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A Study on River Water Temperature in Victoria

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Abstract

Research has shown that freshwater ecosystem occupies only 2.3% of the Earth's surface, yet they are home of at least 9.5% of the animal species. A river is a crucial ecosystem that serves as an essential source for human food and industrial use. According to recent studies, the riverine ecosystems are being negatively impacted by the 1.1℃ rise in global surface temperature during the year 2011 to 2020 compared to the pre-industrial era in the year 1850-1900. These impacts are evidenced by the exaggerated growth of harmful algal blooms and massive fish kills. River water temperature is a key indicator in assessing the quality of aquatic ecosystem, making it imperative to monitor and understand its trend. This study examines the trend in the annual maximum and minimum river water temperature for the selected river stations across Victoria, Australia, with a focus on correlating these patterns with the land temperature, dissolved oxygen, pH level, water level and discharge. To achieve this, the Man-Kendall test, a widely used non-parametric statistical method used in trend analysis, is employed, while Sen's slope is used to quantify the direction and magnitude of the trend. Results show that generally, RWT and LT show a relatively increasing trend across all the selected stations. However, the expected inverse relationship between DO and RWT is not consistently observed. Varied trend patterns were also noted for pH, WL and discharge across all the stations. This study highlights a complex interplay between RWT and various environmental parameters, likely influenced by climatic changes and localized environmental factors. Further investigations are essential to understand the underlying causes of these trends and their impacts on river ecosystem.

Keywords: River water temperature, dissolved oxygen level, climate change, trend analysis, Man-Kendall test, Sen's slope

1. INTRODUCTION

Climate change, predominantly caused by anthropogenic activities, has become a central topic to various discipline worldwide due to the damaging effects being experienced globally. Recent data shows that there has been an increase of 1.1℃ in global surface temperature in the year 2011-2020 compared to 1850-1900 (Lee et al., 2023). The increase in temperature has significantly impacted the riverine environment. As of 2023, it has been recorded that 3,086 out of the 14,898 assessed freshwater species are threatened by extinction because of climate change, with these species sustaining food for 200 million people and livelihoods for 60 million (Simaika, 2024). It is further projected that 9% of the species may encounter threats to over half of their current range under 2°C warming, decreasing to 4%

with a 1.52°C limit (Barbarossa et al., 2021). This is evidenced by the recent massive fish kill found in Darling River primarily caused by low dissolved oxgen (DO) level as reported in The Strait Times (2023). This follows the massive fish kills in 2018 to 2019 where millions of fish died in the same area. Extreme hot weather, significant algal blooms and low oxygen level are the primary cause of this devastating event (Vertessy et al., 2019).

This type of fish killing phenomenon is happening worldwide affecting the river water quality globally. As such, there has been an increasing interest among researchers to study the trend in river water temperature (RWT) and its impacts. However, research on river water temperature (RWT) in Australia, particularly in Victoria, remains limited. To address this knowledge gap, this study examines RWT in Victoria to aid in developing sustainable river management strategies.

2. MATERIALS AND METHODS

2.1. Study Area and Methods

Five river monitoring stations were selected to study the RWT in Victoria, Australia. Location of these stations are illustrated in Figure 1. The selected stations are located in eastern part of Victoria. Details of the selected monitoring stations are outlined in Table 1. All the stations are situated in a Public Conservation and Resource Zone (VicPlan 2024) which means that these stations are located in a protected area where natural resources are preserved. Rivers within these zones are typically free from significant pollution and are managed to prevent human activities that can degrade water quality and disrupt the natural habitat. These zones are generally covered with riparian vegetation that helps in maintaining cooler water temperature.

Farm zones, located approximately 2 to 2.5 km from stations 221212 and 226226, may have implications for water temperature in these areas. Agricultural activities, such as irrigation or runoff from fertilizers, can influence water quality and temperature dynamics in nearby waterways. Additionally, station 221208 is the nearest station to the shore of Tasman Sea, which may experience distinct temperature patterns influenced by coastal factors. Furthermore, farm zone with an area of approximately 9.4 km^2 is located 16 km from station 221208 with its runoff entering into the Wingan River.

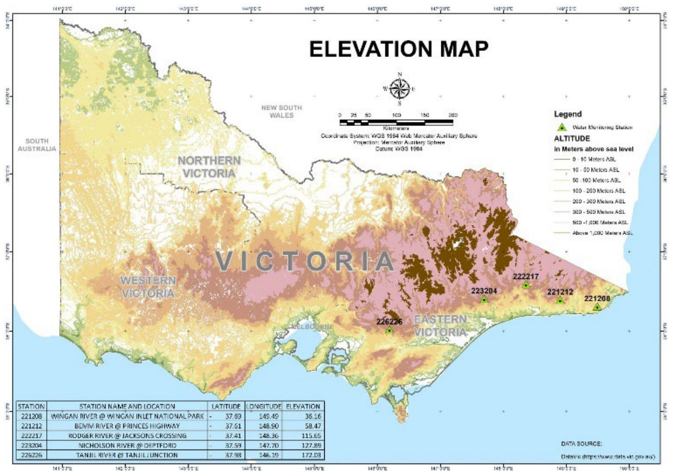


Figure 1: Location of selected five monitoring stations in Victoria

Table 1. Characteristics of the selected stations

River Stations						Nearest BOM site recording Land Temperature with available data from 1991 to 2023					
Station Number	Site Name	Catch-ment Area (km^2)	Lat.	Long.	Elev.	Station Number	Site Name	Lat.	Long.	Elev.	Approximate Distance From River Station (kms)
221208	Wingan River @ Wingan Inlet National Park	420	-37.7	149.5	36.2	84084	Mallacoota	-37.6	149.7	22	24.58
221212	Bemm River @ Princes Highway	725	-37.6	148.9	58.5	84143	Combienbar AWS	-37.3	149	640	33.58
222217	Rodger River @ Jacksons Crossing	447	-37.4	148.4	116	84142	Gelantipy	-37.2	148.3	755	24.57
223204	Nicholson River @ Deptford	287	-37.6	147.7	128	85279	Bairnsdale Airport	-37.9	147.6	49	30.78
226226	Tanjil River @ Tanjil Junction	289	-38	146.2	172	85280	Morwell (Latrobe Valley Airport)	-38.2	146.5	56	23.56

2.2. Methodology

The study focuses on RWT data spanning from 1991 to 2023. RWT, dissolved oxygen (DO), pH level, water level (WL) and river discharge (Q) data were used in this study, which were sourced from the Victorian Department of Environment, Land, Water, and Planning's website (VWMIS 2023). Land temperature (LT) data were taken from the Bureau of Meteorology (BOM) website (Climate Data Online 2024). The raw data from these sources were processed to extract the annual maximum (Amax) and annual minimum (Amin) values of a variable. Land temperature data were taken from the nearest BOM station.

2.2.1. Man-Kendall Test Sen's Slope

This research used statistical techniques to determine the trend in the RWT along with other parameters such as LT, DO, pH level, WL and Q, specifically the Mann-Kendall Test (MK Test). The MK Test is the most commonly used non-parametric test that detects monotonic trends in time series data without assuming a specific distribution. Complementing the MK test, the Sen's Slope estimator is used to determine the magnitude and direction of the trend (Rahman & Dawood, 2016; Umar et al. 2018) The MK test is given by Equation 1.

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

where X represents a univariate time-series, i and j denotes the time indices, n is the number of data points and sign is determined by Equation 2.

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

When $n \geq 8$, the null hypothesis H_0 using the MK test for statistic S can be described by a normal distribution. The mean is given by Equation 3.

$$E(S) = 0 \quad (3)$$

The variance is shown in Equation 4.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{L} t_1(l)(l-1)(2i+5)}{18} = \sigma^2 \quad (4)$$

Where t_i represents the number of ties of extent i and L is the number of tied groups.

The standard test statistics Z_s that serves as a measure of significance of trend is given by the Equation 5.

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

If |Zs| is greater than Zα/2, where α denotes the chosen significance level, the null hypothesis H_o is rejected, indicating that the trend is significant.

The Sen's slope is a non-parametric method used to determine the slope of the trend in a tine series (Sen, 1968). The slope is calculated using Equation (6) where D is the slope and x_i and x_j are data points at times t_i and t_j.

$$D = \frac{x_j - x_i}{t_j - t_i} \tag{6}$$

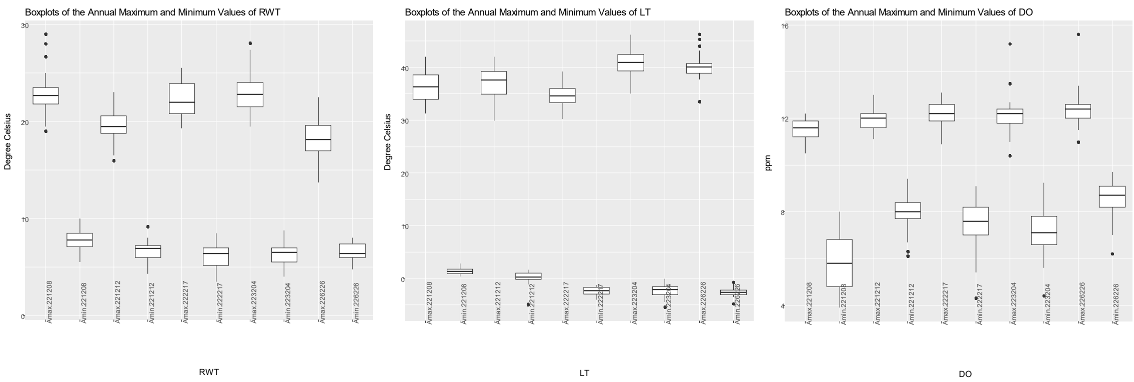
2.2.2. Software and Data Analysis Tool

The R Studio was used in the statistical analysis and data visualization. The package "trend" facilitated the MK test to identify the trends in the annual maximum and minimum values of the selected variables, and Sen's slope to estimate the magnitude of the trend. In addition to R studio, Microsoft Excel was utilized.

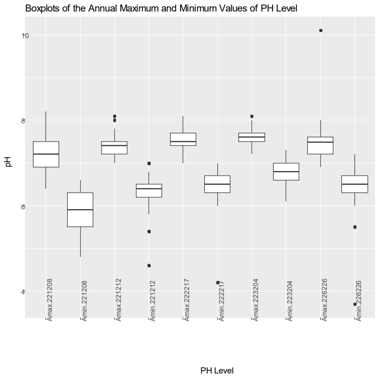
3. RESULTS AND DISCUSSION

This subsection presents the analysis of the Amax and Amin values of the RWT, LT, DO, pH level, water level, and Q across the five selected river stations from 1991 to 2023. Annual mamumum and minimum values were then extracted from the monthly data for further analysis.

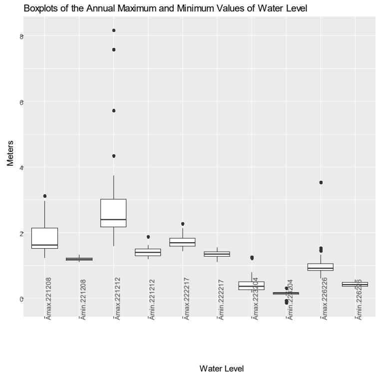
3.1 Characterizing data variability



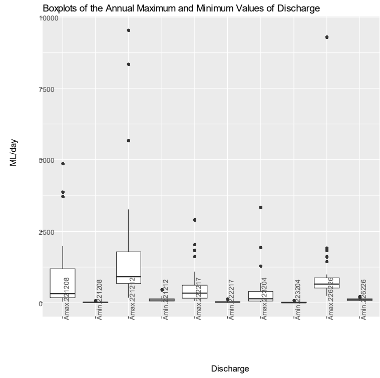
(a) (b) (c)



(d)



(e)



(f)

Figure 2: Boxplots of the Annual Maximum and Minimum Values: (a) RWT. (b) LT. (c) DO. (d) PH Level. (e) Water Level. (f) Discharge (Q)

Figure 2 shows the boxplots of the Amax and Amin values of all the river variables across various stations, revealing key patterns and variability.

Figure 2(a) shows the boxplot for RWT. High Amax temperature variability are observed across the different stations ranging from 13.7 to 29°C. Stations 222212 and 226226 show significantly lower medians, likely due to proximity to agricultural farms. Moreover, station 226226 is located at the highest elevation among all the selected stations. These factors may potentially contribute to the lower reading observed at these station. Stations 223204 and 221208 have the highest median value followed by stations 222217, 221212 and 226226 in descending order. Station 222217 marks the widest interquartile range while station 221208 has the narrowest range. Outliers are observed at stations 221208, 221212 and 223204 which indicates extreme temperature events.

Amin RWT ranges from 3.5 to 10°C. Stations 222217 and 226226 have the lowest median value among the stations at around 6.4°C. Station 221208 has the highest Amin RWT values with median at around 7.8°C. The boxplots shows a relatively narrower range compared to the Amax values indicating somewhat consistent and less variable Amin temperatures. Station 221212 exhibits outlier especially in the higher temperature range. Referring to Figure 2(b), LT Amax values ranges from 30 to 46°C. Stations 223204 and 226226 exhibit higher Amax median values as compared to the other stations at 40 to 42°C. These stations are located at the highest elevations compared to the other three. Relatively high temperature variability is observed in stations 221208, 221212 and 223204 while station 226226 has the narrowest IQR, several outliers are observed both in the upper and lower range.

Amin LT shows less variability as evidenced by the narrower IQR compared to the Amax LT. However, outliers are observed at stations 221212, 223204 and 226226 especially in the lower range. Stations 221208 and 221212 have higher median values compared to the other three stations. As shown in Figure 2(c), the median Amax DO levels range from 11.6 to 12.4 ppm, indicating relatively similar oxygen levels across all the stations. The interquartile ranges are relatively narrow at all the stations, which suggests relatively consistent DO levels throughout the years. Notably, station 221208 has the lowest median DO level. Based on Figure 2(a), this station also has the highest Amax temperature values, highlighting an inverse relationship. Outliers are observed at stations 223204 and 226226 both in the upper and lower range of the data, indicating occasional instances of higher DO levels at 15.6ppm above and lower DO levels below 11ppm. The cause for these outliers should be further investigated to have a better understanding on the underlying issue. Station 226226 exhibits the highest median Amax DO level among the five stations, while station 221208 has the lowest. It should be noted that station 226226 exhibits the lowest RWT in the Amax values, further emphasizing the inverse relationship between the temperature and DO.

For the Amin of DO, 226226 has the highest median DO level at around 8.7ppm which indicates a superior water quality in terms of oxygen availability. This station also exhibits relatively low variability, as demonstrated by its narrower interquartile range and shorter whiskers, suggesting more stable and consistent DO levels throughout the years. However, one outlier is noted in the lower range. On the other hand, station 221208 has the lowest median, approximately 5.8ppm, and the highest variability, as indicated by its wide interquartile range and whiskers. This suggests that the DO levels at this station are not only lower on average but also fluctuate more widely. Additionally, outliers are observed at all the stations except for 221208, specifically at the lower range. The presence of greater range of DO level and outliers highlights the inconsistency, which has potential risk for aquatic organism that relies on stable oxygen levels for respiration and metabolic process.

Figure 2(d) presents the boxplots of the Amax pH levels for the five selected monitoring stations, revealing a generally healthy range for the aquatic ecosystem, spanning from 7.2 to 7.6. The highest median pH value is observed at station 223204, approximately 7.6, indicating relatively stable and favorable conditions for aquatic life at this location. Conversely, station 221208 shows the lowest median Amax pH level with the greatest variability among the stations, as evidenced by its wide interquartile range. It is important to note that station 221208 not only exhibits the lowest median pH level but also has the second highest median Amax RWT, the highest median Amin RWT, and the lowest DO levels for both Amax and Amin readings. These factors collectively suggest that station 221208 faces more challenging environmental conditions compared to the other stations. Outliers are observed at the upper range for stations 221212 and 223204; however, these values remain within the healthy pH range. Maintaining this balance is crucial for sustaining the health and diversity of aquatic life, as extreme pH levels can adversely affect biological processes and organism survival.

Station 221208 shows the lowest Amin median pH level around 5.8 with the widest interquartile range and a minimum pH level just below 5.0, indicating more variability and more acidic condition compared to other stations. Other stations' pH reading ranges within the healthy range, however, outliers are observed at the lower range suggesting occasional acidic condition, which poses a dangerous environment to aquatic life. Figure 2(e) shows the boxplots of the Amax WL of the five selected stations. Stations 221208, 221212 and 222217 have higher Amax values compared to stations 223204 and 226226. Station 221212 shows the highest variability in water levels as evidenced by the wider interquartile range and more extreme outliers. Station 223204 has the lowest median water level values. Outliers are observed at all the station suggesting high annual fluctuations in water levels as expected for an unregulated river. For the Amin WL, stations 221208, 221212 and 222217 have significantly higher Amin water levels compared to stations 223204 and 226226, consistent with the Amax values. Station 221212 still has the highest variability indicated by the widest interquartile range among the stations. Station 223204 has the lowest water levels, consistent with the Amax values. Outliers are observed at stations 221212 and 223204. Figure 2(f) shows the boxplots of the Amax discharge of the five selected stations. As observed, the highest median discharge is at station 226226 and station 223204 has the lowest. All stations have several outliers suggesting occasional extreme discharges values. Notably, station 221212 has an extreme outlier approaching 10000 megalitres/day, indicating a major flood event.

3.2 Trend Analysis

This section outlines the MK test and Sen's slope results, obtained using R software. These results are summarized in Table 2 and is illustrated in Figure 3. The chosen level of significance is 5%, corresponding to a critical Z value (Zcr) of ±1.96. According to this threshold:

- If the computed Z statistic (Zs) is greater than +1.96, the trend is deemed significantly increasing.
- If the computed Zs is less than -1.96, the trend is deemed significantly decreasing.
- If the computed Zs falls between -1.96 and +1.96, the trend is not considered significant, thereby supporting the null hypothesis H0 that there is no significant trend.

Table 2. MK Test and Sen's Slope Results

Stations		221208				221212				222217				223204				226226			
Parameters		tau	Z	p-value	Sen's Slope	tau	Z	p-value	Sen's Slope	tau	Z	p-value	Sen's Slope	tau	Z	p-value	Sen's Slope	tau	Z	p-value	Sen's Slope
RWT	Amax	0.26	2.11	*0.03	↑ 0.060	0.02	0.14	0.89	↑ 0.004	0.00	-0.02	0.99	✗ 0.000	0.08	0.64	0.52	↑ 0.025	0.29	2.33	*0.02	↑ 0.084
	Amin	0.07	0.53	0.60	↑ 0.007	0.16	1.28	0.20	↑ 0.023	0.09	0.68	0.49	↑ 0.016	0.08	0.65	0.51	↑ 0.016	-0.05	-0.39	0.70	↓ -0.005
LT	Amax	0.33	2.67	*0.01	↑ 0.166	0.27	2.16	*0.03	↑ 0.124	0.28	2.23	*0.03	↑ 0.100	0.14	1.16	0.24	↑ 0.059	0.25	1.98	*0.05	↑ 0.063
	Amin	0.03	0.20	0.84	✗ 0.000	0.44	3.47	*0.00	↑ 0.100	0.07	0.51	0.61	↑ 0.004	0.17	1.37	0.17	↑ 0.028	0.01	0.06	0.95	✗ 0.000
DO	Amax	-0.20	-1.57	0.12	↓ -0.016	-0.15	-1.17	0.24	↓ -0.012	0.13	1.01	0.31	↑ 0.010	0.08	0.65	0.51	↑ 0.005	0.11	0.87	0.38	↑ 0.009
	Amin	-0.30	-2.42	*0.02	↓ -0.068	-0.04	-0.34	0.73	↓ -0.003	0.00	0.00	1.00	✗ 0.000	-0.07	-0.53	0.60	↓ -0.011	0.31	2.50	*0.01	↑ 0.031
PH	Amax	-0.24	-1.90	0.06	↓ -0.015	-0.26	-2.04	*0.04	↓ -0.011	0.19	1.46	0.14	↑ 0.006	-0.22	-1.64	0.10	↓ -0.004	0.05	0.37	0.71	✗ 0.000
	Amin	0.03	0.23	0.82	✗ 0.000	0.29	2.27	*0.02	↑ 0.013	0.23	1.81	0.07	↑ 0.010	0.33	2.60	*0.01	↑ 0.015	0.16	1.27	0.20	↑ 0.006
WL	Amax	0.06	0.51	0.61	↑ 0.005	0.14	1.10	0.27	↑ 0.021	0.09	0.73	0.47	↑ 0.004	0.13	1.08	0.28	↑ 0.005	0.04	0.33	0.74	↑ 0.002
	Amin	-0.34	-2.79	*0.01	↓ -0.003	-0.18	-1.47	0.14	↓ -0.005	0.04	0.29	0.77	↑ 0.001	-0.07	-0.59	0.56	↓ 0.000	-0.08	-0.67	0.51	↓ -0.001
Dis-charge	Amax	0.09	0.70	0.49	↑ 6.812	0.17	1.35	0.18	↑ 26.402	0.11	0.88	0.38	↑ 5.042	0.13	1.01	0.31	↑ 4.917	0.00	-0.02	0.99	↓ -0.259
	Amin	-0.17	-1.38	0.17	↓ -0.343	-0.11	-0.88	0.38	↓ -0.847	0.03	0.23	0.82	↑ 0.115	-0.08	-0.60	0.55	↓ -0.044	-0.05	-0.39	0.70	↓ -0.279

*Significant at 95% Level of Confidence

The results as shown in Figure 3(a) indicates that there is an increasing trend for both Amax and Amin RWT across all the stations, except for Station 222217, where no slope is detected in the Amax RWT, and Station 226226, where Amin RWT exhibits a decreasing trend of -0.005°C/year. Significant trend is detected in the Amax value of Stations 221208 and 226226. Highest increasing rate is detected in the Amax value of Station 226226 at 0.084 °C/year followed by Station 221208 at 0.06°C/year. For the Amin RWT, the highest rate of increase is recorded at Station 221212 at 0.023°C/year. Station 226226 has the most significant trend for the Amax values and a decreasing trend in the Amin values. This contrast suggests a wide temperature variation over time, which should be monitored as it can greatly affect the river's ecosystem. In Figure 3(b) significant increasing trends are observed in the Amax LT with station 221208 marks the highest rate of 0.166°C/year and the lowest is at Station 223204 of 0.059°C/year. There is no significant trend for the Amin LT of stations 221208 and 226226, while station 221212 has the highest rate of change for the Amin at 0.1°C/year. LT trend results shows relative congruence with the RWT trend as most of the results show an increasing trend except for the Amax RWT at Station 222217 and the Amin values at Station 226226.

Variation of trends are detected in the Amax and Amin values of DO as shown in Figure 3(c). Significant trends are noted in the Amin DO values at Stations 221208 and 226226. There is a concern regarding the decreasing trends in both Amax and Amin DO values at Stations 221208 and 221212, which range from -0.003 to -0.068ppm per year. Although the values are not extremely large, persistent decrease in DO can negatively impact the river ecosystem health. For the pH levels in Figure 3(d), decreasing trends are observed in the Amax values of Stations 221208, 221212 and 223204, with Station 221208 showing the highest decreasing trend of -0.015/year. While it is not conclusive that decreasing trend is beneficial for the river ecosystem, as the maximum pH values of these stations are in the higher range from 8.1 to 10.1, it is important to continue monitoring these trends. On the other hand, Amin pH levels across all the stations show an increasing trend, which ranges from 0.006 to 0.02/year except for Station 221208, which does not show any trend. The trends for the Amax and Amin of WL and discharge generally align across most of the stations as shown in Figure 3(e) and (f), except for station 226226, where the trends differ. A notable increasing trend for the Amax discharge of station 221212 is observed at 26.40ML/year.

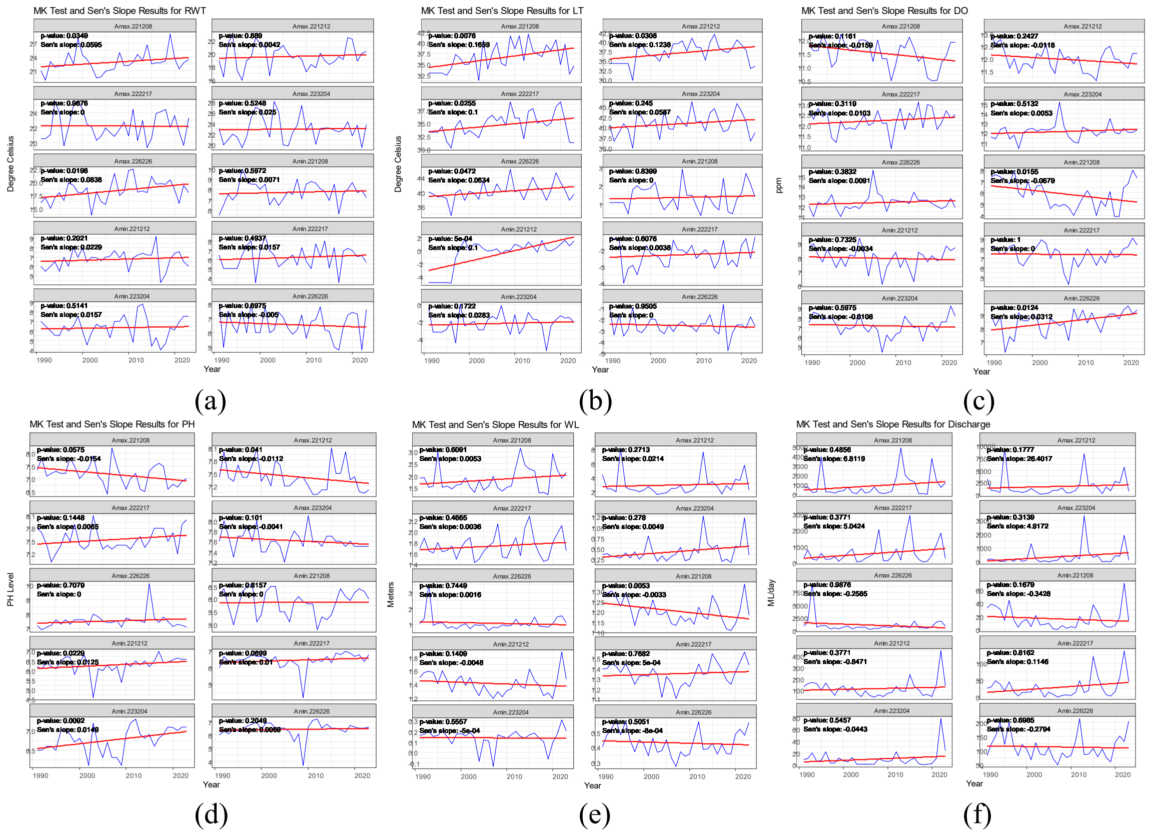


Figure 3: Trend of the Annual Maximum and Minimum Values: (a) RWT. (b) LT. (c) DO. (d) PH Level. (e) Water Level. (f) Discharge

4 CONCLUSION

The purpose of this study is to investigate the trend of RWT in Victoria, Australia, based on publicly available data. Study was conducted at five selected river stations: 221208, 221212, 222217, 223204, and 226226. These stations are within the PCRZ. However, stations 221212 and 226226 are closest to farm zones, while station 221208 is nearest to the Tasman Sea shoreline. The stations exhibit diverse temperature and water-related characteristics influenced by their unique locations and environmental factors. Station 221208 appears to have the most challenging conditions among the five rivers marked by the highest temperature medians, greatest variability in RWT and LT, and the lowest DO values with significant fluctuations in Amax and Amin values. It also has more acidic condition than other stations. It recorded the second-highest increasing RWT trend. In contrast, Station 226226 shows the healthiest river among the five rivers. It records the lowest Amax and Amin RWT, optimal DO and pH levels. It should be noted that this station records the highest Amax discharge. However, this station has the highest increasing rate for the Amax of RWT and its Amin RWT trend is decreasing, which shows high temperature variations.

Stations 221212 and 226226 show extreme discharge variability and lower Amax RWT, possibly due to cooling effects from irrigation and higher discharge levels, likely influenced by their proximity to farm zones, which can affect water volume and quality. A notable increasing trend for discharge is recorded at station 221212 at 26.40ML/year. Station 223204 RWT values are in the upper range for both Amax and Amin values, with the highest median pH level and relatively consistent DO level. In contrast, station 222217 shows typical characteristics of PCRZ-protected areas, with less agricultural influence and stable environmental parameters. Generally, RWT and LT show a relatively increasing trend across all the selected stations both for Amax and Amin. However, contrary to the typical inverse relationship between DO and RWT, this study finds that this inverse correlation is not always true as in the case of the Amax values of Stations 222217, 223204 and 226226. Varied trend patterns are also noted for pH level, WL, and discharge across all the stations. These observations indicate a complex interplay between geographic location, environmental factors, and agricultural influence, shaping the temperatures, DO, pH, WL, and discharge across the stations. Further investigations should be conducted to better understand the factors that influence the RWT as this is very crucial to the health and sustainability of the aquatic ecosystem.

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