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THE RELATIONSHIP BETWEEN INDIAN OCEAN HIGH PRESSURE AND RUNOFF VARIABILITY IN THE DONNELLY RIVER CATCHMENT IN SOUTHWEST WESTERN AUSTRALIA: A CASE STUDY

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This paper investigates the relationship between changes in the Indian Ocean High Pressure and the runoff variability in Donnelly river catchment of Southwest Western Australia (SWWA). Significant outcomes suggests that the intensity as well as the Zonal movement of Indian ocean high pressure significantly influence on winter stream flow. When Indian ocean high pressure shifted towards West, stream flow in Donnelly river increases, and vice versa. The multiple correlation between stream flow and Indian Ocean High Pressure (IOHP & IOHLN) is 0.48, while correlation between Southern Oscillation Index (SOI) is 0.40. Centers of Action (COA) indices explains 21% stream flow variability while Southern Oscillation Index (SOI) explains only 15% stream flow variability.

Keywords: El-Nino Southern Oscillation, Centers of action, Indian ocean high pressure, Indian ocean high longitude, Southern oscillation index.

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]. This decline accounts not only for having negative bearing on economic activities in Western Australia, 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 [3]. As for stream flow [4] investigated the impacts of climate variability on stream flow in the region and concluded that any changes over the long term were part of natural climate variability. The dry trend currently observed in the climate of the south-west region has been mainly attributed to the influences of natural climate variability, and the effect of El Nino-Southern Oscillation events [5]. The rainfall fluctuation could mainly be attributed to ENSO activity across disparate Spatial-temporal scale. Therefore, stream flow, which is comprehensive integrators of rainfall over vast areas, may be connected with ENSO activity. Water resource management can be brought about by creating a linkage between ENSO and stream flow.

The large-scale semi-permanent High and Low pressure centers which are prominent on a global map of monthly averaged sea level pressure were called the ‘‘Centers of Action’’ (COA) by Rossby, et.al. (1939), [6]. A key point noted by Rossby et al. (1939) [6] the changes in pressure as well as the position of a center of action influence regional circulation. In the scheme used in this paper a COA is characterized by three indices representing its area averaged longitude, latitude, and pressure. Recently, the centers of action approach has been found to be useful in investigations of a number of regional phenomena. Hameed et al. (2004) [7] showed that the inter-annual variability of Gulf Stream north wall position has higher correlation with the longitude position of Icelandic Low than with the North Atlantic Oscillation (NAO). The variability of the transport of Saharan dust to the tropical Atlantic in winter has a higher correlation with the latitude position of the Azores High than with the NAO and the transport of dust to the Caribbean islands in summer is governed by the longitude of the Azores High [8]. The Greenland Tipjet which is associated with deep water formation in the Irminger sea is related to the latitude position of the Icelandic Low [9]. Variations in winter rainfall in northern South Asia are related

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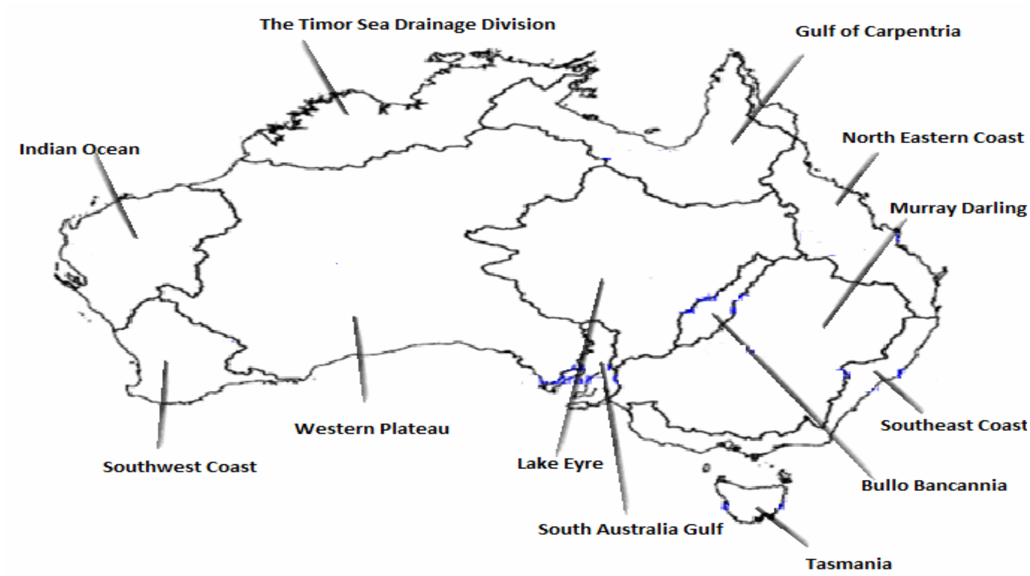

Figure 1. Australian drainage divisions and river basins.

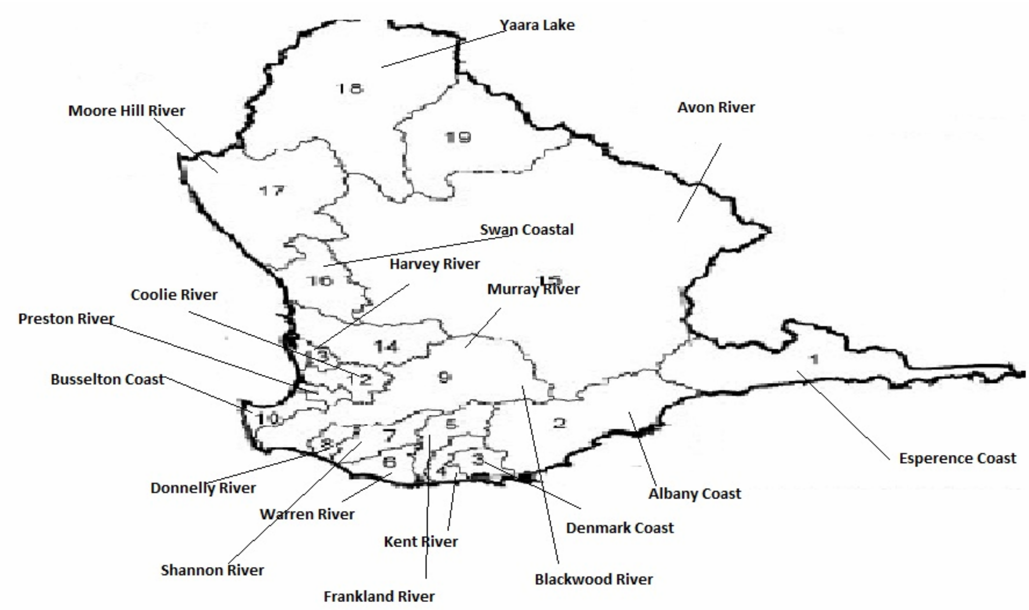

Figure 2. South west coastal drainage divisions and river basins.

to changes in Icelandic Low pressure [10]. The main objective of this study is to examine the runoff variability in Donnelly river catchment of South-west Western Australia using the centers of action approach.

2. Study Area and Catchment Description

Australia is divided into 12 major drainage divisions (Figure 1). Donnelly river is one of the major rivers in South west coast division (SWWA) and it is located on coastal fringe of SWWA (Figure 2). The main tributaries of the Donnelly River are Barlee Brook and Carey Brook. It originates between bridgetown and manjimup. The river flows for approximately 151 km has a full catchment area of approximately 1725 km^2, which encapsulates the towns of bridgetown and manjimup (Figure 3) and finally discharging into the Indian Ocean. The mean annual flow is approximately 14183 Mega liters.

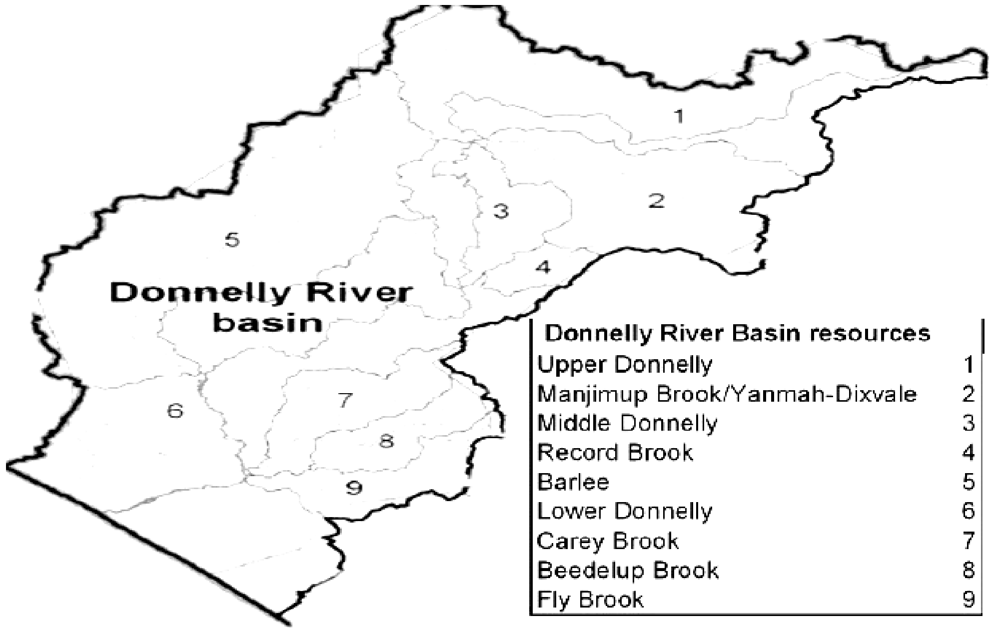

Figure 3. Locality map of the Donnelly river catchment.

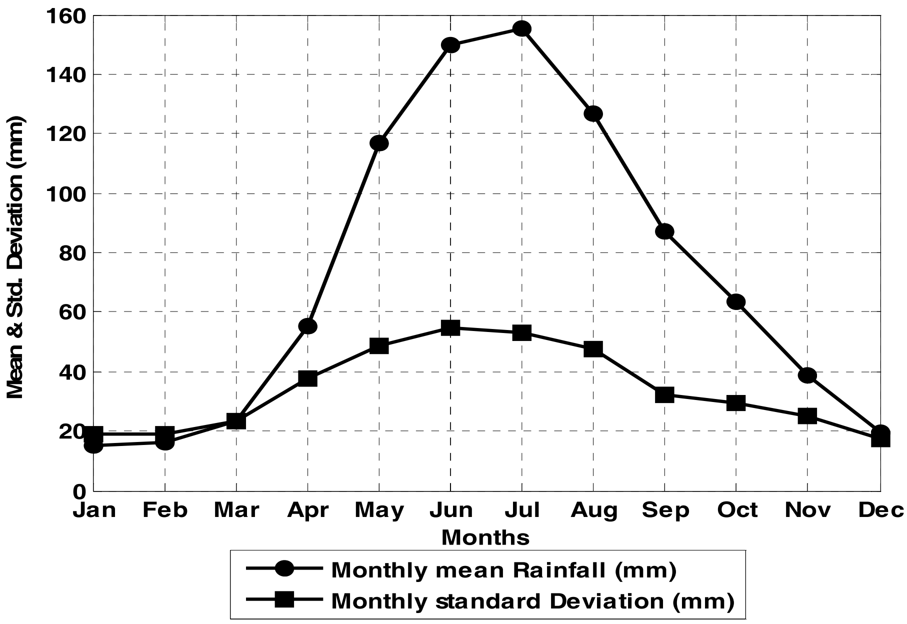

Figure 4. Mean and standard deviation of monthly rainfall totals for the lower Donnelly river catchment from 1951−2008. Note : Overlap point described that March shows no variance and its mean and variance both are same.

Figure 4 describes the mean monthly rainfall and their variance since 1951−2008. The maximum rainfall received during May-October (MJJASO). This trend of a seasonal rainfall sometime also known as Cool season rainfall [11]. Rainfall in summer is very low because the climate is typically Mediterranean. Temperatures across the catchment vary depending on the proximity to the coastline and latitude. Places further south and inland have more variation in temperature. Figure 5 shows that average maximum temperature in January is around 38 °C, similarly, average minimum temperature in July is 8 °C. Figure 6 describes the rainfall−stream flow patterns in Donnelly river catchment.

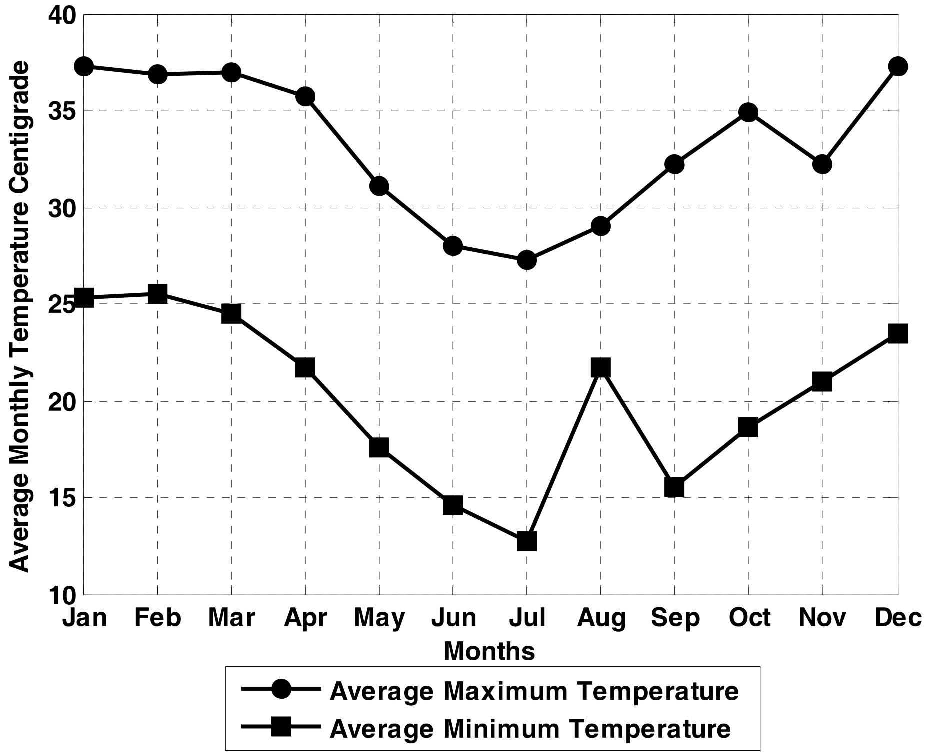

Figure 5. Monthly Temperature for Donnelly river catchment based on bureau of meteorology data from 1951-2008.

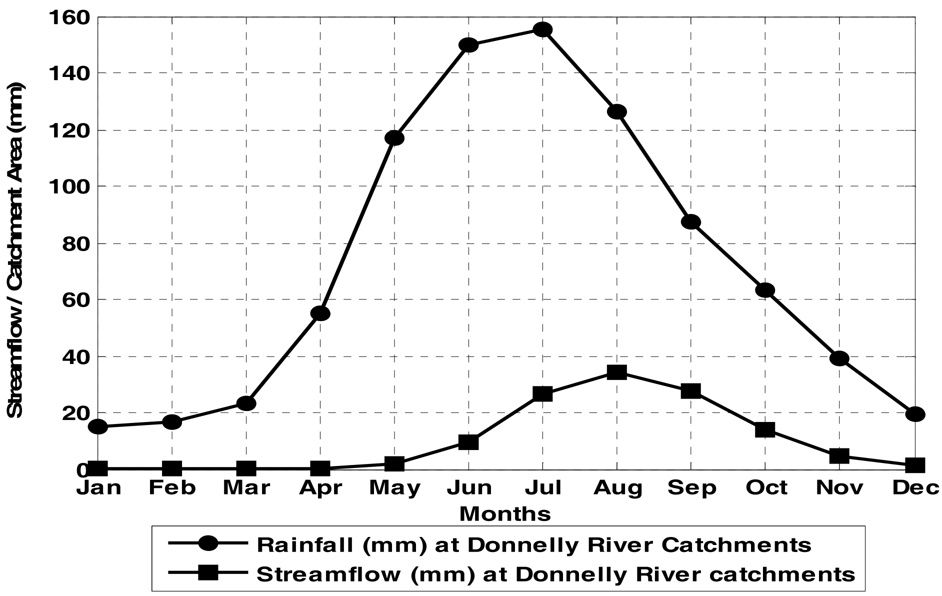

Figure 6. The seasonal cycle of catchment rainfall and stream flow in lower Donnelly river catchment station number 608151.

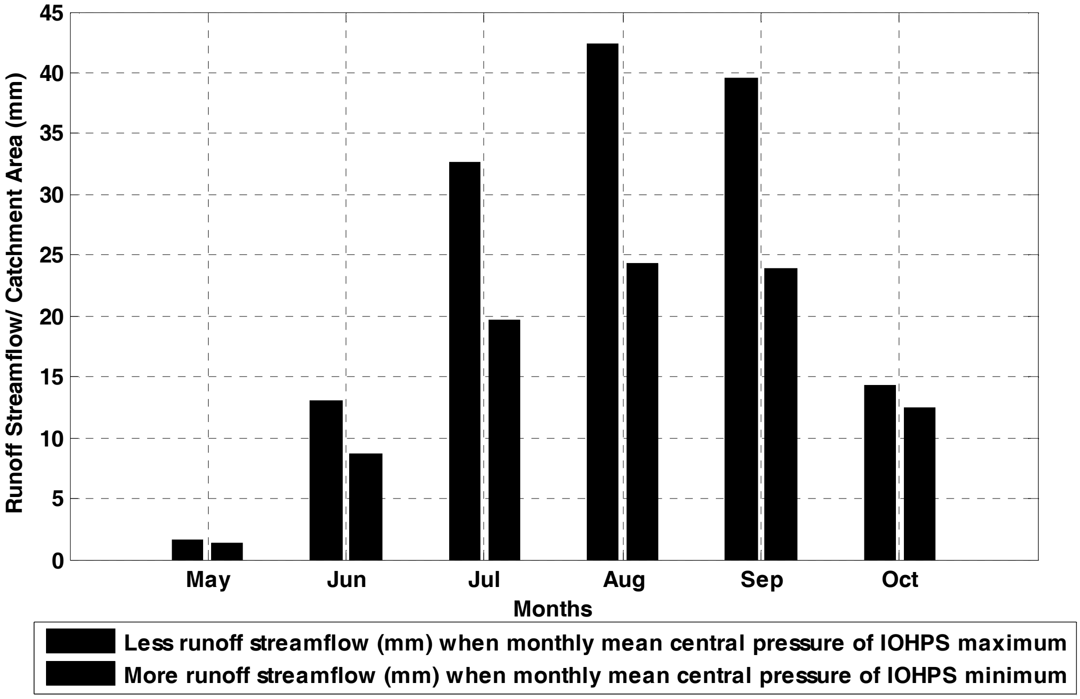

Figure 7. The average monthly runoff at Donnelly river catchment.

3. Data

3.1. Stream Flow Data

Monthly stream flow data were obtained from Department of Water (DOW), Western Australia. For easy comparison between rainfall and stream flow in mm unit, stream flow data were normalized by dividing its catchment area.

3.2. Climate Indicators

Monthly averaged gridded SLP data from NCEP reanalysis [12] used for calculating objective COA indices for the monthly averaged pressure, latitude and longitude of the Indian Ocean High by using COA methodology [7]. The sea-surface-temperature (SST) based indices of NINO12, NINO3, NINO3.4 and NINO4 were used as indices for ENSO obtained from Climate prediction center. The Multivariate ENSO Index (MEI) (Wolter & Timlin, 1993, 1998) is employed. Monthly Southern Oscillation Index (SOI) values used in this study were obtained from the National Climate Centre of the Australian Bureau of Meteorology.

4. Analysis of Indian Ocean High Pressure influences on runoff in Donnelly River Catchment

This section investigates the influence of IOHPS on runoff stream flow at Donnelly river using data for the period from 1976 to 2008.

4.1. Monthly Influence

Average of monthly stream flow was calculated for 10 years out of 33 years when Indian High Pressure was maximum and while selecting those 10 years out of 33 years when the mean monthly central pressure of IOHPS was minimum (Figure 7). We observe that when the monthly mean central pressure of IOHPS was maximum there were less amount of runoff in the river, Similarly for all months when the monthly mean central pressure of IOHPS was minimum there were more amount of runoff in the catchment. Clearly, it demonstrate that the intensity of Indian Ocean High pressure has impact on runoff in Donnelly river catchment. Figure 7 shows that there is significant runoff in Donnelly river during May to October.

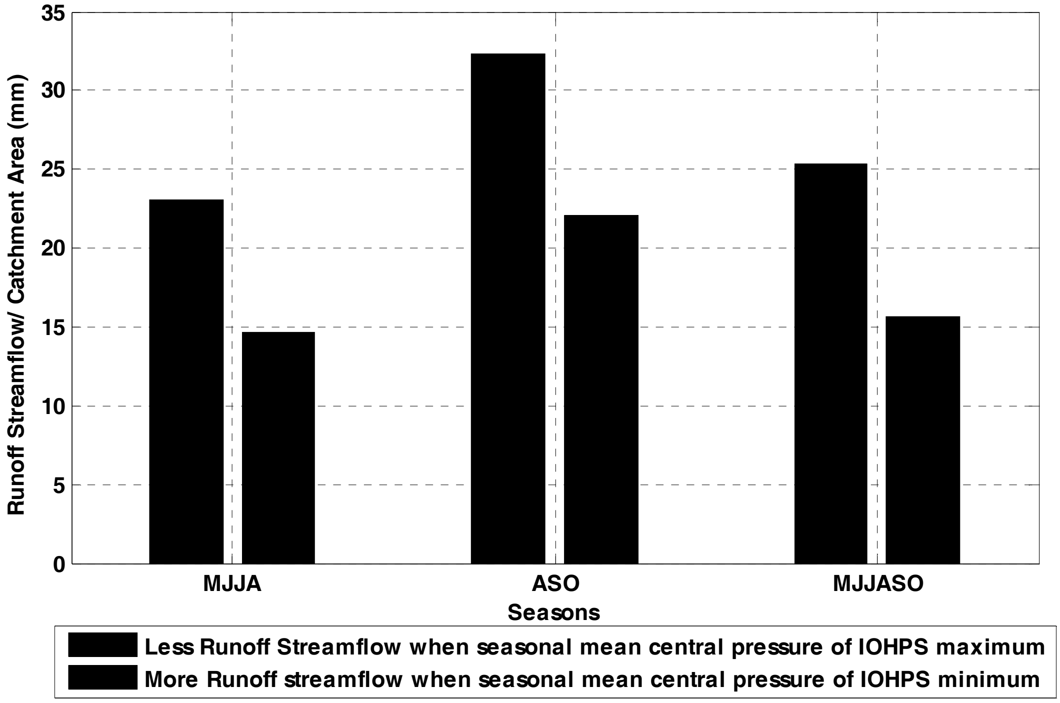

Figure 8. The average seasonal runoff at) in the Donnelly river catchment.

4.2. Seasonal Influence

As shown in Figure 8, during winter (May - October) when the mean central pressure of IOHPS was maximum there were less stream flow, Similarly when the mean central pressure of IOHPS was minimum there were more stream flow at Donnelly river catchment. The minimum seasonal mean central pressure of IOHPS in (MJJA) around 1019.7 mb and average seasonal maximum runoff approximately 23.033 mm, similarly the maximum seasonal mean central pressure of IOHPS around 1020.86 mb then runoff was 14.69 mm. Again, our calculations suggest that Indian ocean High pressure has influence on winter run off in Donnelly river catchment.

5. Impact of Indian Ocean High Longitude on Runoff in Donnelly River Catchment

5.1. Monthly Influence

The influence of Indian Ocean High Longitude (IOHLN) on catchment runoff analyze by selecting the 10 years out of 33 years, when then monthly mean central pressure of Indian Ocean High Pressure system located most to the West (Low longitude), similarly, selecting those 10 years out of 33 years when monthly mean central pressure of Indian Ocean High Pressure system located most to the East (High Longitude).

Figure 9 suggests that changes in the longitudinal position of the Indian Ocean High pressure has major influence on runoff stream flow in Donnelly river catchment. When the Indian Ocean High center shifted towards most to the West then catchment has more runoff. On contrary, when the Indian Ocean High center shifted towards most to the East then catchment has less runoff. This pattern is consistent throughout the Winter season (MJJASO). The maximum streamflow occurs in July which is approximately 42 mm when the center of high pressure system (calculated from 10 years average of lowest longitude) located at 66.37 °E (Low Longitude) and its far from SWWA. For the same month when the center of high pressure system (calculated from 10 years average of highest longitude) located at 74.57 °E (High Longitude) and its located towards SWWA the catchment has minimum runoff and it approximately 19 mm. The influence on stream flow 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 throughout the Winter.

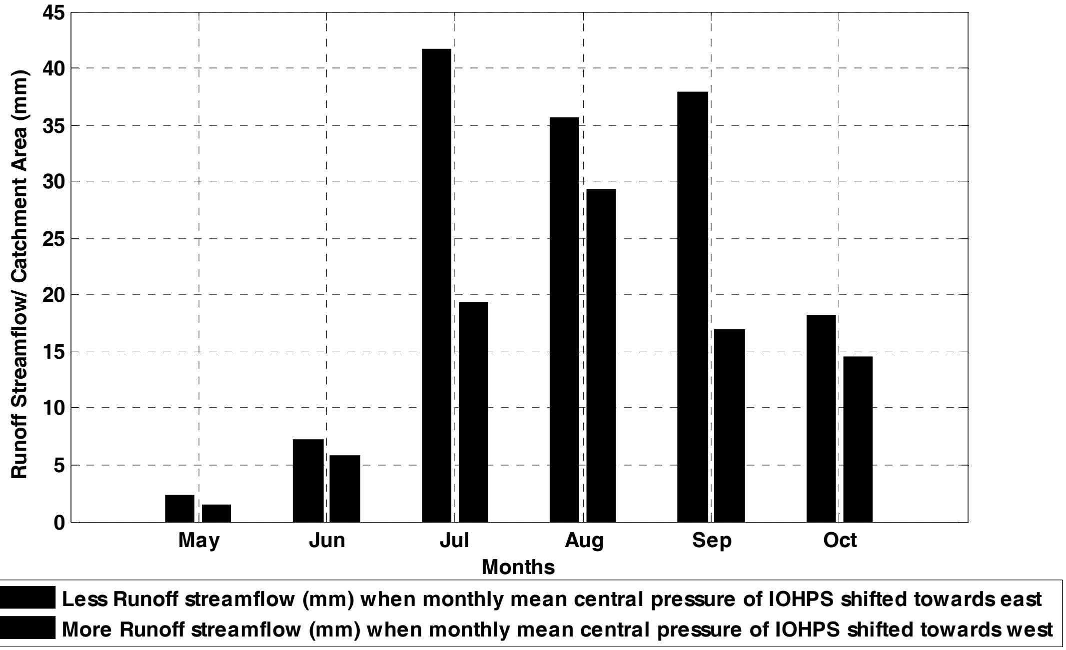

Figure 9. The average monthly runoff (mm) in the Donnelly river catchment.

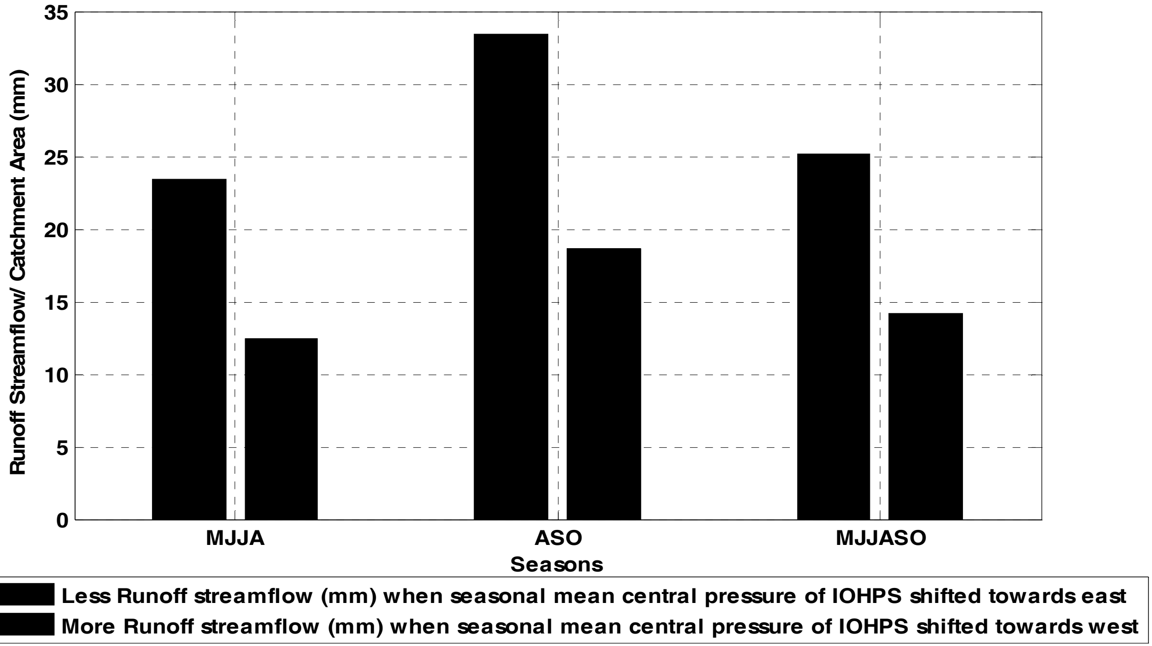

Figure 10. The average seasonal runoff (mm) in the Donnelly river catchment.

5.2. Seasonal Influence

When the center of high pressure system shifted towards West (Low Longitude) maximum seasonal stream flow occurs, similarly, when the center of High pressure shifted towards East (High Longitude) the minimum seasonal stream flow occurs. These calculations suggests that when the seasonal (MCP) located most to East (High Longitude) there were less streamflow in the Catchments (Figure 10). On contrary, when the mean seasonal (MCP) located most to the West (Low Longitude) there were more stream flow in the Catchments.

Table.1. Correlation Matrix of MJJA of runoff streamflow at Donnelly river catchment.

Parameters	Runoff (Donnelly River)
Time	-0.19
IOHLN	-0.41
IOHPS	-0.34
MEI	-0.23
NINO3.4	-0.35
NINO4	-0.32
NINO3	-0.29
NINO12	-0.08
IOHLT	0.33
SOI	0.40
IOHPS & IOHLN	0.48(23%)

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	0.1400						
MEI	0.4450	0.1580					
NINO3	0.3520	0.2220	0.8700				
NINO3.4	0.3690	0.2500	0.8600	0.9040			
NINO4	0.4000	0.1220	0.8130	0.6840	0.8830		
NINO12	0.2280	0.1490	0.7670	0.8610	0.6190	0.3900	
SOI	-0.4030	-0.3350	-0.8150	-0.7270	-0.8430	-0.8080	-0.4930

6. Correlation Analysis of Stream Flow in Donnelly River Catchment

The correlation between runoff stream flow and IOH pressure at Upper Donnelly catchment is -0.34 which is also significant at $p<0.01$ level. Similarly the correlation between winter runoff stream flow and Indian High Longitude at Upper Donnelly river is -0.41 which is significant at $p<0.01$ level. The Donnelly river catchment stream flow is significantly influenced by zonal movement of Indian High Longitude as well as IOHPS. The negative correlation implies that when the High is shifted to the east there is less runoff stream flow over upper Donnelly catchment and vice versa. The correlation between SOI and runoff stream flow at Donnelly river is 0.40 which is significant at $P<0.01$ level. The Correlation Matrix for COA indices and ENSO indicators are shown in Table 2 where it is noted that the Indian Ocean High pressure (IOHPS) and Indian Ocean High longitude (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 runoff stream flow in the Donnelly river catchment. As Indian Ocean High pressure and Indian Ocean longitude are mutually independent, Therefore, we construct linear model of winter runoff stream flow at Donnelly river: Runoff Stream flow = 3974857.704- 3819.141 (IOHPS) - 914.961 (IOHLN). With R^2 for this regression is 0.23, a significant enhancement over the SOI value of $R^2=0.15$ which shows that SOI has a weaker influence by comparison with $R^2=0.23$. Moreover, the regression with Indian Ocean High captures some of the major patterns of observed wintertime volume discharge variations from 1976 to 2008

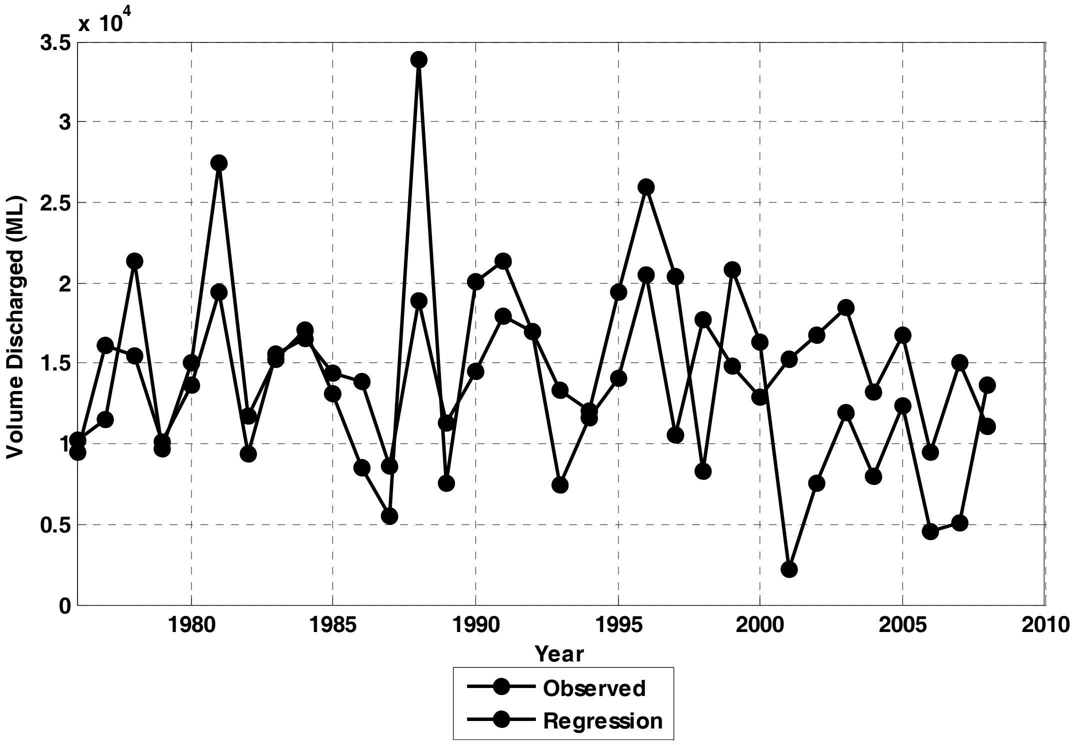

Figure 11. Donnelly river volume discharge (Mega Liters) in (MJJA) compared with regression with IOH longitude.

at Donnelly river (Figure 11). The decline in stream flow volume discharge maximum in 1993 is reproduced by the regression model. During 2001-2008 volume discharge at Donnelly river fluctuated in a narrow range. Figure 11 shows that the IOH was locked in a narrow range of east-west fluctuations during these years. The subsequent increase in volume discharged during the 2001-2008 is also captured by the regression model.

7. Conclusion

The results demonstrate the fact that runoff stream flow in the Donnelly River catchment is strongly influenced by COA indices. It is found that the Zonal movement of subtropical Indian Ocean high has significantly influence on stream flow in Donnelly river catchment. When the Indian Ocean High shifts towards the West (Low Longitude), runoff stream flow in Donnelly river (SWWA) increases, and vice versa. The Winter stream flow had a strong correlation with Indian Ocean High Pressure (IOHP) and Indian Ocean High Longitude (IOHLN), both were significant at the 99% confidence level. A statistical model of MJJA stream flow volume discharged in Donnelly river using the Indian Ocean high pressure and Indian Ocean high longitude as independent variables is presented. It explains 23 % of the observed stream flow variance during 1976–2008. 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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References

[1] P.B. Wright, Mon. Weath. Rev. **102** (1974) 219.

[2] N. Nicholls and B. Lavery, Int. J. Climatol. **12** (1992) 153.

[3] N. Nicholls and L. Chambers, IOCI Report, 3rd (1999) 251.

[4] S. Rodgers and J. Ruprecht, Water and Rivers Commission (1999) 55.

[5] A. Kevin, 9th IPCC Conference (2011) 161.

[6] Rossby et.al., J. Marine Res. **2** (1939) 38.

[7] S. Hameed and S. A. Piontkovski, Geophys. Res. Lett. **31** (2004) L09303.

[8] O. M. Doherty, N. Riemer and S. Hameed, J. Geophysical Research **113** (2008) D07211.

[9] F.M. Bakalian, S. Hameed and R. Pickart, Journ. Geophys. Res. (Oceans) (2006).

[10] M.J. Iqbal and K. Ilyas, Arabian Journal of Geosciences (2011), DOI 10.1007/s12517-011-0355-y.

[11] L. Fuqin, E. Chambers and Neville. Nicholls, Aust. Met. Mag. **54** (2005) 23.

[12] E. Kalnay, et al., Bull. Amer. Meteor. Soc. **77 (**1996) 437.

[13] R.J. Allan and M.R. Haylock, J. Climate **6** (1993) 1356.

[14] N. A. Amarasekera and ER. Williams, J. Hydrol. **200** (1997) 24.

[15] T.J. Ansell and K. Keay, Int. J. Climatol. **20** (2000) 1113.

[16] AWRC, 1965. Review of Australia's water resources 1963, Canberra.

[17] F.H.S. Chiew and T.A. McMahon, Hydrological. Sci. J. **47**, No. 3 (2002) 505.

[18] M.H Glantz, R. Katz and N. Nicholls, Cambridge University Press (1991).

[19] IOCI, Indian Ocean Climate Initiative, (2002) 34.

[20] D. A. Jones, W. Wang and R. Fawcett, Aust. Met. and Ocean. J. **58** (2009) 233.

[21] E. Kahya and JA. Dracup, Wat. Resour. Res. **29**, No. 8 (1993) 2491.

[22] E. Kahya and MC. Karabork, Int. J. Climatol **21** (2001) 1231.

[23] A.D. Knighton and G.C. Nanson, Second Ed. John Wiley & Sons, (1997) 185.

[24] A.D. Knighton and G.C. Nanson, J. Hydrol. **254** (2001) 102.

[25] T.J. Lyons, Smith, Bull Am. Met. Soc. **74** (1993) 1327.

[26] T.J. Lyons, Report No. SLUI **38** (2002).

[27] G.T. Narisma and A.J. Pitman, J. Hydromet. **4** (2003) 424.

[28] T. Piechota and J.A. Dracup, Water Resour. Res **32**, No. 5 (1996) 1359.

[29] TC. Piechota, JA. Dracup, F.H.S. Chiew and TA. McMahon, Water Resour. Res. **34** (1997) 3035.

[30] A.B. Pittock, Climatic Change **5** (1983) 321.

[31] CF. Ropelewski and MS. Halpert, Mon. Wea. Rev. **115** (1987) 1606.

[32] CF. Ropelewski and MS. Halpert, J. Climate **2** (1989) 268.

[33] J. Shukla and DA. Paulino, Mon. Wea. Rev. **111** (1993) 1830.

[34] HJ. Simpson and MA. Cane, Wat. Resour. Res. **29**, No. 11 (1993) 3671.

[35] I.N. Smith et al., Int. J. Climatol. **20** (2000) 1913.

[36] M.G. Smith and R.N.M. Dixon, Wat. Resour. Res. Technical Series No. WRT **32** (2006).

[37] CB. Uvo and NE. Graham, Wat. Resour. Res. **34**, No. 12 (1998) 3515.

[38] G. Wang and EAB. Eltahir, J. Climate. **12** (1999) 1726.

[39] W.H. Press, S.A. Teukolsky, W.T. Vetterling & B.P. Flannery, The art of scientific computing. Second Edition. Cambridge University Press (1992).

[40] A. Williams, Murdoch University, Honors. Thesis (1991) 240.

[41] Yu. et al., J. Hydrol. **262** (2002) 84.