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THE IMPACT OF INDIAN OCEAN HIGH PRESSURE SYSTEM ON RAINFALL AND STREAM FLOW

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Centre of Action approach is very useful in getting insight of rainfall and stream flow variability of specific region. Hameed et al. [17] showed that Inter-annual variability of Gulf Stream north wall is influenced by low Icelandic pressure system and has more statistically significant correlation than North Atlantic Oscillation (NAO) with longitude of Icelandic low. This study also aims to explore possible relationships between rainfall and stream flow in Collie river catchment in Southwest Western Australia (SWWA) with Indian Ocean high pressure dynamics. The relationship between rainfall and stream flow with Indian Ocean high pressure system have been investigated using correlation analysis for early winter season (MJJA), lag correlation for MJJA versus SOND rainfall and stream flow are also calculated and found significant at 95% confidence level. By investigating the relationship between COA indices with rainfall and stream flow over the period 1976-2008, significant correlations suggests that rainfall and stream flow in Collie river basin is strongly influenced by COA indices. Multiple correlations between rainfall and stream flow with Indian Ocean high pressure (IOHPS and IOHLN) is 0.7 and 0.6 respectively. Centers of Action (COA) indices explain 51% and 36% of rainfall and stream flow respectively. The correlation between rainfall and stream flow with IOHPS is -0.4 and -0.3 whereas, with IOHLN is -0.47 and -0.52 respectively.

Keywords : Indian ocean, Centre of Action (COA), Stream flow, IOHP, IOHLN

1. Introduction

Since mid of the last century, reduction in winter rainfall over Southwestern Australia, is the key issue of Australian climate variability. Several studies have shown that Australian hydro climate have considerable spatial and temporal variability [5, 13], in the mid-1970's, rainfall over SWWA decreased by about 15% to 20 % [7] and this variability is particularly in Southwestern Australia climate is dominated by winter rainfall [15, 16] and observed in early part of the Winter May-July [7]. Climate variability has been linked with Ocean–Atmospheric process occurring in Indian Ocean and Pacific Ocean. McBride and Nicholls (1983), Drosdowsky (1993), Risbey et al. (2009) [8, 10, 19] showed that El Nino/ Southern Oscillation and Power et al. (1999), Kiem et al. (2003), Kiem and Franks, (2004) [1, 2, 18] showed that the inter-decadal Pacific Oscillation (IPO) and Saji and Yamagata, (2003), Verdon and Franks, (2005), Meyers et al. (2007), Risbey et al. (2009) [3,6,10, 12] identified that Indian Ocean dipole (IOD) has shown influence on much of this variability. ENSO activity may be connected with stream flow, which is comprehensive integrator of rainfall over vast areas, because fluctuation in rainfall could be attributed with ENSO activity.

"Centers of Action" (COA) are the large scale high and low pressures centers which are prominent on global maps of monthly average sea level pressure, defined by Rossby et al. [9]. A key point noted by that regional circulations are not only influenced by the change in pressure but also the change in position of center of action. In our analysis COA is characterized by area average longitude, latitude and pressure as the three indices. Several other authors have also found that

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COA methodology is useful in analysis of regional phenomena. Inter-annual variability of Gulf Stream north wall is influenced by low Icelandic pressure system, and has more statistically significant correlation than North Atlantic Oscillation (NAO) with longitude of Icelandic low [17]. The Saharan dust transport variability has higher correlation with latitude position of the Azores High and the Caribbean island dust transportation has higher correlation with the longitude position of Azores High [14]. The main aim of study is to analyze the rainfall and stream flow variability in Collie river catchment using Center of action approach.

2. Study Area and Catchment Description

Collie river is one of the major rivers of Southwest coast division which covers 3000 km^2, also includes the Wellington reservoir (Fig. 1). Collie river East, Collie river south, Bingham river, Brunswick River, Gervase river, Hamilton river, Harris river, Ironstone Gully, Silver Wattle Gully, Worsley river, Riches Gully and Mill Brook are the main feeder of Collie river. Length of Collie River is 154 km approximately. It originates from Darkan and discharge in Indian Ocean at Bunbury. Figure 2 shows the monthly rainfall and their variance over the period 1951-2008. It is implied from the Figures 2 and 3 that maximum rainfall and stream flow over Collie river catchment is in May to October season, which is sometimes known as cool season [11]. Since the climate is typically Mediterranean (wet winter and dry summer), summer rainfall is very low.

Figure 1. Collie River Map.

3. Data Analysis

Monthly Stream flow time series data from 1976 to 2008 is used. Data were obtained from Department of water (DOW), Western Australia. Stream flow data and rainfall data in mm is used for comparison purpose, stream flow data were normalized by dividing its catchment area. Monthly averaged gridded SLP data obtained from NCEP reanalysis [4] is used for calculating COA indices for the monthly averaged Pressure, latitude and longitude of the Indian Ocean high. The Sea-surface temperature (SST) based indices NINO3, NINO12, NINO3.4 and NINO4 were used for ENSO from climate prediction center. Southern oscillation index (SOI) values on monthly basis were obtained from National climate centre of the Australian Bureau of Meteorology.

4. Results and Discussion

4.1. Influence of IOHP on Monthly and Seasonal Rainfall Variability Over Collie River

The rainfall variability over Collie river catchment and its connection with monthly mean central pressure of Indian Ocean high pressure (IOHP) is analyzed by calculating 15 years monthly mean rainfall when Indian Ocean high pressure minimum, similarly selecting 15 years when Indian Ocean high pressure was maximum. Since available stream flow record is from 1976-2008, therefore, for comparison purpose we used rainfall data for same 33 years. Figure 4 shows that when IOHP minimum there was more rainfall than those years when IOHP maximum. In July approximately 160 mm was recorded when IO HP was 1020.42 hpa and approximately 135 mm rainfall was recorded in July when IOHP was 1021.58 hpa. The relationship between seasonal mean central pressure of IOHP and rainfall for the seasons MJJA is analyzed, by calculating 15 years mean of seasonal rainfall when Indian Ocean high pressure (IOHP) minimum and 15 years mean of seasonal rainfall when Indian Ocean high pressure (IOHP) was maximum. It is found that when seasonal mean central pressure of IOHP minimum there were more rainfall in Collie river catchment than those years when seasonal mean central pressure of IOHP was maximum there were less rain in the catchment area. In MJJA approximately 135 mm rain was recorded when seasonal IOHP was about 1019.93 hpa and about 122 mm rainfall was recorded when IOHP was about 1020 hpa (Fig. 5).

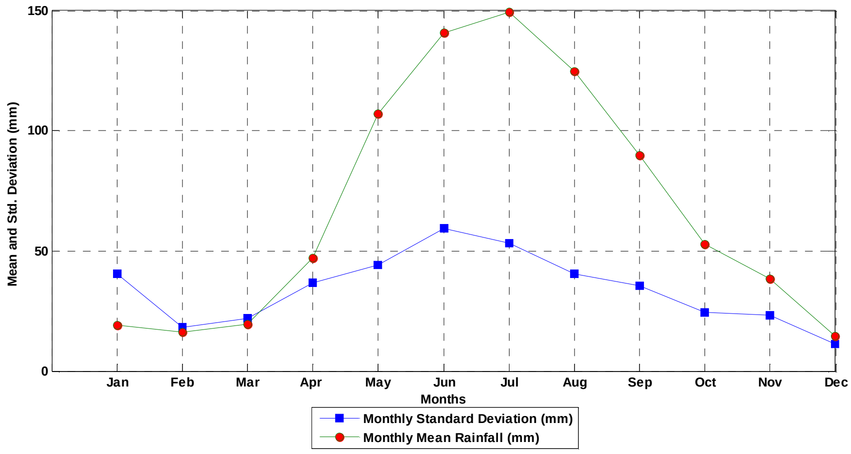

Figure 2. Mean and standard deviation of monthly rainfall totals for the lower Collie river catchment from 1951−2008. Note: Overlap point indicates that March shows no variance and its mean and variance both are same.

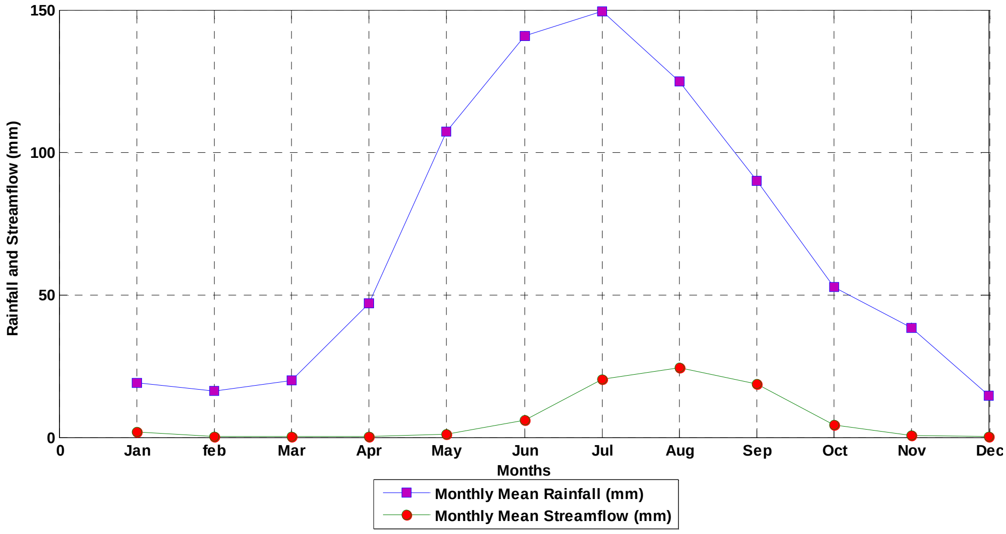

Figure 3. The seasonal cycle of catchment rainfall monthly sum and stream flow monthly sum in lower Collie river catchment.

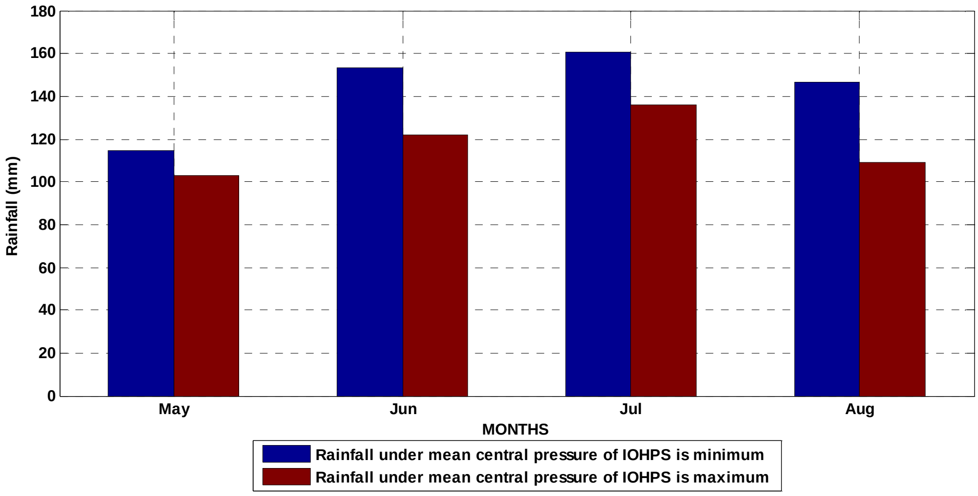

Figure 4. Comparison of average rainfall (mm) at Collie river catchment under maximum and minimum pressure.

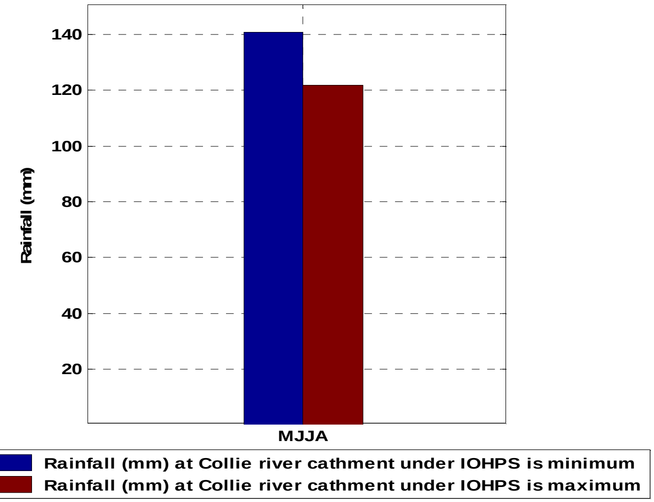

Figure 5. Comparison of average seasonal rainfall (mm) at Collie river catchment under mean central pressure of IOHP is maximum and minimum.

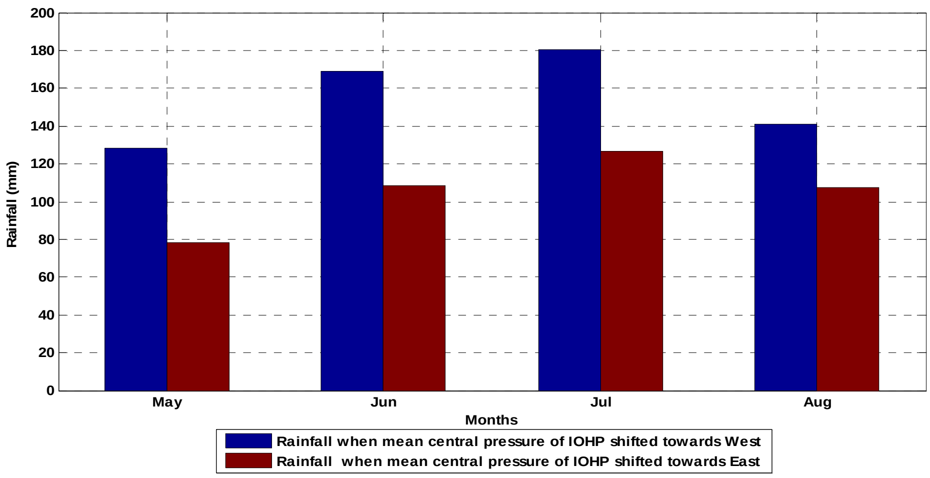

Figure 6. Comparison of average rainfall (mm) at Collie river catchment under mean central pressure of IOHP shifted toward East and West.

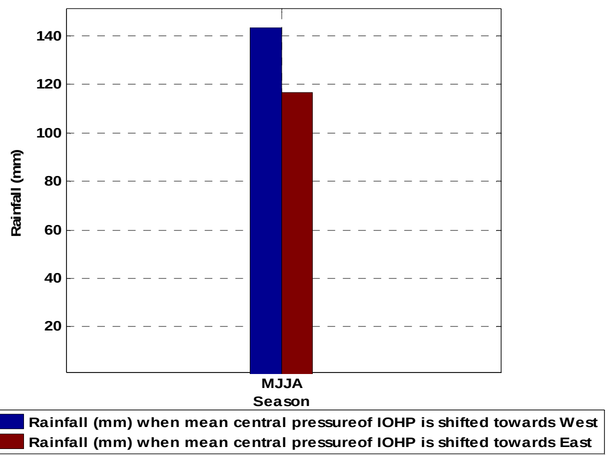

Figure 7. Comparison of average seasonal rainfall (mm) at Collie river catchment under mean central pressure of IOHP shifted towards East and West.

4.2. Influence of IOHLN on Monthly and Seasonal Rainfall Variability Over Collie River

Rainfall over Collie river catchment is not only influenced by monthly mean central pressure of IOHP but also by the zonal movement of high pressure systems. For getting insight of the idea average of monthly rainfall was calculated for 15 years rainfall when Indian Ocean High pressure was shifted at most to the West and 15 years monthly mean of rainfall when Indian Ocean high was shifted most to the East. It is clearly evident that rainfall in Collie river catchment was more when Indian Ocean high pressure longitude (IOHLN) shifted most to the West and less rainfall was recorded when Indian Ocean high pressure longitude shifted to most the East. In July approximately 180 mm rain was recorded when high pressure system shifted at 65.69 East and about 125 mm was recorded when Indian ocean high was shifted at 71.53 East (Fig. 6) This gives clear signs that zonal movement of Indian Ocean high longitude is one of the factors that affect rainfall in Collie river catchment.

Rainfall in SWWA is in declining phase since mid of the last century and this declining phase is observed in early cool season i.e. MJJA rainfall is influenced by seasonal zonal movements of Indian Ocean high pressure system. Seasonal mean rainfall was calculated for 15 years when Indian Ocean high pressure was located most to the east and most to the West. Fig. 7 shows that when Indian ocean high pressure was located at most to the east there were less rainfall and when Indian Ocean high was located most to the west there were more rainfall in Collie river catchment. When seasonal central high pressure system was at 67.66 E approximately 140 mm rain was recorded and when seasonal central high pressure was at 72.18 east approximately 120 mm rain was recorded.

4.3 Influence of IOHP on monthly and seasonal stream flow variability over Collie River

It is implied from the Figure 8 that there is an inverse relationship between mean monthly central Indian Ocean high pressure and stream flow. 10 years mean of monthly runoff was calculated when the Indian Ocean High pressure maximum and 10 years mean of monthly stream flow when Indian Ocean High pressure minimum. It demonstrate that there were more amount of runoff in Collie river when Indian Ocean high pressure was minimum while low runoff were recorded in river when Indian ocean high pressure was maximum. This gives us clear understanding that the runoff variability is also related with the Indian Ocean high pressure.

The seasonal runoff in Collie river catchment is also in connection with the seasonal Indian Ocean high pressure, when Indian Ocean high pressure was maximum there were less runoff and when Indian Ocean High was minimum there were more runoff (Figure 9). The maximum runoff approximately 6.80 mm when the minimum season pressure of IOHP in cool season (MJJA) is 1019.79 hpa, similarly 3.283 mm of runoff was observed when maximum mean central pressure of IOHPS in winter is 1020.86 hpa.

4.4 Influence of IOHLN on Monthly and Seasonal Stream Flow Variability Over Collie River

The influence of Indian Ocean high pressure longitude on runoff is analyzed by selecting 10 years when monthly mean central pressure of Indian Ocean was located most to the west and 10 years when the central pressure of Indian Ocean was located most to the East that is low and high longitude respectively. When Indian Ocean high pressure was located most to the west there were more runoff was recorded and when Indian Ocean high pressure was located most to the east less runoff amount of runoff was recorded (Fig. 10). This observation is consistent in winter, in July approximately 27 mm was observed when Indian ocean high was located at 66.37 ^{o}E and approximately 16 mm when centre of high pressure system was located at 74.57 ^{o}S (high longitude).

Seasonal stream flow in collie river catchment is also influenced by Indian Ocean high pressure longitude. Mean stream flow for the seasons MJJA was calculated for 10 years when Indian Ocean high pressure located at most to the west and most to the East. As in Fig.10 it is quite evident that when Indian Ocean High pressure was located at West runoff in Collie river catchment maximum and when Indian Ocean high pressure was located at East (high longitude) runoff minimum that is towards Southwest Western Australia (SWWA).

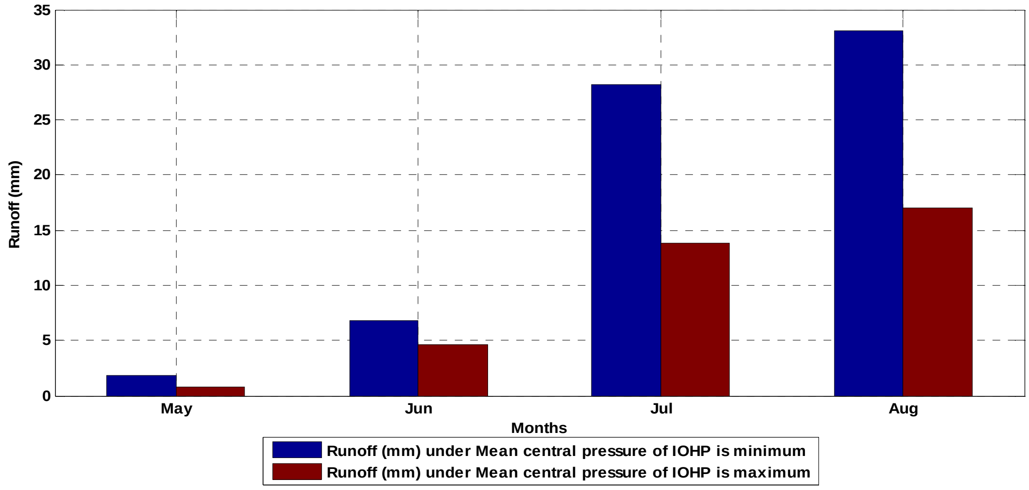

Figure 8. Comparison of average seasonal rainfall (mm) at Collie river catchment under mean central pressure of IOHP is maximum and minimum.

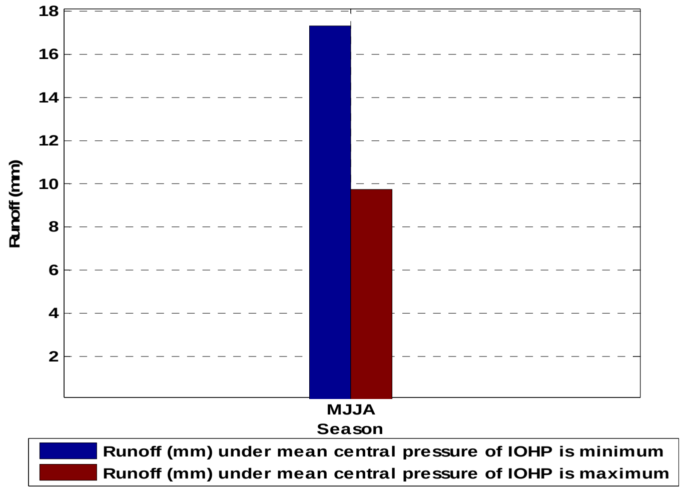

Figure 9. The Comparison of average seasonal rainfall (mm) at Collie river catchment under maximum and minimum seasonal pressure.

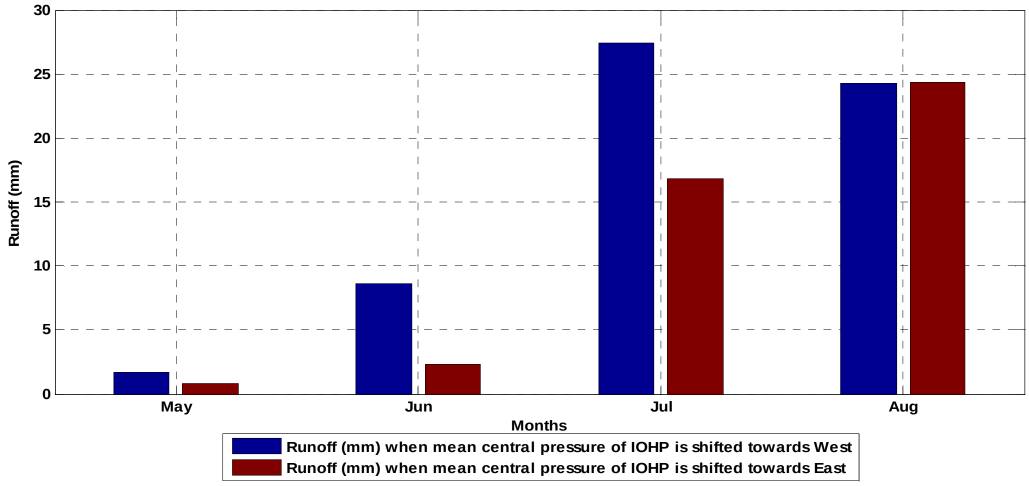

Figure 10. Comparison of average monthly rainfall (mm) at Collie river catchment under mean central pressure of IOHP shifted toward East and West.

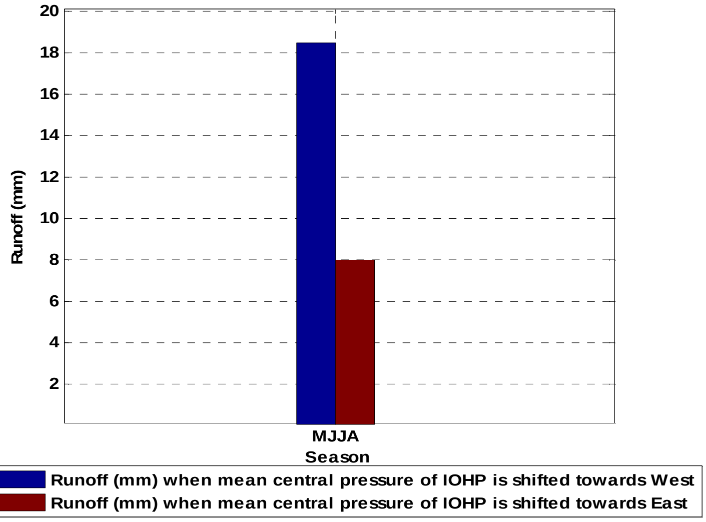

Figure 11. Comparison of average seasonal runoff (mm) at Collie ri0ver catchment when mean central pressure of IOHP shifted toward East and West.

Table 1. Correlation Matrix of rainfall and stream flow for Collie river catchment for MJJA season during 1976-2008. Values significant at the 0.05 level of significance are shown with *.

Variables	Rainfall (MJJA)	Stream flow (MJJA)
MEI	-0.13366	0.005422
NINO3	-0.26889	-0.05448
Nino12	-0.09288	0.084061
NINO3.4	-0.29406*	-0.16047
NINO4	0.159117	-0.09074
SOI	0.410516*	0.316734*
IOHPS	-0.42614*	-0.31836*
IOHLN	-0.66433*	-0.53999*
IOHLT	0.563812*	0.55206*
IOHPS & IOHLN	0.7141*	0.6*

4.5. Correlation Analysis

In order to investigate the association of COA indices with rainfall and stream flow Peairson's correlation coefficient between the pressure, longitude and latitude of the Indian Ocean and the MEI, NINO3, NINO12, NINO3.4, NINO4, SOI of ENSO indicators with stream flow and rainfall over Collie river catchment of SWWA for the early winter season i.e. MJJA of 1976-2008 was computed all correlations are at p<0.05 level of significance. As shown in Table 1 rainfall in Collie river catchment has significant correlation with IOHPS and IOHLN. The correlation with IOHP is -0.42 at p<0.05 level of significance and the correlation with IOHLN is -0.6 at p <0.05, which implies that COA indices has inverse relationship with rainfall. Correlation with SOI is 0.4 at p < 0.05 level of significance. Correlation Matrix of COA indices and ENSO variables are presented in Table 2, it is of noteworthy that Indian Ocean high (IOHPS) and Indian Ocean high longitude (IOHLN)

Table 2. Correlation Matrix for MEI, NINO 3, NINO 3.4, NINO 4, NINO 12, SOI, Indian ocean high pressure and Indian Ocean high longitude. Correlation of IOHP and IOHLN shown in bold.

	MEI	NINO3	NINO12	NINO3.4	NINO4	SOI	IOHPS	IOHLON	IOHLT	SPHPS
MEI	1									
NINO3	0.87735*	1								
NINO12	0.777592*	0.852132*	1							
NINO3.4	0.859086*	0.899778*	0.598595*	1						
NINO4	0.79461*	0.669864*	0.362609*	0.878161*	1					
SOI	-0.79999*	-0.72033*	-0.46748*	-0.84522*	-0.79862*	1				
IOHPS	0.426133*	0.333898*	0.207167	0.345903*	0.375308*	-0.39757*	1			
IOHLON	0.188056	0.233152	0.147001	0.264933	0.135986	-0.35277*	0.14497	1		
IOHLT	0.00039	-0.20932	-0.16485	-0.13491	0.051634	0.096676	-0.1832	-0.1674	1	
SPHPS	-0.34911*	-0.4707*	-0.29668*	-0.49078*	-0.32147*	0.410655*	-0.0664	-0.2741	0.14117	1

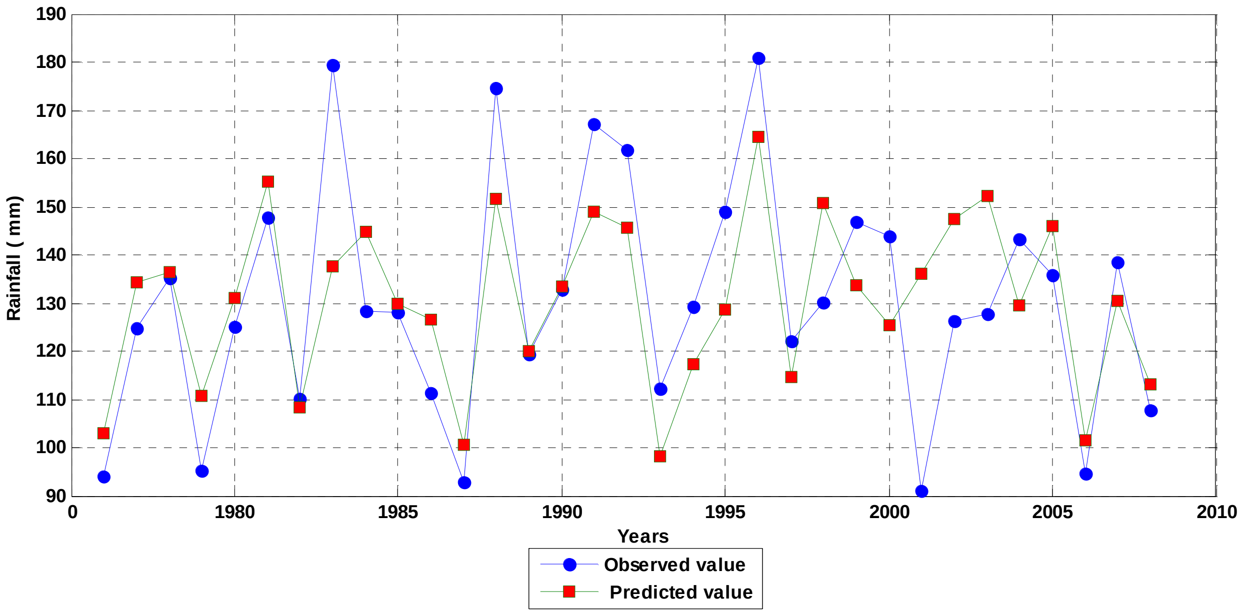

Figure 12. Collie river rainfall (mm) in (MJJA) compared with regression with IOH longitude.

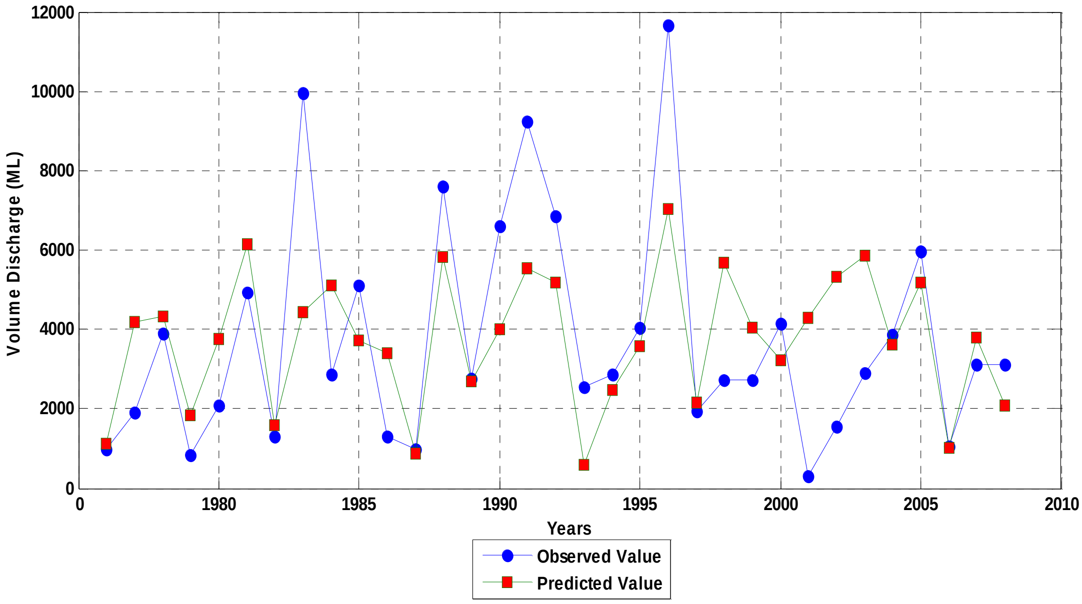

Figure 13. Collie river runoff (ML) in (MJJA) compared with regression with IOH longitude.

are independent whereas ENSO indicators are significantly correlated with both COA indices and other ENSO variables (Table 2), therefore a multi-linear model of rainfall in collie river catchment is presented (Fig 12): Rainfall=15038.50 -14.24*IOHPS-5.38*IOHLN with R^2 0.51 whereas SOI value of R^2 is 0.16 implies that SOI has weaker influence on rainfall as compared to SOI. The correlation with IOHPS is -0.31 and with IOHLN is -0.53 at $p < 0.05$ level of significance (Table 1). Collie river catchment has significantly influenced Indian Ocean high longitude zonal movements and IOHPS. Correlation of stream flow with SOI index is 0.31 which is significant at $p < 0.05$ level of significance. Correlation of COA indices and ENSO variables are also calculated and shown in Table 2 since Indian Ocean high pressure (IOHP) and Indian Ocean high longitude (IOHLN) are independent whereas ENSO indicators are significantly correlated with both COA indices, therefore a multi-linear model is presented: Stream flow =1516127 -1447*IOHPS-510*IOHLN with R^2 0.36 which is significant at $p < 0.05$, whereas SOI value of R^2 is 0.1003, which shows that SOI has weaker influence as compared to COA indices. Furthermore, multi-linear model for early winter time stream flow captured some of the major patterns for 33 years period at Collie River catchment (Figure 13). The reduction in stream flow volume discharge in 2006 was reproduced by the regression model.

4.6. Forecasting Implication of COA Indices

Stream flow and rainfall variability is higher in Australia then elsewhere in the World and therefore, forecasting can benefit water management in Collie river catchment area. The COA hydroclimate teleconnections has strong influence on South West Western Australian rainfall and stream flow and can be used for forecasting rainfall and stream flow. This study aim to investigate lag correlations for seasons MJJA variables and SOND rainfall and stream flow. Table 3 shows that the lag correlation of SOND rainfall with MJJA IOHP is -0.35 at $p < 0.05$ level of significance, whereas with IOHLN correlation is -0.53 at $p < 0.01$. SOND stream flow is also significantly correlated with MJJA Indian Ocean High pressure (IOHP) and Indian Ocean High longitude (IOHLN), correlation with IOHP is -0.28 and with IOHLN is -0.50 at $p < 0.05$. Correlation between SOI and rainfall is 0.44 and with stream flow is 0.36 also significant at $p < 0.05$ level of significance but IOHP and IOHLN together are more significantly correlated with rainfall and stream flow then SOI correlation with rainfall is 0.57 and 0.53 respectively at $p<0.05$ level of significance.

Table 3. Lag Correlation Matrix of MJJA variables versus SOND rainfall and stream flow for Collie river catchment. Values significant at the 0.05 level of significance are shown with *.

Variables MJJA	Stream flow (SOND)	Rainfall SOND
MEI	-0.044	-0.2390
NINO3	-0.0737	-0.2448
NONO12	0.0860	-0.0930
NINO3.4	-0.2124	-0.3503*
NINO4	-0.1790	-0.14247
SOI	0.36289*	0.4410*
IOHPS	-0.2827*	-0.3509*
IOHLN	-0.5073*	-0.5357*
IOHLT	0.4728*	0.3955*
IOHP & IOHLN	0.53118*	0.5792*

5. Conclusion

Several studies have explored that ENSO has strong impact on climate signals over many part of the world. However, several other climate variables and approach can be used in seeking relationship with rainfall and stream flow. Here, in this study we identify the relationship between COA indices and rainfall and stream flow in collie river catchment. The results in this study suggest that the rainfall and stream flow variability is linked with COA indices. Rainfall and stream flow in Collie river catchment were maximum when Indian Ocean high pressure system was located most to the west (low longitude), whereas minimum when Indian Ocean high pressure system was located most to the east (high longitude), i.e. Zonal moment of Pressure system significantly influenced on the rain fall and stream flow. The early winter MJJA rainfall and stream flow in Collie river catchment had a strong significant correlation with Indian Ocean High pressure (IOHPS) and Indian Ocean High longitude (IOHLN).A statistical model of MJJA rainfall and stream flow volume discharge in Collie river catchment explains 51.08% of the observed rainfall and 36.86% of the observed stream flow variances during 1976 to 2008.

Australia rainfall, drought and stream flow strongly related with ENSO activity; however it is not that strong to consider for predicting climate variables accurately in western Australia. In eastern Australia it can be use to predict rainfall to some extent in spring and stream flow in north Australia with some success several months ahead [5]. Lag correlations for MJJA variables versus SOND rainfall and stream flow are shown in Table 3. MJJA Indian Ocean High pressure system is strongly correlated with the SOND rainfall and stream flow, suggesting that there is link between SOND rainfall and stream flow and COA indices and can be exploited for rainfall and stream flow forecast. This study of rainfall and stream flow in Collie river catchment suggests another methodology for diagnosing global and Australian climate change.

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