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Relationship between Seasonal Streamflow Variability and their Evolution through Time: A Case Study Over Avoca River Catchment

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Authors' contributions

This work was carried out in collaboration between all authors. Author SUR designed, supervised and worked with co-authors to the final corrected draft of the study. Author KS wrote the first draft of the manuscript and performed the mathematical/statistical analysis. Authors AA and MABK managed the literature searches and checked the performed mathematical/statistical analysis of the draft. All authors read and approved the final manuscript.

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ABSTRACT

It has been widely documented that ENSO factors play vital rule in climate variability over many parts of the globe. In this study, used only high pressure centers and their location as a variable and found useful explanation in the variability of the Avoca River. It is clearly evident in this study that not only the magnitude of the pressure, but also the position of the center is important in studying the variability of the Avoca River. Analysis of the long term trends in the indices were computed, and found to have a significant increasing correlation with the pressure of the Indian Ocean while South Pacific did not show any significant increasing or decreasing trend. Streamflow data for the May- August (MJJA) data also showed an increasing trend in the streamflow, which shows that streamflow and Indian Ocean high pressure has significant correlation, which is

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confirmed by the correlation matrix. A multiple regression model has been constructed using Indian Ocean High pressure and longitude and South Pacific high longitude, which explains 22% of the variability of the streamflow in Avoca River.

Keywords: ENSO; climate variability; streamflow; correlation and multiple regression analysis.

1. INTRODUCTION

Numerous studies have linked the climate variability with the many climate drivers such as, ENSO, which shows a significant relationship with the rainfall and streamflow in many parts around the globe [1,2]. ENSO is largely occurring as a result of interaction between Ocean and large scale circulation pattern in the atmosphere, it has three phases one corresponds to cold phase, which is commonly known as La Nina, while Warm phase is termed as El Nino events and Neutral phase corresponds to the moderate temperature phase. Several indices based on Sea Surface Temperature (SST) and pressure have been utilized to quantify the El Nino and La Nino Phases. The most commonly used index employed are Troup Southern Oscillation Index (SOI), which is the pressure difference between Darwin and Tahiti [3]. Several other indices have also been available based on the SST in the equatorial Pacific region (NINOl, NIN03, NIN03.4 and NINO1+2). This index indicates uncertainty in the location of the ENSO phenomena. Another index, which is commonly known as a Multiple ENSO index (MEI) is used in measurement of ENSO is found to be useful than SST and SOI indices, since this index was constructed by the multiple climate parameters so it gathers more information [4,5].

Apart from SOI and SST based indices several other indices have also been examined, e.g. Southern Annular mode, North Atlantic oscillation index and Artic oscillation. Recently a new methodology has been adopted in analyzing the variability of climate, known as “Centers of Action”. According to this methodology a large scale semi-permanent centers of highs and lows are prominent on the mean global maps, these centers were first identified by [6]. According to this approach not only the magnitude of the pressure, but also its position is important in defining the climate variability. Several studies have used this methodology and found useful in the assessment of climate variability, for example, [7] found, inter-annual variability of Gulf Stream North Wall significantly correlates with the longitude position of the Icelandic low. In this study a similar methodology was also used but with a modified approach, which gives better results as compared to [8]. In this paper our aim is to analyze the trends in the May to August Indian Ocean High pressure and South Pacific high pressure indices and to estimate the linkage of these indices with the Avoca River streamflow. Water resource management has now become a vital need throughout the world, as many of the river basin around the globe showed a declining trend. Australia is one of the region where climate has shown so much diversity, Western part of the continent, and particularly, southwest of Western Australia (SWWA) showed severe decreasing trends in rainfall and streamflow [8], while much of eastern part showed decreasing trends in the rainfall and streamflow. Avoca River is the fifth largest river in Victoria, and a part of Muray-Darling river basin. It has a catchment area of about 12000 Km^2, it has thirteen tributaries namely, Glenlogie Creek, Number Two Creek, Mountain Creek (Victoria), Cherry Tree Creek, Smoky Creek, Tarpaulin Creek, Campbell Creek, Sandy Creek (Victoria), Brown Hill Creek (Victoria), Fentons Creek (Victoria), Sandy Creek (Victoria), Yeungroon Creek, Mosquito Creek (Victoria). Avoca river is one of the highest variable river, where the mean annual flow is of about 85 gigalitres, ranging from the low flow for the long period less than 55 goals, while in dry years flow reaches its minimum value for several months.

2. DATA AND METHODOLOGY

Mean monthly gridded Sea level pressure data were obtained from the Nation Center of Environmental Prediction NCEP analysis [9] for calculating Indian Ocean high pressure (PS IOH), Indian Ocean longitude (LN IOH) and Latitude of the Indian Ocean high pressure (LT IOH), similarly for South Pacific Ocean high pressure centers (PS SPH, LN SPH, LT SPH). Monthly streamflow data from May to August were obtained from the Australian Department of Water, (www.bom.gov.au). Streamflow data were used for 45 years from 1967 to 2011. All analysis carried out only for MJJA season. Monthly variability of the streamflow is not the subject of this study.

As discussed earlier that low and high pressure centers are prominent on the mean and seasonal maps of Sea level pressure (SLP), which are known as centers of action. It has been observed that Indian Ocean High pressure center significantly influenced the stream flow and rainfall of Southwest of Western Australia [8]. In this study similar, methodology is adopted, but with different threshold value and region which gives more significant results as compared to [8]. The objective indices were defined by I_p, I_z, I_m, for Indian Ocean High and South Pacific pressure, longitude and latitude, bounded by the region 10°S to 45°S and 100°E to 142.5°E and 10°S to 45°S and 150°E to 220°E. Mathematically, it can be defined as,

$$I_P(t) = \overline{P_{(x,y)}}(t) \tag{1}$$

$$I_Z(t) = \overline{Z_x(t)} \tag{2}$$

$$I_M(t) = \overline{M_y(t)} \tag{3}$$

Where $I_P(t)$ is the area average pressure of the SLP, when pressure at a particular grid node is greater than a threshold value of 1016 hpa, this threshold value is selected by examination of the mean SLP map. Z_x(t) and M_y(t) are the corresponding longitude and latitude when mean SLP is less than 1016 hpa respectively.

All indices and streamflow data were analyzed for average flow from May to August, maximum and minimum flow and standard deviation and slope or trend in the data are also calculated. The scheme of this study is to use these information form a regression model which best described the mean flow of the Avoca River.

3. RESULTS AND DISCUSSION

3.1 Sea Level Pressure Indices

Table 1 represents the trend summary for both the Indian Ocean and South Pacific Ocean indices. The most important thing in the Table 1 is the slope of the regression line, which explains the upward or downward trends in the data. The regression line with zero slope depicts the no trends in the data, while in positive slope shows an increasing trend in the data and negative slope is termed as downward or decreasing trend in the data. All indices of Indian Ocean showed a positive slope while Pacific Ocean indices except Latitude showed negative slope. Among all indices only Indian Ocean high pressure showed a significant increasing trend (see Fig. 1), while the Indian Ocean latitude showed the lowest value of the slope. The mean value of the pressure for Indian Ocean High pressure is about 1019.84 hpa, with a standard deviation of 0.57. It means that Indian Ocean high pressure is increasing and possible consequences of this increasing trend in the pressure may lead to the less rainfall and streamflow in the regions of the Australian territory.

3.2 Streamflow Data

Table 2 represents mean, maximum, minimum and standard deviation of the flow of the Avoca River. The slope of the best fitted line for the MJJA Avoca river is -309.1 ML/season (see Fig. 2), which is -2.8% of the mean flow of the data, here another interesting thing is that mean of the river is less than its standard deviation, which indicates that mean is not the good estimate of the river.

The declining trend in the river might be the result of the changes which occurred in the catchment area, when levees were constructed leading to a consequent reduction in the wetlands area. Also construction of new water reservoirs, increasing population and expansion in the agricultural area are suggested as the reason for the reduction in the area if catchment. Evapotranspiration is one the most important factor which has been influenced by the wetland effects and agricultural. Among all these, some factors enhanced the flow of the river while others are the cause of the reduction of the flow of the river. Now it is important to analyze the indices which influenced most and explained the variability of the river.

It is found on the basis of the above discussion that streamflow has the significant trend in the data, with the slope of the best fitted line equal to -309.1 ML per season, which is significant at 95% confidence interval, here negative sign indicates that the flow of the river showed a declining trend. This declining trend is marked with the less number of reservoirs with low capacity. Although high flooding has been evident throughout the season since 1973 to 1998 but after that the extremely low flow is observed (see Fig. 2). A Similar analysis was also performed for the indices and it is found that only Indian Ocean high pressure centers showed a significant increasing trend in the data. All other indices are marked with the no significant values of the slope. The Increasing trend in the PS IOH indicates that during the period of study, the selected region of the high pressure centers of the Indian Ocean will become more intensified, this intensification of the pressure may lead to the reduction of the streamflow and rainfall throughout the continent. While South Pacific high pressure center, longitude and latitude did not show any significant slope of the regression line. So it is evident that the decrease in flow is connected with the increase in the Indian Ocean high pressure.

Table 1. Trend summary of the indices of the Indian Ocean and South Pacific Ocean

	Mean	Minimum	Maximum	Standard deviation	Slope	P-value
PS IOH	1019.84	1018.64	1020.89	0.57	0.0124	0.044
LN IOH	109.28	103.05	112.91	2.11	0.03941	0.10462
LT IOH	-29.21	-30.859	-27.74	0.68	0.00302	0.70156
SPH PS	1018.61	1017.66	1019.67	0.56	-0.001	0.82752
SPH LN	176.56	160.576	198.81	8.76	-0.041	0.68831
SPH LT	-31.69	-35.701	-28.12	2.04	0.0137	0.56552

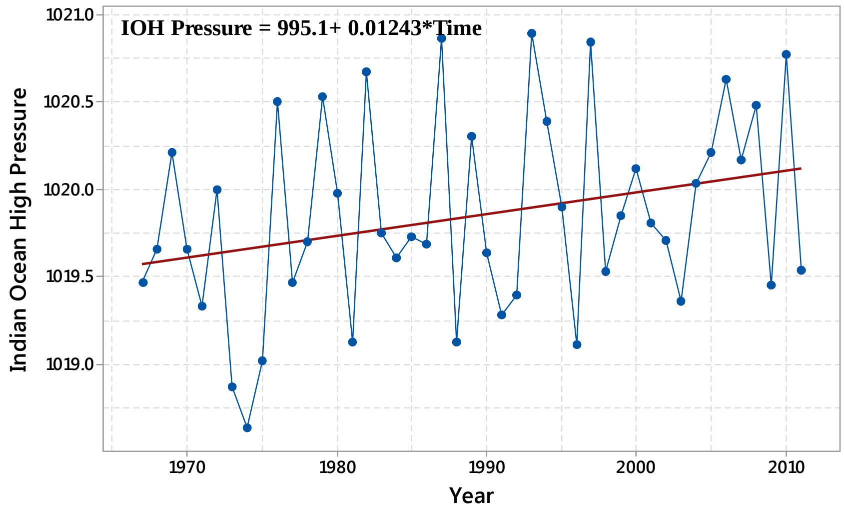

Fig. 1. Indian Ocean high pressure trend for the period of 1967 to 2011

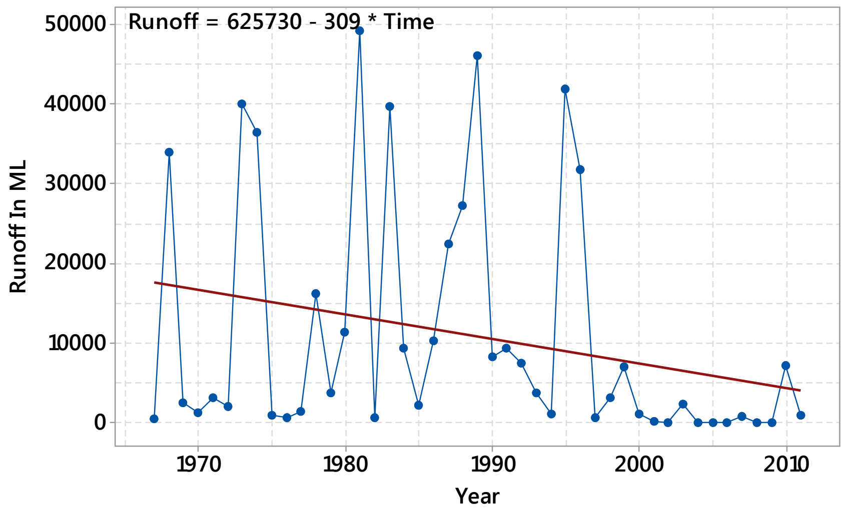

Fig. 2. Runoff trend for the period of 1967 to 2011

For further investigation a correlation matrix has been computed between streamflow and all indices (see Table 3). It is found that streamflow is significantly correlated with the Indian Ocean high pressure and its longitude position (-0.344 and -0.377 with PS IOH and LN IOH respectively), while with South Pacific high pressure indices it is only significantly correlated with the longitude position of the South Pacific high pressure centers (0.308). Here negative and positive signs have physical justification also. Negative signs for Indian Ocean high pressure indicates that the high pressure in the Indian Ocean inversely related with the streamflow that means a high pressure low flow and vice versa, while the correlation with longitude position indicates that more flow will be observed if the high pressure center moves towards the Western side of the region, while low flow will be observed if the center moves towards the Eastern side, i.e. towards the Australia. South Pacific high, however has positive correlation unlike LN IOH. It indicates that the center of the pressure follows the increasing longitude results more rainfall and streamflow, while at smaller longitude it is near the Victoria region and hence low flow should be observed.

In order to understand the variability of the Avoca River a multiple regression model has been constructed using PS IOH, LN IOH and LN SPH, those variable which are significantly correlated with the Avoca River flow. One main problem which arises in multiple regression analysis is the multicolinearity of the variables i.e. varaiables that are significantly correlated and are not independent. This problem was resolved by a calculation of variance inflation factor, it is widely accepted that VIF less than 1 implies that variables in the regression model are independent and can be used in a regression model while VIF greater than 1 but less than 5 is a moderate value and independent nature of variables cannot be ignored while VIF greater than 5 indicates significant relationship among the predictors. In this model those variables were selected which were independent and have VIF values of 1.24, 1.12 and 1.16 for PS IOH, LN IOH and LN SPH. This model, $\text{MJJA Runoff} = 5267600 - 4998 * \text{PS IOH} - 1973 * \text{LN IOH} + 320 * \text{LN SPH}$ explains 22% of the variability of the data. Several other models were also tested for better understanding, but the maximum variability of the flow is explains by this model, also this model best explains the flow of the river except few values of the very high flow that might be the cause of the extreme events such as flooding (see Fig. 3).

Table 2. Trend summary of the streamflow data

	Streamflow
Mean	10861.9
Minimum	0
Maximum	49280.6
Standard deviation	15023.1
Slope	-309.1
P-value	0.05

Table 3. Correlation matrix of streamflow with indices of both Indian Ocean and South Pacific Ocean

	Streamflow	P-value
PS IOH	**-0.3442**	p=.021
LN IOH	**-0.3718**	p=.012
LT IOH	0.1806	p=.235
SPH PS	-0.1773	p=.244
SPH LN	**0.3081**	p=.039
SPH LT	0.169	p=.267

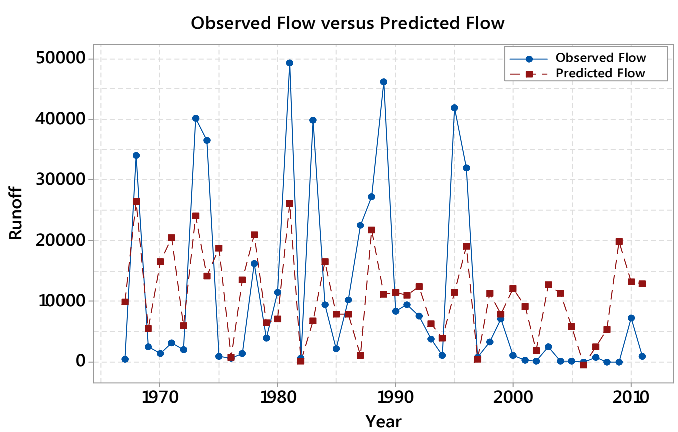

Fig. 3. Observed flow versus predicted flow for the Avoca River

4. CONCLUSION

In this study, only the impact of the Indian Ocean and South Pacific Ocean high pressure on the Avoca River were examined, and no other climate indicators or indices were not employed. Since in many studies ENSO phenomena are the major subject or factor, which explains the variability of the climate mainly, in terms of the rainfall and streamflow. But only Pressure indices are found useful in explaining variability of the Avoca River. Significant Long term trends were also found in Indian Ocean high pressure centers and streamflow of the river. On the basis of above results and discussion, a regression model was constructed, which explains 22% of the variability of the Avoca River. It is evident from the study that the zonal movement of the high pressure center over the Indian Ocean and South Pacific Ocean affects the variability of the river.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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