$\text{where,} \quad X_m \text{ is the value of closest location}$$

$$\text{where,} \quad Y_m \text{ is the value of target location}$$

Here, the Y_m is the collected data of the target location in the same month and year as X_m. The slope, a and intercept, b are estimated using linear regression. If the p value of the linear model is less than 0.05 (that is, statistically significant), we will use the model to predict the rainfall or temperature that occurred on the same month and year in the target location.

2.3 Data smoothing

After the missing data is infilled, we look into the need to smooth the data. Since the data of rainfall and temperatures are highly fluctuating, it is necessary to remove the noise and simplify the changes in order to predict the trend clearly. In this project, both rainfall and temperature data are smoothed by the following equation.

$$Y_t = \alpha \times X_t + (1 - \alpha) \times Y_{t-1}$$

$$\text{where,} \quad 0 < \alpha < 1$$

$$\text{where,} \quad X_t \text{ is the value of present year}$$

$$\text{where,} \quad Y_t \text{ is the smoothed data}$$

The α is the smoothing ratio, and which determines how much of the variation is removed. In this project, the value of alpha is determined at 0.2. If the variation of smoothed data is too small or too large, the smoothing ratio will be adjusted.

The initial value (that is X_0) is determined based on the significance of the trend. If there appears to be a significant increasing or decreasing trend, then the value of X_0 is the value of the first year. However, there does not appear to be significant change over time - as determined by eye - the mean of all available data since the initial year will be used as the initial value (X_0) to reduce the effect on the results of regression modelling by a data point of high influence. If the climate variable value at the starting year is extreme high or low, the smoothed values of the following years calculated based on this initial value will be larger or smaller. That may affect the statistical significance and the coefficients of the regression line.

2.4 Trend analysis

The smoothed data are used in the trend analysis for finding how the rainfall and mean maximum and minimum temperatures change over years in the time slot from 1960 until now.

In this project, we are interested in finding whether the climate variables increase or decrease after years. The linear regression (LR) test was recommended in trend analysis and used to identify whether there is a significant relationship between time and rainfall in Rezaul et al's work [3]. Moreover, in the data sets examined, there was not any significant evidence that the trend is curvilinear. So, we decided to use the linear regression model and that is computationally built using the R language.

3 Results and analysis

3.1 Rainfall trends on Eyre Peninsula

Table 3 demonstrates the linear models of rainfall trend and their p values in all selected locations on Eyre Peninsula. Figure 2 summarises and visualises the changes of rainfall that have happened in each town on a map.

Location	P value	Slope	Intercept
Cummins	0.00007	-0.6295	430.1256
Tumby Bay	0.00038	-0.5832	336.6081
Cleve	0.0479	-0.3718	418.8358
Koppio	0.0622	-0.4744	524.2083
Yallunda Flat	0.0719	-0.3382	527.0557
Port Lincoln	0.2223	-1.455	501.958

Table 3: Linear models of rainfall for locations on Eyre Peninsula.

Both Cummins and Tumby Bay display a significant decreasing trend of rainfall in the past 62 years (1960-2021) with p value very much less than 0.05 (see Table 3). As shown in Figures 3 and 4, there is a clear decreasing line fitting in the smoothing data. The p value of the linear model of rainfall in Cleve is 0.0479. Although it is not much smaller than 0.05, the slightly decreasing trend in the Figure 5 is still statistically significant. As Table 1 tells, the number of available data collected in Cleve and used for analysis is only 18. Collecting more data in Cleve will be useful to make a confident conclusion.

Figure 2: Changes of rainfall (blue) at Cummins, Tumby Bay, Cleve, Koppio, Yallunda Flat and Port Lincoln.

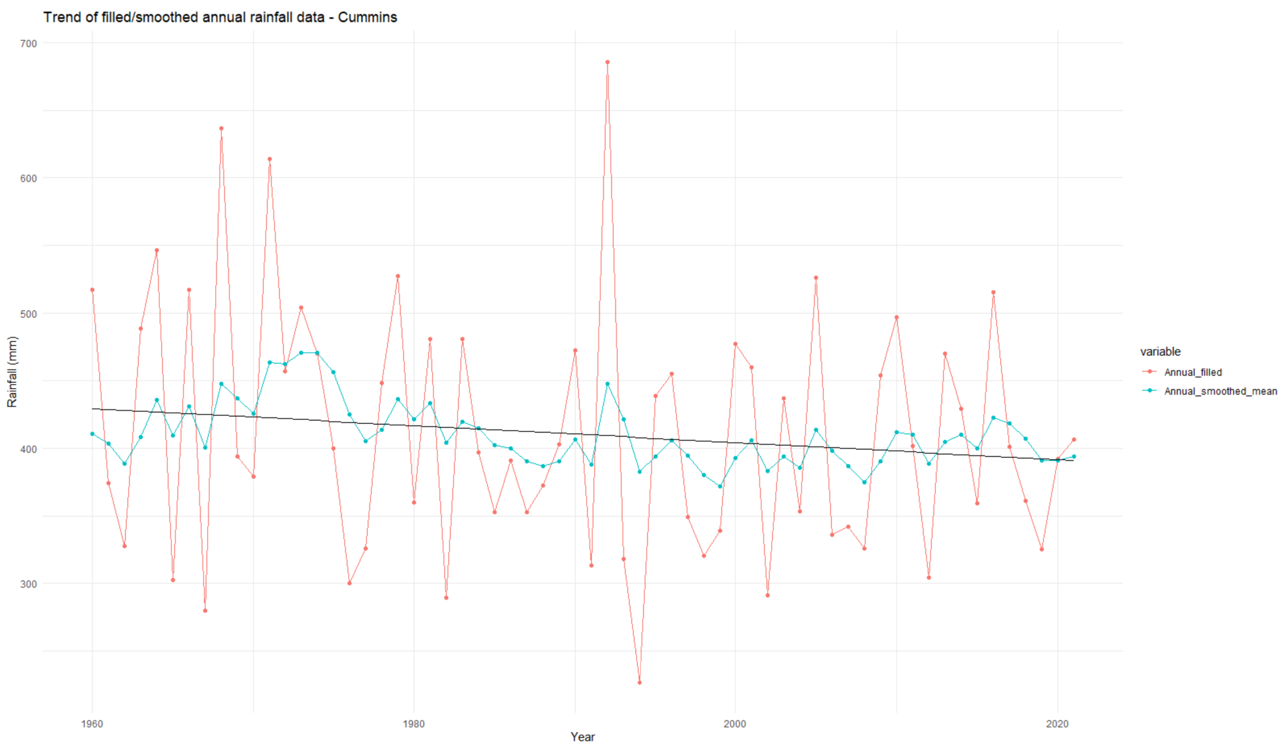


Figure 3: Rainfall trend at Cummins.

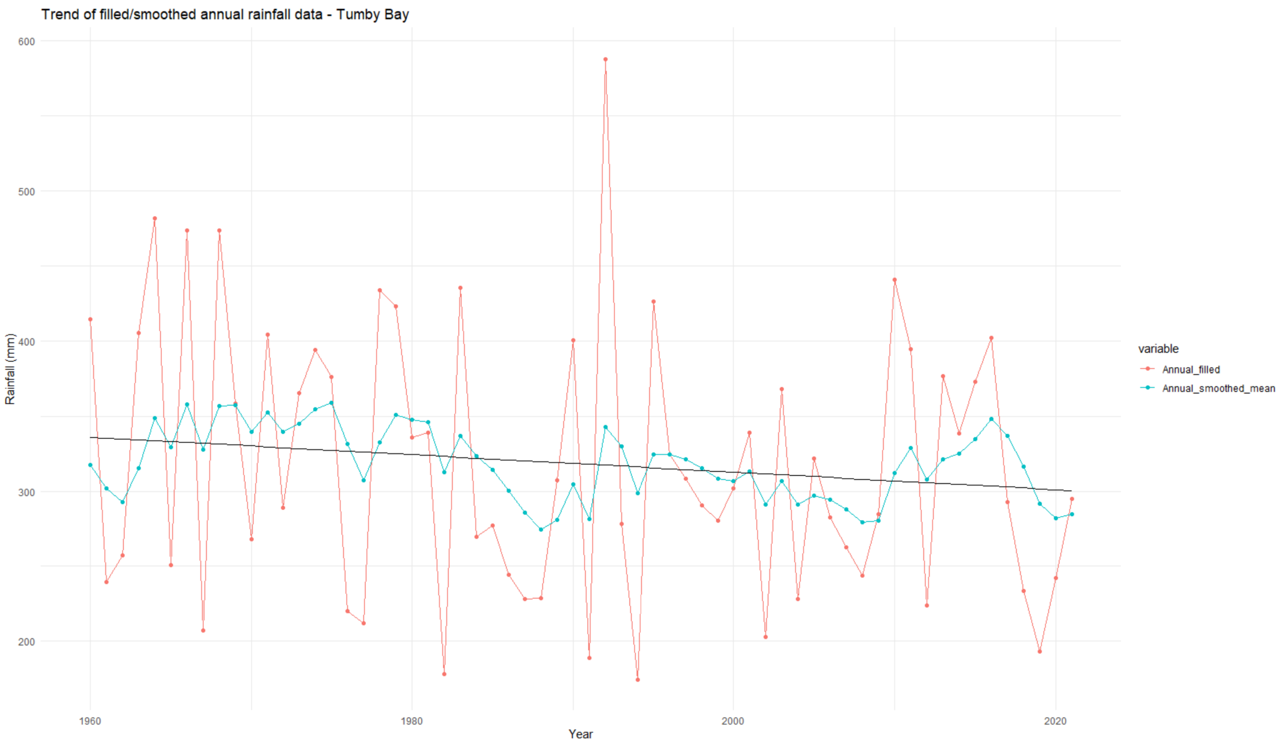


Figure 4: Rainfall trend at Tumby Bay.

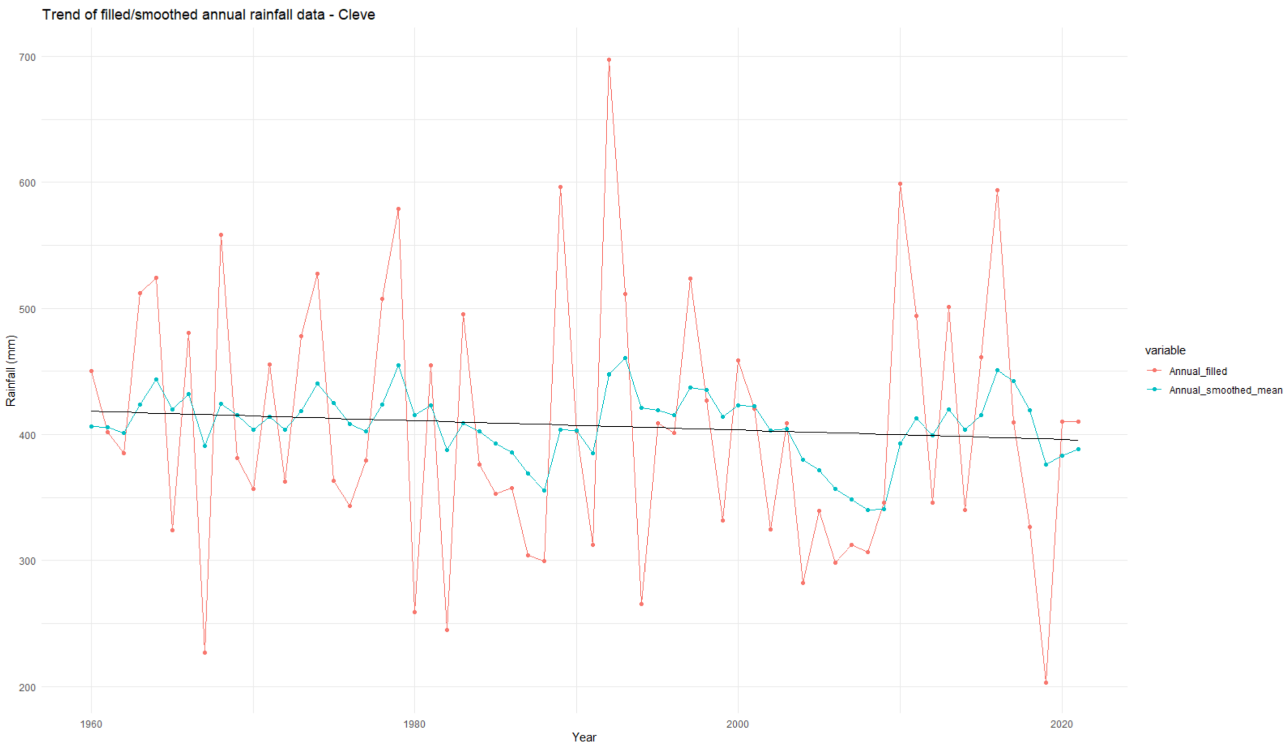


Figure 5: Rainfall trend at Cleve.

For Koppio, Yallunda Flat, and Port Lincoln, according to their p values of linear models are more than 0.05 in Table 3, there are no significant changes found over years at a significance level of 0.05.

3.2 Rainfall trends at Monarto and surrounding areas

Table 4 and Figure 6 summarise and visualise the changes of rainfall happened at Monarto and surrounding areas. The rainfall in Monarto Zoo and Callington increases significantly over time with p-value less than

Location	P value	Slope	Intercept
Callington	0.0003	0.7306	366.5200
Monarto Zoo	0.0155	1.6611	367.2486
Tailem Bend	0.0325	-0.2952	369.7280
Murray Bridge	0.0790	0.2756	350.0357
Strathalbyn	0.3336	-0.1782	487.1653
Mount Barker	0.8187	0.0505	727.33101
Pallamana	0.8332	-0.2662	318.5579

Table 4: Linear models of rainfall for locations at Monarto and surrounding areas.

Figure 6: Changes of rainfall (blue) at Callington, Monarto Zoo, Tailem Bend, Murray Bridge, Strathalbyn, Mount Barker and Pallamana.

0.05, as the Figures 7 and 8 show below. Since the station in Monarto Zoo was built and used to collect data since 1998, so there are only 23 available records. For another location on the plateau, Murray Bridge, the p value of the linear model of rainfall is 0.079. Although it has an increasing trend and was not considered as a significant change at the significance level of 0.05, the p value is just over 0.05, so when more data is available it might become clearer as to what is happening.

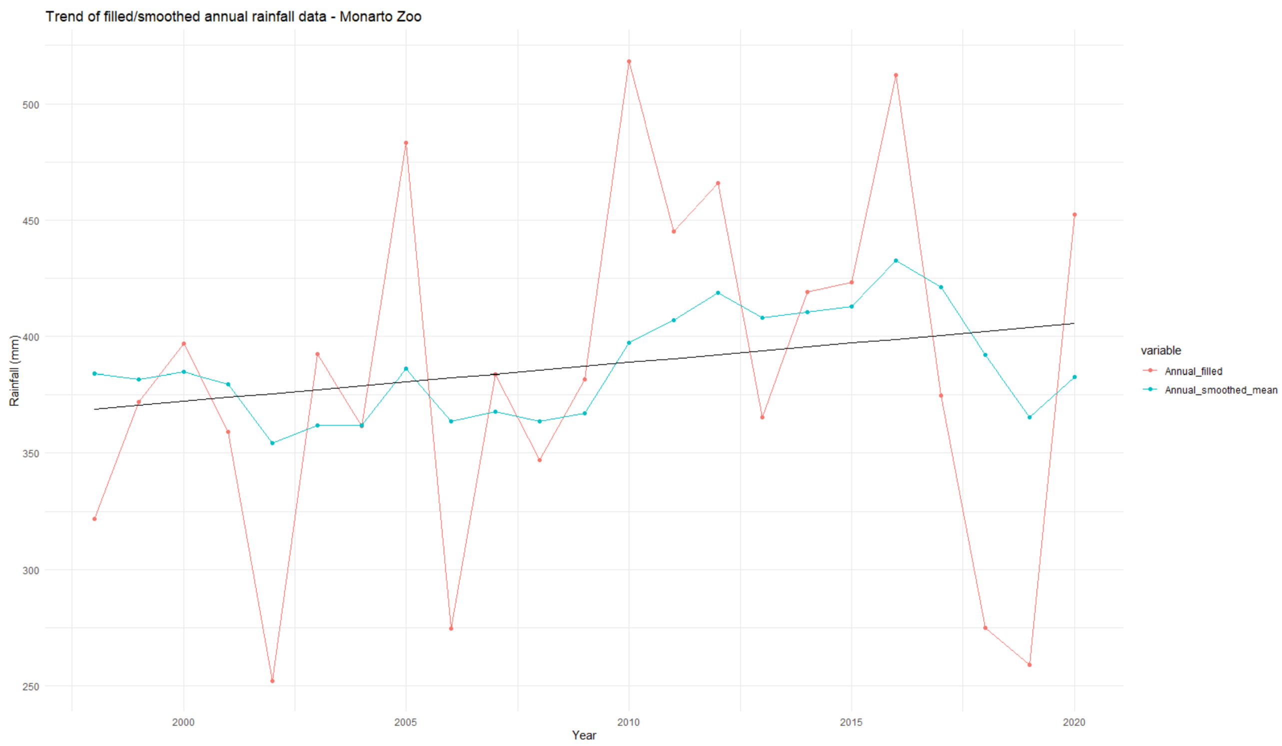


Figure 7: Rainfall trend at Monarto Zoo.

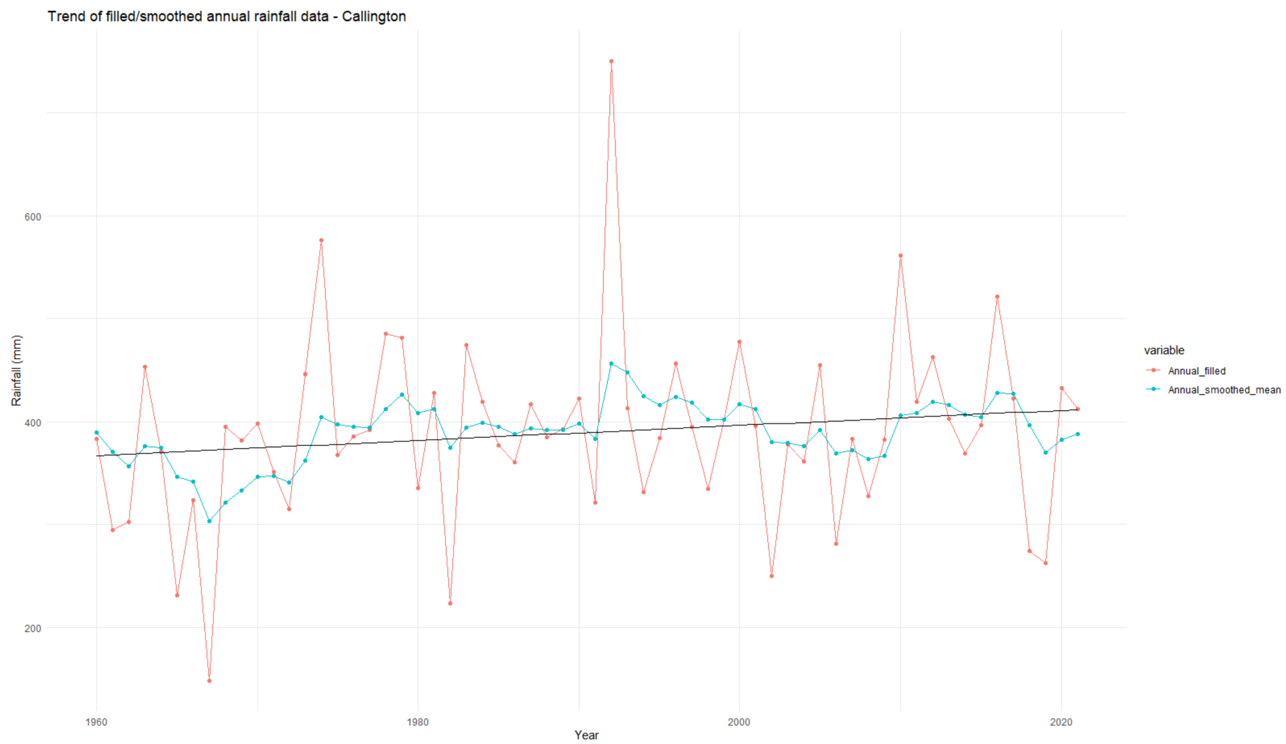


Figure 8: Rainfall trend at Callington.

In the remaining four areas removed from the plateau and selected for analysis, only the rainfall in Tailem Bend declines significantly over the last 62 years with p value of 0.0325 (see Figure 9). No significant changes

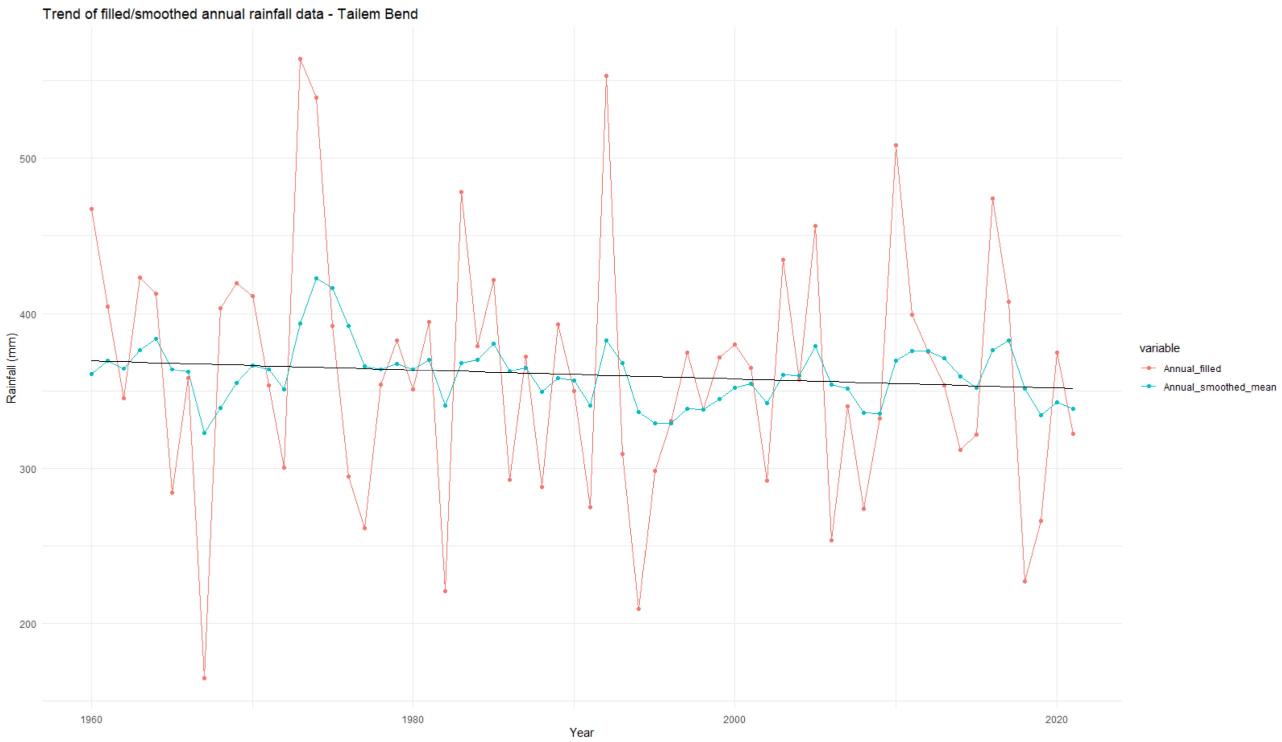


Figure 9: Rainfall trend at Tailem Bend.

of rainfall were found in Mount Barker, Strathalbyn and Pallamana based on the p values of their linear models in Table 4. However, it is worth noting that Pallamana only has 15 available records of rainfall (see Table 1), which is not sufficient to tell what changes happened.

3.3 Rainfall change estimates

For those places showing significant changes over years, the amount of increased or decreased rainfall after the number of years which is the same as the time used in building prediction models is estimated based on the linear models. That means we predicted the amount of changed rainfall after 62 years in Cummins, Tumby Bay, Cleve, Callington and Tailem Bend, and after 23 years in Monarto Zoo. As the Figure 10 shows, after 62 years both Cummins and Tumby Bay will reduce over 30 mm in rainfall. However, Monarto Zoo and Callington will increase the similar amount of rainfall after 62 years or even in shorter time.

3.4 Temperature trends on Eyre Peninsula

Table 5 indicates the linear models of mean maximum and minimum temperature for those places on Eyre Peninsula and collected temperature data. The Figure 11 summarises and presents the changes of temperature in a map.

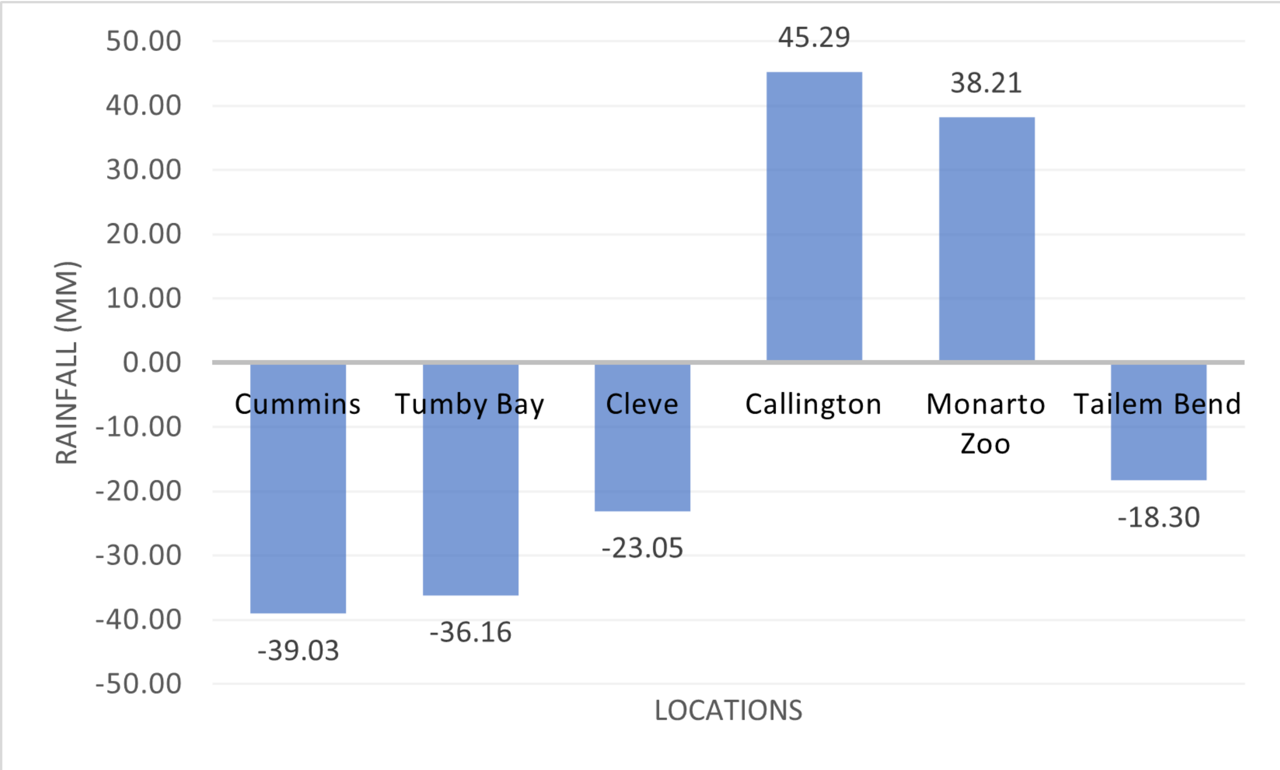


Figure 10: Estimates of increased/decreased rainfall after certain years for locations on Eyre Peninsula and Monarto Plateau.

**Notes: 23 years in Monarto Zoo or 62 years in other locations.*

Location	Temperature	P value	Slope	Intercept
Cummins	max	0.305	0.0068	23.0010
	min	0.028	-0.0215	10.0188
Port Lincoln	max	7.106e-15	0.0586	20.3597
	min	0.030	-0.0044	11.4723
Cleve	max	3.634e-09	0.0099	22.0154
	min	5.812e-12	0.0137	11.1667

Table 5: Linear models of mean maximum and minimum temperature for locations on Eyre Peninsula.

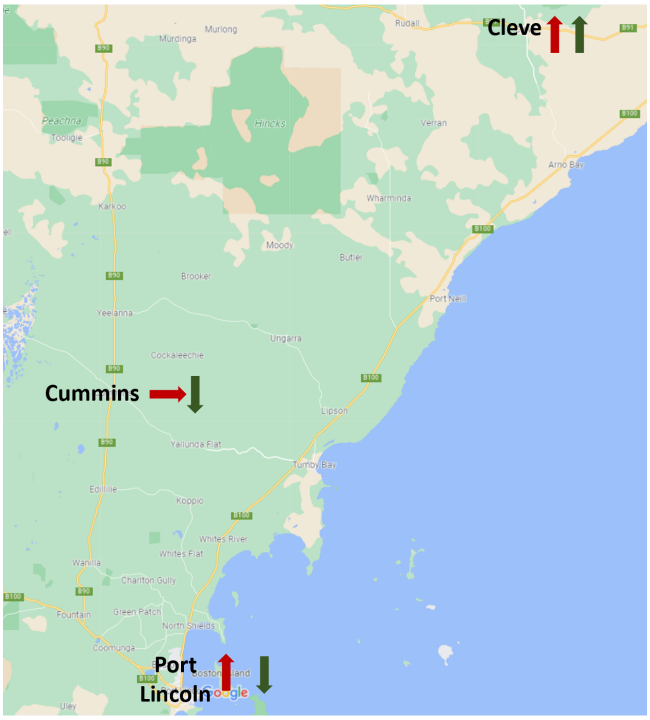


Figure 11: Changes of mean maximum (red) and minimum temperatures (green) at Cleve, Cummins and Port Lincoln.

For the mean maximum temperature, both Cleve and Port Lincoln show an increase over time with p value far smaller than 0.05 (see Table 5). However, the mean minimum temperature changes are opposed in Cleve and Port Lincoln. Cleve has a significant increasing minimum temperature same as its maximum temperature. In contact, for both Cummins and Port lincoln, the minimum temperatures decreases over time. Limited available temperature data size of Cummins may have an impact on the confidence of the conclusion.

3.5 Temperature trends at Monarto and surrounding areas

Table 6 and Figure 12 demonstrate the mean minimum and maximum temperature changes of locations having available temperature data in the region of Monarto Plateau. Different with results of Eyre Peninsula, all temperatures increase significantly over years except for the maximum temperature on Tailem Bend. All of their p values are much smaller than 0.05 (see Table 6). The temperature dataset of Tailem Bend contains only 15 records from 1960 and 1975 (see Table 2), so it is hard to conclude the trends persist until now. More data in this area is needed to confirm how the temperature changed in a longer time range.

3.6 Temperature change estimates

If temperature changes follow the same trend as what happened in the location in the same time period, the increased or decreased degrees of the mean maximum and minimum temperature in the places showed significant changes over time are estimated by using the corresponding linear models in Table 5 and Table 6. The results

Location	Temperature	P value	Slope	Intercept
Mount Barker	max	<2.2e-16	0.0357	19.1068
	min	<2.2e-16	0.0218	7.7047
Murray Bridge	max	<2.2e-16	0.0283	22.2181
	min	0.0008	0.0045	9.7973
Strathalbyn	max	0.0021	0.0093	21.1675
	min	<2.2e-16	0.0407	8.7331
Tailem Bend	max	0.5536	-0.0077	22.5957
	min	0.0554	0.0073	9.7813

Table 6: Linear models of mean maximum and minimum temperature for locations on Monarto Plateau.

Figure 12: Change of mean maximum (red) and minimum temperatures (green) at Mount Barker, Murray Bridge, Strathalbyn and Tailem Bend.

are shown in Figure 13, which highlights that after about half century temperature in Mount Barker, Murray Bridge, and Strathalbyn will increase more than 1 degree.

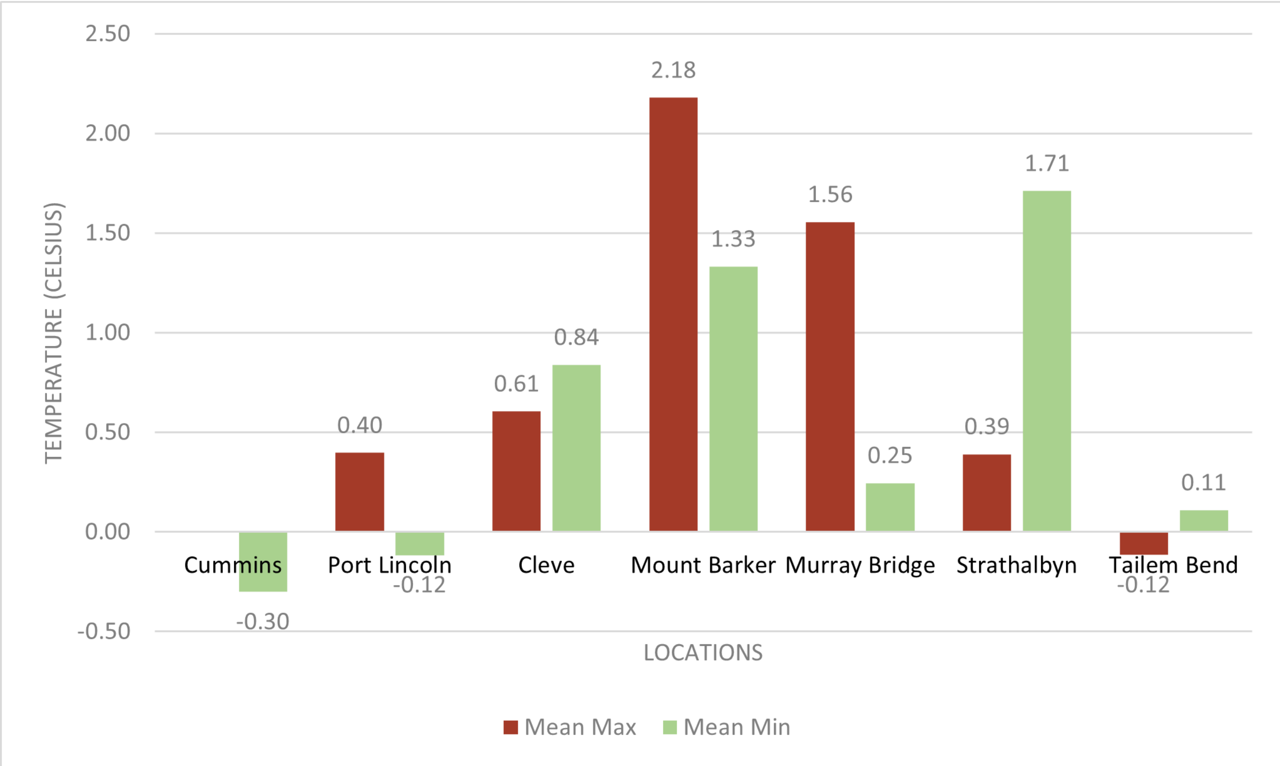


Figure 13: Estimates of increased/decreased maximum and minimum temperature after certain years for locations on Eyre Peninsula and Monarto Plateau.

**Notes: 14 years in Cummins, 26 years in Port Lincoln, 55 years in Murray Bridge, 42 years in Strathalbyn, 15 years in Tailem Bend and 61 years in Cleve and Mount Barker.*

4 Conclusions and future work

It is known that the land clearance occurred from the 1950s around Cummins [1]. As Figure 3 indicates, rainfall of Cummins starts decreasing from 1960, just after the period of clearance. In contrast, there were extensive plantings on the Monarto plateau in 1970s [2]. The two places on the plateau, Monarto Zoo and Callington, show increasing rainfall since then. We could suggest that the land use change may be another factor having potential influence in the rainfall changes. But there are still more work needing to be done to confirm the relationship between land use and rainfall.

After exploring the temperature trend, we find that annual mean minimum and maximum temperature changes are not consistent in the places on Eyre Peninsula. The mean maximum temperature increases in both Cleve and Port Lincoln. However, the increasing minimum temperature occurred only in Cleve. Both Cummins and Port Lincoln shows a decline. Different with what happened on Eyre Peninsula, almost all of the temperature at Monarto and its surrounding places increase significantly.

In the next step, researchers can deeply investigate of why the significant changes of rainfall and temperature happening in these selected places, and what things or combinations are the influencing factors, like climate and land-use change.

References

[1] J. Boland, "Perceptions of landscape and the interplay between rainfall and vegetation," *AlterNative: An International Journal of Indigenous Peoples*, vol. 10, no. 5, pp. 462–477, 2014.

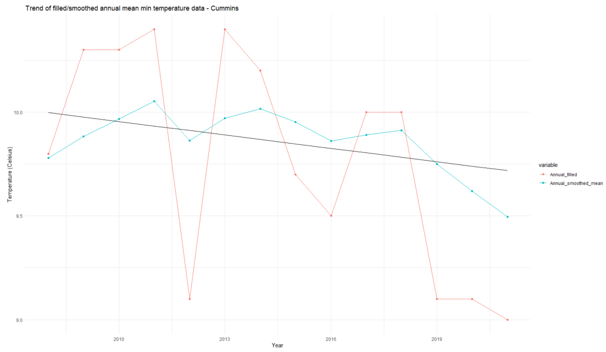
[2] J. Boland, "Rainfall Enhances Vegetation Growth but Does the Reverse Hold?" *Water*, no. 6, pp. 2127–2143, 2014.

[3] R. K. Chowdhury, S. Beecham, J. Boland, and J. Piantadosi, "Understanding South Australian rainfall trends and step changes," *International Journal of Climatology*, vol. 35, no. 3, pp. 348–360, 2014.

Appendices

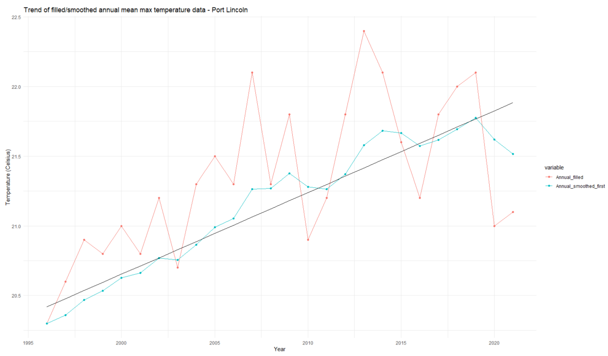
Appendix A Temperature trends on Eyre Peninsula

The significant temperature trends happened at Cummins, Port Lincoln and Cleve are as follow.

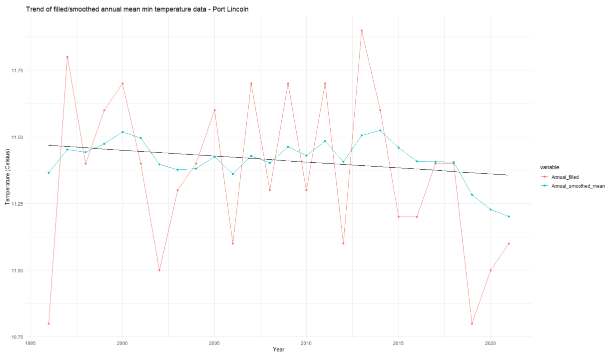


(a) Mean minimum temperature

Figure 14: Mean minimum temperature trend at Cummins.



(a) Mean maximum temperature



(b) Mean minimum temperature

Figure 15: Mean maximum and minimum temperature trend at Port Lincoln.

(a) Mean maximum temperature (b) Mean minimum temperature

Figure 16: Mean maximum and minimum temperature trend at Cleve.

Appendix B Temperature trends at Monarto and surrounding areas

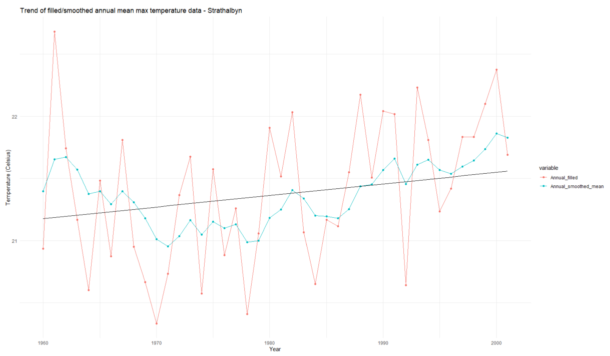
The significant temperature trends happened at Mount Barker, Murray Bridge, Strathalbyn and Tailem Bend are as follow.

(a) Mean maximum temperature (b) Mean minimum temperature

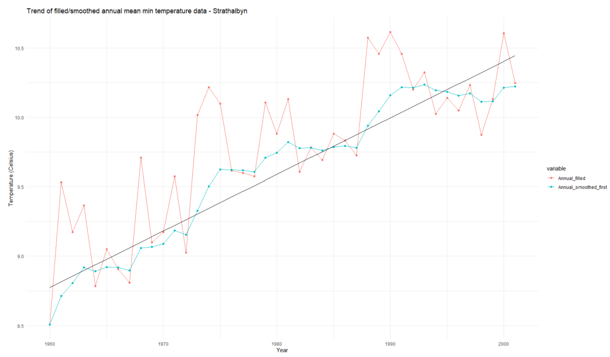
Figure 17: Mean maximum and minimum temperature trend at Mount Barker.

(a) Mean maximum temperature (b) Mean minimum temperature

Figure 18: Mean maximum and minimum temperature trend at Murray Bridge.

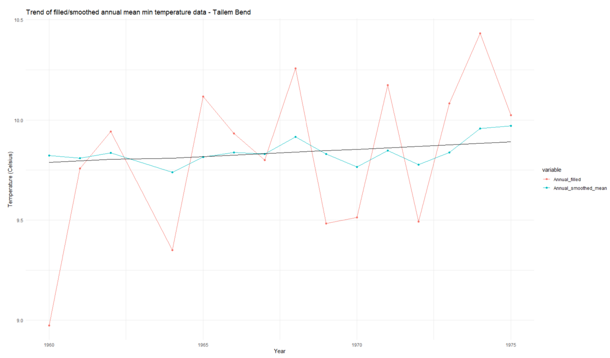


(a) Mean maximum temperature



(b) Mean minimum temperature

Figure 19: Mean maximum and minimum temperature trend at Strathalbyn.



(a) Mean minimum temperature

Figure 20: Mean minimum temperature trend at Tailem Bend.