Journal of Science and Technology

COA Induced Rainfall-Streamflow Variability in Warren River: Case Study

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Abstract

Previous studies have linked ongoing winter drought in Southwest Western Australia (SWWA) to changes in local, as well as large-area, sea-level pressure. This paper examines the linkages between changes in the Indian Ocean High and rainfall-streamflow in Warren river basin in Southwestern Australia. The highest mean central pressure (MCP) of Indian Ocean High Pressure (IOHP) associated with decreased wintertime rainfall-streamflow and lowest MCP of IOHP associated with increased wintertime rainfall-streamflow. It was also found that east-west shifts in the position of this subtropical Indian Ocean high significantly influence winter rainfall-streamflow in Warren river. (IOHP and IOHLN) explain 29% variability of stream flow while SOI explains only 19%.

Keywords: coa induced, rainfall-streamflow; indian ocean high

1. INTRODUCTION

Ever since the last of middle century, a statistically conspicuous decline in the rainfall in southwest western Australia has been reported in myriad number of studies [1,2,3,4,5]. This decline accounts not only for having negative bearing on economic activities, but dearth of deciphering the dynamics pertaining to this trend may skew the predictive capacity of SWWA climate forecasts, Hence impacting its influence on water resource management and agriculture planning [2]. What causes steep decline in the rainfall in SWWA, over the last century, is still a question for open debate. There are vague agreements, namely, it goes hand in hand with natural variability, the greenhouse effect, or other anthropogenic influence, such as land clearing or pollution. Some authors have opined that sharp fall is caused by variation in vegetation cover [6,7,8,9] while a separate guild suggest connection with Indian Ocean climate change [10] or changes in regional mean Sea level pressure [1,10]. Increased greenhouse effect and natural variability have been deemed as contributing factors in decreased rainfall by IOCI (2002).

The El Nino Southern Oscillation (ENSO) activity has developed a nexus with climate change throughout many parts of the world (e.g. [12,13,14,15]). The rainfall fluctuation could mainly be attributed to ENSO activity across disparate Spatio-temporal scale. Therefore, streamflow which is comprehensive integrators of rainfall over vast areas may be connected with ENSO activity. An extensive analysis of these and other efforts is available in [12].

Conversely to ENSO the centers of action (COA) are large semi permanent pressure systems observed in the global distribution of sea level pressure Rossby *et. al.* (1939) namely, the Azores High or Icelandic Low, occupying the atmospheric circulation covering large region. The key point noted by Rossby was that changes not only in pressure, but the longitudinal and latitudinal position of Indian Ocean High Pressure System effectuate regional circulation. Three indices described by COA approach: the longitudinal and latitudinal positions of its center of gravity and its central pressure. Opposite to ENSO, the COA methodology puts into use information about positions along with pressure. As a result, it provisions vast extent of freedom which in turn directly expounds the regional climate variability. Recently, the COA approach has been found to be useful in investigations of a number of regional phenomena. The inter-annual variability of Gulf Stream northwall position has higher correlation with the longitude position of the Icelandic Low than with the North Atlantic Oscillation (NAO) [16]. The Greenland Tipjet, which is associated with deep water formation in the Irminger Sea, is related to the latitude position of the Icelandic Low [16]. Variations in winter rainfall in northern South Asia are related to changes in Icelandic Low pressure [11]. Winter rainfall in Southwestern Australia significantly influence with Indian Ocean High [16]. The winter streamflow in Donnely river in Southwestern Australia has higher correlation with the pressure and Longitude position than with the Southern Oscillation [17]. Our significant outcomes suggest that SWWA rainfall and streamflow variation implies COA as major player instead of ENSO.

1.1 Data Description

Rainfall and streamflow data were obtained from Department of Water (DOW) Western Australia for a period of approximately 33 years between 1976- 2008 in the Warren river basin (Perup river and Wilgarup river). We compare rainfall with streamflow in upper and lower Warren catchments so we have included Dombakup Brook river observations but for large missing values we have availed only twelve years dataset 1988-1999 only. Monthly averaged gridded SLP data from NCEP reanalysis [18] were used for calculating objective COA indices for the monthly averaged pressure, latitude and longitude of the Indian Ocean High and the South Pacific High systems as described by [16]. Other global climate indices obtained from Climate prediction center.

1.2 Study Area and Catchments Description

The upper warren catchments at Perup river has annual volume discharge approximately 12240 ML similarly at wilgarup river, its annual volume discharge approximately 24646 ML (see Figure 1) the highest volume discharge at Wilgarup rivers due to its catchments location. Statistical information play major role in establishing a notion for climatic patterns of this region. Figure 2 shows the mean monthly rainfall totals and their variance 1951-2008 of Warren River catchments. As can be seen, the majority of rainfall is received in May-October (MJJASO). This trend of a seasonal rainfall sometime also known as Cool season rainfall. Next to 80 percent of annual rainfall takes place in cool season from May to October [19]. Rainfall in the months of summer is evidently low with Dec-Feb only receiving averages of 17 mm and 16 mm, respectively. Average annual rainfall totals range from 850 mm to 900 mm for this catchments. Spatial and temporal analysis has shown that the strongest COA-induced rainfall variability occurs during the early part (MJJA) of Cool season months but also some significant variance shows in September and minor change in October. It has also been shown that COA-induced variability within these catchments is substantially magnified in streamflow in comparison to that induced in rainfall.

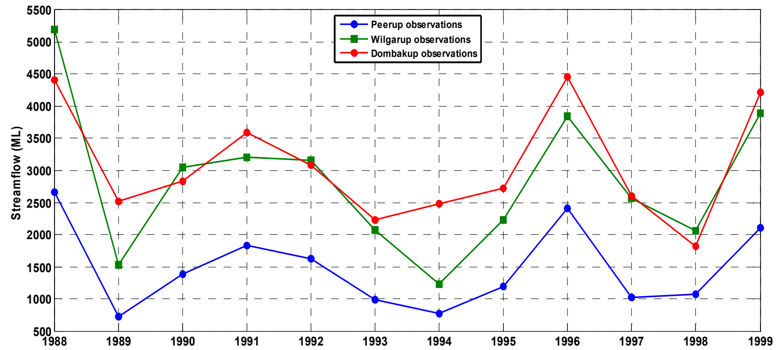

Figure 1: The time traces of the annual (January to December) streamflow at Perup river, Wilgarup river and at Dombakup brook (lower Warren river)

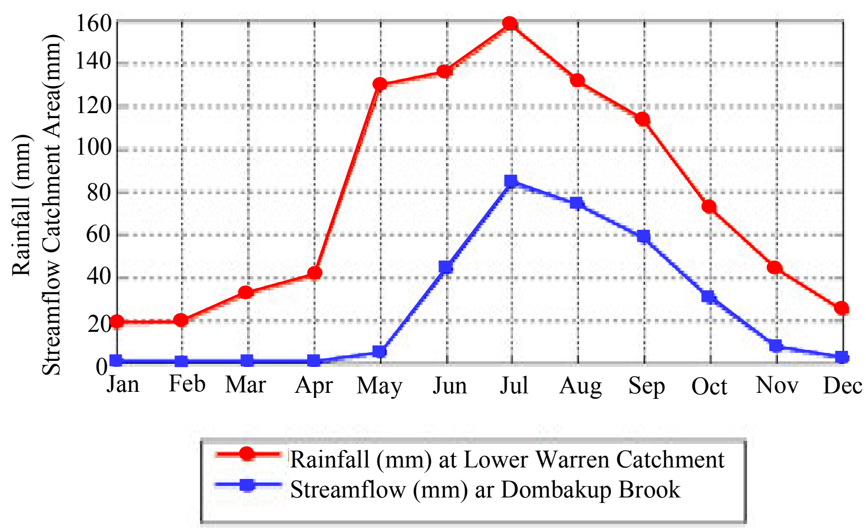

Figure 2: The seasonal cycle of rainfall and streamflow in lower Warren river station number 607155. The rainfall and streamflow were estimated on records from 1988 to 1999. The streamflow has been normalized by the catchments area (118.54 km^2) and has been presented in units of millimeters for easy comparison with rainfall.

2. METHODOLOGY

An estimate of the influence of atmospheric pressure fluctuations on rainfall variability over Australia can be attained through a quantitative assessment of the fluctuation in the pressure and locations of the Indian Ocean High and the South Pacific High, the two atmospheric centres of action that flank Australia. The pressure index I_p of a High pressure system can be defined as an area-weighted pressure departure from a threshold value over the domain (I, J) as suggested by [16].

$$I_{p,\Delta t} = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\left(P_{ij,\Delta t} - P_t\right)\cos\phi_{ij}\delta_{ij,\Delta t}}{\sum_{i=1}^{I}\sum_{j=1}^{J}\cos\phi_{ij}\delta_{ij,\Delta t}}$$

Where $P_{i\,j,\,\Delta t}$ is the SLP value at grid point (i, j) averaged over a time interval Δt, in this case monthly SLP values are taken from NCEP reanalysis, P_t is the threshold SLP value (P_t = 1016 hPa for both the Indian Ocean High and the South Pacific High), ϕ_{ij} is the latitude of the grid point (i, j). $\delta = 1$ if $(P_{i\,j,\,\Delta t} - P_t)>0$ and $\delta = 0$ if $(P_{i\,j,\,\Delta t} - P_t) <0$. This ensures that the pressure difference is due to the High pressure system. The intensity is thus a measure of the anomaly of the atmospheric mass over the section (I, J). The domain of the Indian Ocean High was chosen as 10^{o}S to 45^{o}S and 40^{o}E to 120^{o}E and that of the South Pacific High as 10^{o}S to 45^{o}S and 160^{o}E to 70^{o}W. The domains of the two Highs and their threshold values P_t were chosen by examining their geographical ranges in NCEP Reanalysis data over the period 1948-2006. Similarly, the latitudinal index is defined as:

$$I_{\phi,\Delta t} = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\left(P_{ij,\Delta t} - P_t\right)\phi_{ij}\cos\phi_{ij}\delta_{ij,\Delta t}}{\sum_{i=1}^{I}\sum_{j=1}^{J}\left(P_{ij,\Delta t} - P_t\right)\cos\phi_{ij}\delta_{ij,\Delta t}}$$

and the longitudinal index $I_{\lambda,\,\Delta t}$ is defined in an analogous manner.

3. RESULTS AND DISCUSSION

3.1 Impact of IOHP and IOHLN on Winter Rainfall and Streamflow in Warren River

The impact of IOHPS on catchments rainfall analyze by selecting the 16 years out of 33 years when Seasonal mean central pressure (MCP) of IOHP system was maximum. Similarly selecting those 16 years out of 33 years when the seasonal (MCP) of IOHPS was minimum. Figure 3 shows that when the MCP was maximum, there were fewer amounts of rainfall and vice versa. The mean rainfall trend in MJJA shows the highest amount of rainfall received by the catchments was approximately 130 mm when the seasonal (MCP) was minimum and it was around 1019.93 hpa, Similarly when seasonal mean central pressure was maximum 1020.68 hpa the rainfall received by the catchments was minimum and it was around 116 mm. The influence of Zonal movement of the high pressure system on Warren river catchment's rainfall is clearly evident from Figure 4 and 5. Figure 4 suggests that changes in the longitudinal position of the Indian Ocean High pressure has dominant influence on winter rainfall in Warren river. As we described above the displacement of longitudinal position in subtropical Indian Ocean effectuates the regional circulation [17]. The influence of IOHLN on catchments rainfall analyze by selecting the 16 years out of 33 years when seasonal pressure located most to the west. Similarly selecting those 16 years out of 33 years when Indian Ocean High Pressure center located most to the east. When the MCP of Indian High was shifted towards most to the west then catchments receive more rain on the contrary the Indian Ocean High center shifted towards most to the east then catchments received less rainfall. The influence on rainfall when the center of high pressure system located most to east were in the opposite sense of that for center of high pressure system located most to west.

Figure 5 describes the streamflow pattern in MJJA when the MCP of IOHPS was maximum there were less streamflow at Wilgarup river (upper warren catchments) and vice versa. The minimum Seasonal mean central pressure (MCP) of IOHPS in MJJA was around 1020.43 hpa and average seasonal maximum streamflow was approximately 9.5 mm. Similarly the maximum seasonal mean central pressure of IOHPS was around 1020.68 hpa then streamflow was 6.72 mm. Figure 6 suggests that Warren catchments streamflow is significantly influenced by zonal movement of Indian High. When the Indian High was shifted towards most to the west then catchments has more streamflow but when the Indian Ocean High center shifted towards most to the east then catchments streamflow reduced. The highest seasonal average streamflow in MJJA is approximately 10.11 mm and the center of high pressure was located most to the west The longitudinal position of IOH was at 67.66 E, Similarly the minimum streamflow approximately 6.6 mm when the center of High pressure was located most to the east and the longitudinal position was 72.18 E.

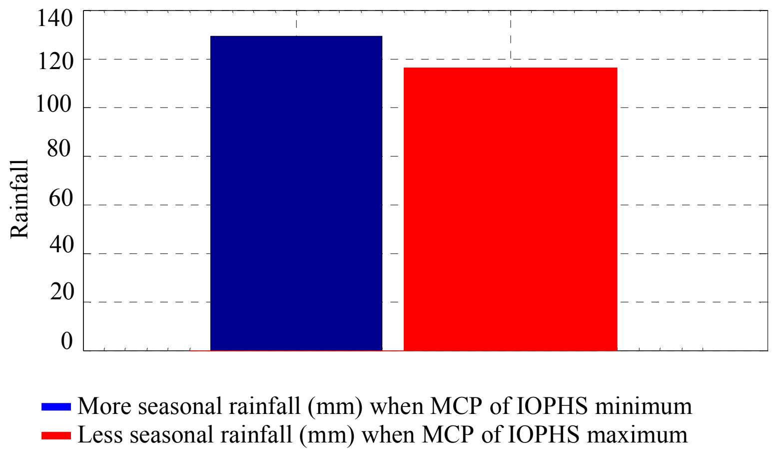

Figure 3: The average seasonal rainfall in the Upper Warren River catchments during the 16 years with highest pressure (less rain) and 16 years with lowest Pressure (more rain) based on records from 1976 to 2008

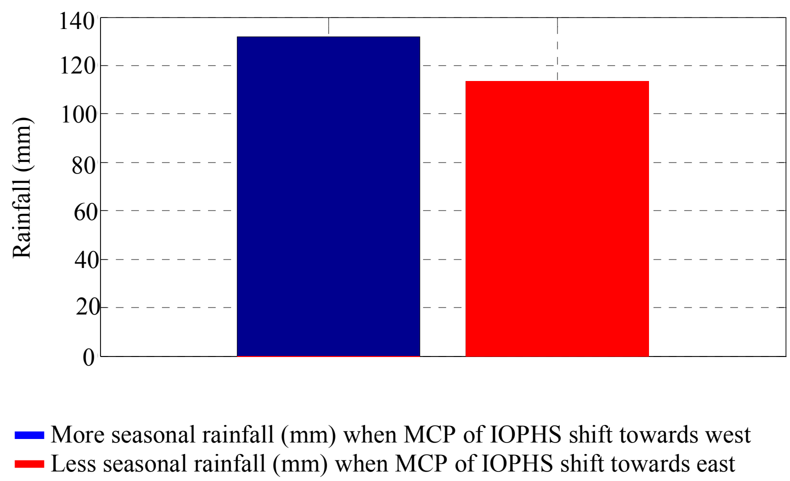

Figure 4: The average seasonal rainfall in the Warren River catchments during the 16 years when Center of IOHPS located most to West (more rain) and 16 years when Center of IOHPS located most to East (less rain) based on records from 1976 to 2008.

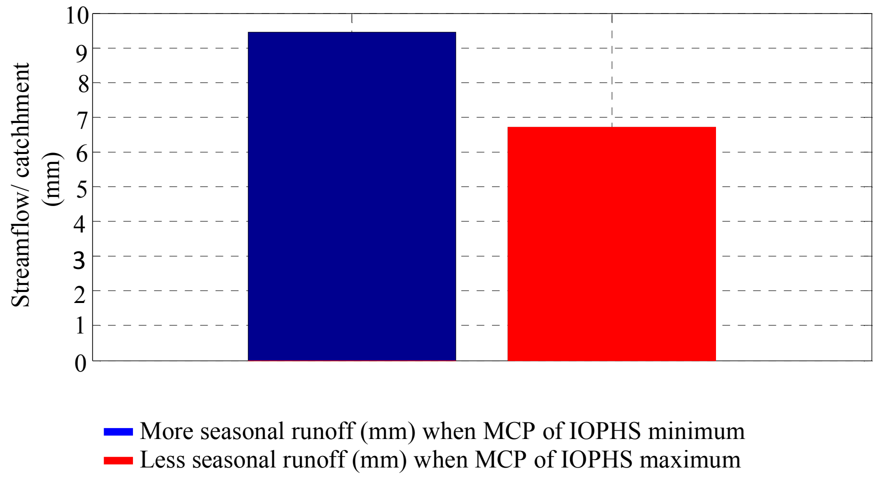

Figure 5: The average seasonal streamflow at (Wilgarup river) Upper catchments of Warren river normalized by its catchments area along the Warren river in SWWA during the 16 years with lowest pressure and 16 years with highest pressure

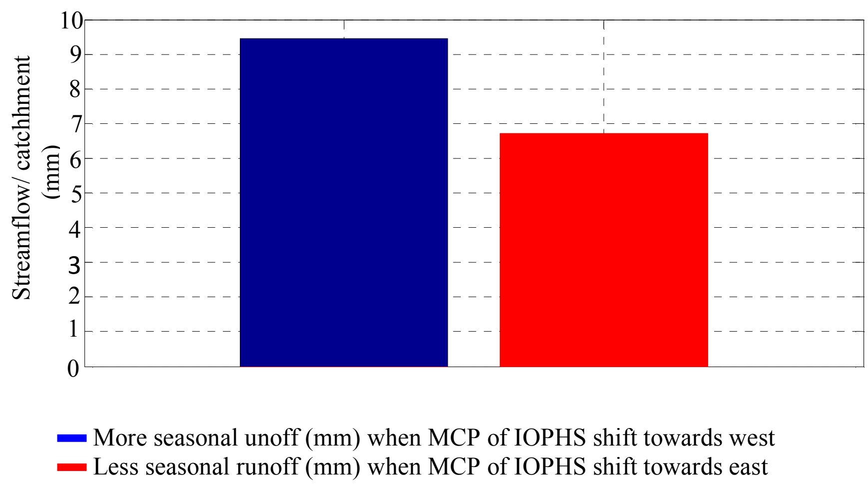

Figure 6: The average seasonal streamflow (mm) in the Warren River catchments during the 16 years when Center of IOHPS located most to West (more streamflow) and 16 years when Center of IOHPS located most to East (less streamflow) based on records from 1976 to 2008

3.2 Correlation Analysis of Streamflow in Warren River

Table 1 describes the significant correlation between IOH and ENSO with rainfall and streamflow. The Warren river basin rainfall and streamflow both are significantly influenced by zonal movement of Indian High as well as IOHPS. The negative correlation implies that when the Indian Ocean High Pressure maximum there is less rainfall and streamflow observed. Similarly when the Indian High shifted to the east there is less rainfall and streamflow over upper Warren catchments and vice versa. The correlation b/w SOI and streamflow at Perup river is 0.48 which is significant at $P < 0.01$ level. The correlation matrix describe in Table 2 for COA indices and ENSO indicators we note that the IOHP and IOHLN are independent of each other while the ENSO indicators are statistically significantly correlated with both the COA indices and other ENSO indicators. An interesting question is whether the IOH Pressure and IOH longitude provide independent information about precipitation and streamflow in the Warren river. Therefore we construct linear model of wintertime streamflow at Perup river. Streamflow = 1506 - 1.45 *IOHPS - 0.270 *IOHLN. R^2 for this regression is 0.29, a significant enhancement over the SOI value of R^2=0.19 which shows that SOI has a weaker influence by comparison with R^2=0.29. Moreover, the regression with Indian Ocean High captures some of the major patterns of observed wintertime volume discharge variations from 1976-2008 at Perup river (see Figure 7). The decline in streamflow volume discharge maximum in 1993 is reproduced by the regression model. During 1990-2000 volume discharge at Perup river fluctuated in a narrow range. Figure 8, shows that the IOH was locked in a narrow range of east-west fluctuations during these years. The subsequent increase in precipitation during the 1980s is also captured by the regression model. However, the estimated values for 2001-2006 are much larger than the observations.

The correlation b/w SOI and streamflow at Wilgarup river is 0.46 which is significant at $P<0.01$ level we also construct linear model of wintertime streamflow at Wilgarup river Streamflow= 1608232 - 1554 IOHPS - 271 IOHLN. R^2 for this regression is 0.25. A significant enhancement over the SOI value of R^2=0.21 which shows that SOI has a weaker influence by comparison with R^2=0.21. Moreover, the regression with Indian Ocean High captures some of the major patterns of observed wintertime volume discharge variations from 1976 to 2008 at Wilgarup river. The decline in streamflow volume discharge maximum in 1993 is reproduced by the regression model. During 1993-2000 volume discharge at Wilgarup river fluctuated in a narrow range. Figure 8 shows that the IOH was locked in a narrow range of east-west fluctuations during these years. The subsequent increase in discharge during the 1980s is also captured by the regression model. However the estimated values for 2001-2006 are much larger than the observations. We have observed significant statistical trend in streamflow at Perup river and in Precipitation of Warren river.

Therefore we need to detrending the data at Wilgarup river streamflow and Warren river precipitation and after detrending we have obtained the significant correlations.

Table 1: Correlation matrix of MJJA precipitation and streamflow at perup and wilgarup river.

Parameters	Precipitation	Detrended	Treamflow (Perup river)	Streamflow (Wilgarup river)	Detrended
Time	-0.54	0	-0.22	-0.28	0
IOHLN	-0.54	-0.57	-0.44	-0.42	-0.45
IOHPS	-0.49	-0.38	-0.42	-0.41	-0.39
MEI	-0.37	-0.29	-0.41	-0.4	-0.42
NINO3.4	-0.36	-0.33	-0.33	-0.37	-0.33
NINO4	-0.36	-0.28	-0.33	-0.33	-0.35
NINO3	-0.33	-0.31	-0.28	-0.27	-0.31
NINO12	-0.22	-0.22	-0.11	-0.08	-0.13
IOHLT	0.25	0.27	0.41	0.4	0.42
SOI	0.45	0.39	0.48	0.46	0.46
IOHPS & IOHLN	0.72 (52%)	0.70 (50%)	0.53(29%)	0.50(25%)	0.48(24%)

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.

	IOHPS	IOHLN	MEI	NINO3	NINO3.4	NINO4	NINO12
IOHLN	0.14						
MEI	0.445	0.158					
NINO3	0.352	0.222	0.87				
NINO3.4	0.369	0.25	0.86	0.904			
NINO4	0.4	0.122	0.813	0.684	0.883		
NINO12	0.228	0.149	0.767	0.861	0.619	0.39	
SOI	-0.403	-0.335	-0.815	-0.727	-0.843	-0.808	-0.493

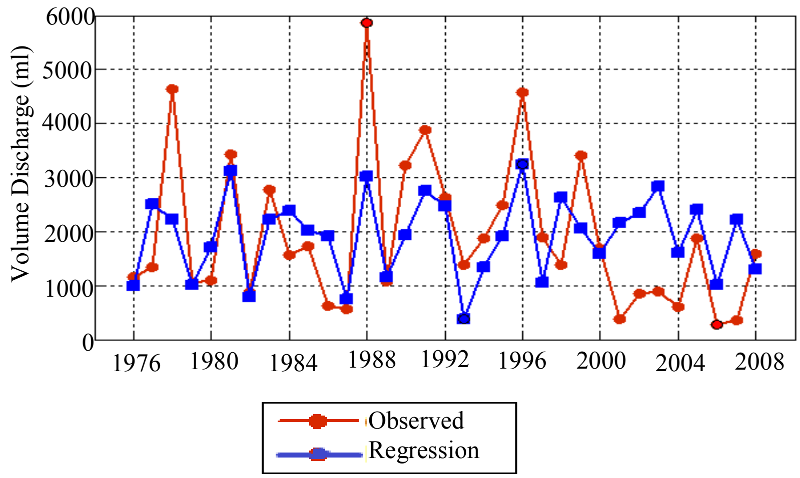

Figure 7: Perup River Volume Discharge (ML) in (MJJA) compared with regression with IOH longitude.

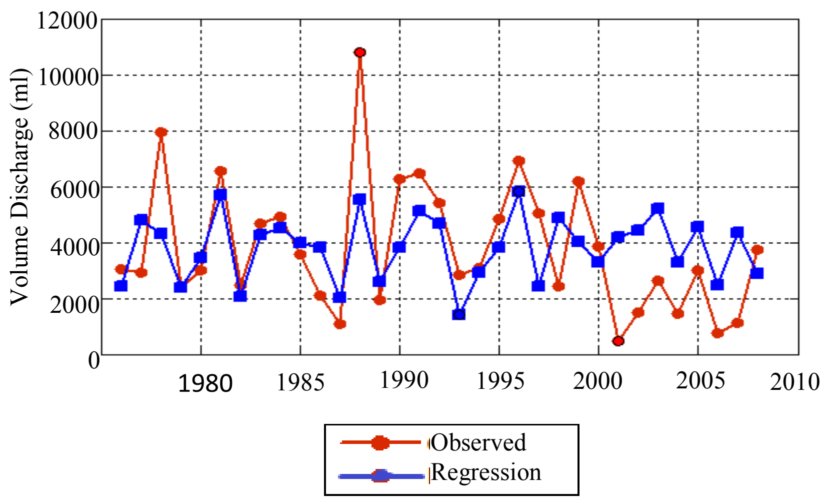

Figure 8: Wilgarup River Volume Discharge (ML) in (MJJA) compared with regression with IOH longitude

3.3 Lag Correlations and Implications for Forecasting

In this section we analyze the lag correlations between streamflow and IOHP and SOI in the previous season to forecast streamflow in Warren river. The forecasts can benefit the management of water resources systems considerably, particularly in Australia where the streamflow variability is higher than elsewhere in the world ([3,20,21]). The lag correlations between Sep-Oct-Nov-Dec streamflow versus May-Jun-Jul-Aug IOHP and SOI in the Warren river of southwest coast division are statistically significant 99% confidence level. The lag correlation between streamflow and IOHP is -0.54 while the correlation between streamflow and SOI is 0.47. The ENSO-hydroclimate teleconnection is particularly strong in Australia and can be exploited to forecast rainfall and streamflow several months ahead but our calculations suggest that IOHPS has dominating impact and better to forecast streamflow in SWWA. Therefore, when the hydroclimate-IOHP relationship is relatively strong the relationship can be used to provide long lead-time forecasts in Southwest coast division.

4. CONCLUSION

Previous researchers have identified increases in sea-level pressures in southwest Western Australia as the immediate cause of the ongoing drought in this region. The present paper has examined this relationship in terms of the dynamics of the Indian Ocean High pressure system. Specifically, it was found that east-west shifts in the position of this subtropical high significantly influence winter rainfall and streamflow in Warren river. When the Indian Ocean High shifts to the west, rainfall and streamflow in Warren river increases, and vice versa. In addition, rainfall and streamflow is significantly and negatively correlated with the area-averaged pressure of the Indian Ocean High. The pressure and the longitude position of the IOH are not significantly correlated with each other. A statistical model of MJJA streamflow in Warren river using the IOH pressure and longitude as independent variables is presented. It explains 29 per cent of the observed streamflow variance while SOI explains on 19% variability during 1976–2008. The lag correlation between streamflow and IOHP is -0.45 while the correlation between streamflow and SOI is 0.40. It is noteworthy that winter streamflow in SWWA is much more sensitive to changes in the pressure and longitudinal position of the Indian Ocean High than it is to fluctuations of sea surface temperatures as represented by the Indian Ocean Dipole. The results presented in this paper offer an alternate pathway to diagnosing the role of global climate change in the progression of drought in Southwest Western Australia.

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