British Journal of Applied Science & Technology
12(3): 1-9, 2016, Article no.BJAST.20100
ISSN: 2231-0843, NLM ID: 101664541

SCIENCEDOMAIN *international*
www.sciencedomain.org

Association between the Dynamics of Indian Ocean Subtropical High and Winter Time Precipitation and Stream Flow: A Case Study Over Acheron River Catchment, Victoria

Saqib Ur Rehman[1*], Kamran Khan[1] and Absar Ahmed[1]

[1]Mathematical Sciences Research Center, Federal Urdu University of Arts, Science and Technology, Karachi, Pakistan.

Authors' contributions

This work was a result of team work of all authors. Author SUR designed, supervised, finalized the mathematical/ statistical analysis and worked as senior author of the manuscript. Author AA performed mathematical/ statistical analysis and prepared the first draft of the study and managed literature searches. Author KK performed further worked on the study and changed it into final manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/20100
Editor(s):
(1) João Miguel Dias, Habilitation in Department of Physics, CESAM, University of Aveiro, Portugal.
Reviewers:
(1) Kabi Pokhrel, Tribhuvan University, Nepal.
(2) Bharat Raj Singh, Uttar Pradesh Technical University, Lucknow, India.
Complete Peer review History: http://sciencedomain.org/review-history/11668

Original Research Article

Received 11th July 2015
Accepted 14th August 2015
Published 5th October 2015

ABSTRACT

In this study, we explore the relationships between winter (May-August) Acheron River catchment (ARC), Victoria, Australia, rainfall and streamflow and winter Indian Ocean Subtropical High Pressure (IOSHPS) and Indian Ocean Subtropical High Longitude (IOSHLN) through correlation and regression analysis. Analysis is performed for the period of 1951-2011. It is found that the correlation of IOSHPS with winter ARC rainfall and streamflow are -0.46 and -0.33 respectively and IOSHLN are -0.54 and -0.57 are observed. Dynamics (zonal movements) of IOSHPS analysis showed that east-west shifts of IOSHPS are responsible for the variable amounts of rainfall receive in the ARC that resulted in variable streamflow. Regression analysis suggested IOSH indices describe 38% and 36% variability in rainfall (May-August) and streamflow (May-August) over ARC

**Corresponding author: E-mail: saqiburrehman@fuuast.edu.pk;*

respectively further investigations showed that southern oscillation index (SOI) and El-Nino southern oscillation (ENSO) have weak association independently as well as combination with IOSHLN than IOSH indices over ARC winter rainfall and streamflow.

Keywords: Regression analysis; streamflow; Indian Ocean subtropical high pressure; correlation.

1. INTRODUCTION

Generally the climate all over the world is changing and this change impacts on the earth surface. It is investigated that the climate is changing faster as compared to the historical records [1] and this may persist in the future as well [2]. The causes of climate change are numerous but one of them is global warming. The concentration of greenhouse gases is responsible for the increase in global warming. The greenhouse gases caused to rise the surface air temperature by 0.9℃ since 1910 in Australia [3]. The climate change causes to increase drought conditions as it associated with the decrease in precipitation, surface water and ground water level [4]. Drought over Australia have become more severe due to increase in temperature than average temperature since 1970s further investigations showed that rainfall over Victoria in winter and spring is projected to be more decrease while in summer and autumn moderately decreased and catchments situated in northeast and southwest of Victoria may experience up to 30% recession in runoff by 2030 [5]. Variability in southern annular mode (SAM) may be partly associated with the recent reduction in winter rainfall in southern south Australia, Victoria and Tasmania but it does not explain the long-term winter rainfall recession over southwest western Australia [6]. Timbal et al. [7] has found early winter (March-July) rainfall decline over south east Australia is associated with subtropical ridge (STR) intensity and its position since 1970s. Murphy et al. [8] found an indirect association of El-Nino southern oscillation (ENSO) and Indian Ocean with autumn rainfall decline over southeastern Australia. Kiem et al. [9] investigated the severe drought conditions over Victoria in autumn since mid of the 1990s, a Big Dry, and found these conditions are due to the increase of STR intensity and its southwards propagation further investigations also proved the contribution of ENSO and SAM. ENSO alone shows weak association with autumn streamflow over Victoria [10]. CSIRO [11] investigated that recession in streamflow have been as much as four-times the decline in rainfall observed in few parts of Victoria and this decline is mostly observed in autumn than in winter and spring. The association of southern annular mode is particularly play an important role in southwest and southeast of Australia rainfall and Indian Ocean Dipole (IOD) has influenced June-October rainfall of over southwest and southeast Australia [12]. Mean sea level pressure over Indian Ocean associated with the interannual variability between South west of Western Australia (SWWA) and South West of Eastern Australia (SWEA) rainfall variability [13]. IOSHPS and its east-west shifts over Indian Ocean influenced early winter (May-August) streamflow variability over southwestern Australia since the mid of the last century [14]. Precipitation over Southwest Western Australia is associated with mean central pressure (MCP) over Indian Ocean [15]. The aim of this study is to explore which of the climate driver(s), used in this study, is associated with the variability in winter (Mau-August) ARC rainfall and streamflow.

2. CATCHMENT AND DATA DESCRIPTION

This section of the study comprises on the catchment and data description used in this study. The Acheron River Catchment (ARC) is Perennial River of the Goulburn Broken catchment, part of the Murray-Darling basin (MDB), is located in the lower southeastern highland. The river bounded by Rubicon River Catchment from east and from west by Yea River Catchment. It starts to flow downstream from the Goulburn Weir and meet the Lake Eildon (Fig. 1). The ARC comprises 643 kilometers and covers an area of 629 Km^2. The mean annual flow remains 329 GL/yr and the seasonal (May-August) cycle show highly variable streamflow (Fig. 2). To analyze the streamflow pattern of ARC in its streamflow dominating season (May-August), the austral cool season, the monthly mean sea level (MSLP) pressure gridded (2.5 by 2.5) data was obtained from National Center of Environmental Prediction (NCEP) reanalysis [16] to calculate sea level pressure (over the region $(82.5^{\circ}\text{ to }137.5^{\circ}\text{E} - 10^{\circ}\text{ to }50^{\circ})$ based the Indian Ocean Subtropical High (IOSH) Indices (IOSHPS, IOSHLN and IOSHLT). The El-Nino southern oscillation (ENSO), sea surface temperature based indices, [17] and monthly averaged index for Southern Oscillation Index (SOI) were obtained from NCEP. Southern Annular Mode (SAM) (1957-2011) was obtained from the NERC Science of the Environment. Arctic oscillation (AO), Multivariate ENSO Index (MEI) [17], Pacific North American Index (PNA), Western Pacific Index (WP) and North Atlantic Oscillation (NAO) were obtained from Climate Prediction Center (CPC). The East Pacific/ North Pacific Oscillation (EP/NP) obtained from National Oceanic and Atmospheric Administration (NOAA). To analysis the variability in Acheron River streamflow (June-August) and its causes for recession, monthly streamflow observation data for satiation at Acheron River at Taggerty station (405209) and rainfall data (m) within the catchment were acquired from Bureau of Meteorology (BOM) for the period of 61 years (1951-2011). For the comparison between streamflow and rainfall, streamflow data then converted in millimeter (mm) unit through usual calculation.

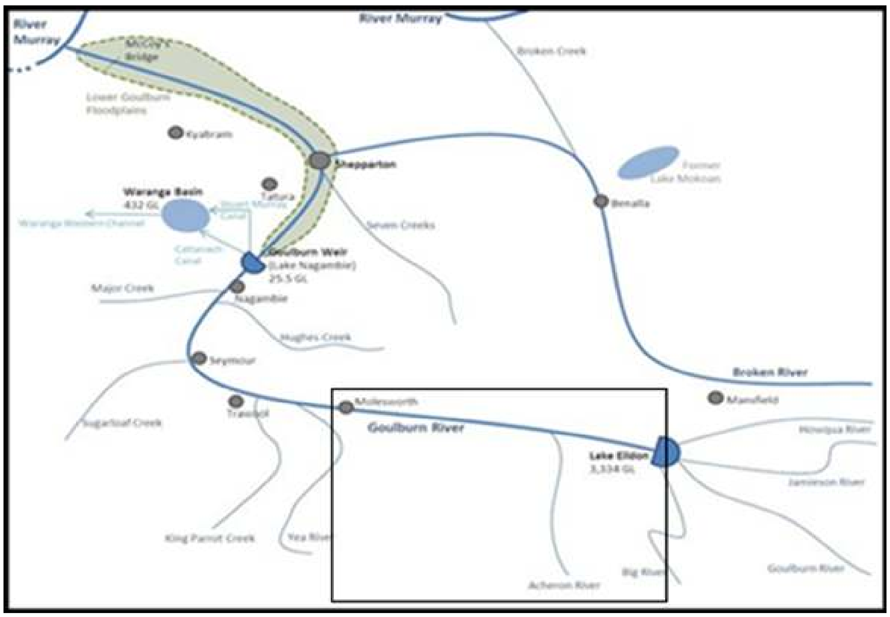

Fig. 1. Shows location map of Acheron River Catchment (ARC) Victoria, Australia and study area (rectangular box)

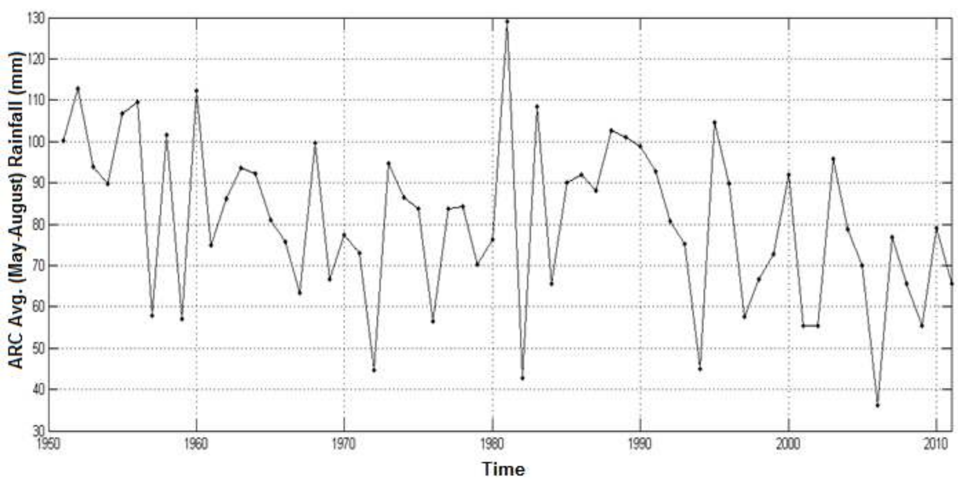

Fig. 2. Shows average seasonal (May-August) cycle of Acheron river catchment streamflow (1951-2011)

3. METHODS

Rossby et al. [18] investigated high and low pressure areas presented on a global map of averaged sea level pressure (SLP) which were named as 'Centers of Action' by him further investigations revealed that the variable intensities as well as changes of locations by these high and low pressure regions influenced the regional circulation and climate variability over adjacent continent. This manuscript presents a neat and simple methodology to evaluate the strengths and locate the centers of High pressure system over Indian Ocean which provides the more significant results comparatively to the results obtained by the application of previous methodology [19].

Table 1. Correlation matrix for the large scale climate indices with winter (May-August) rainfall and streamflow in Acheron River catchment

Indices	Rain (mm)	Streamflow (mm)
Time	-0.34	-0.37
IOSHPS	-0.46	-0.33
IOSHLN	-0.54	-0.57
AO	-0.01	0.00
SOI	0.49	0.42
Nino 3	-0.37	-0.38
Nino 3.4	-0.36	-0.32
Nino 4	-0.36	-0.31
MEI	-0.34	-0.39
NAO	-0.03	-0.07
EP/NP	-0.03	0.07
PDO	0.08	-0.10
PNA	0.05	-0.01
WP	-0.02	0.02
SAM	-0.21	0.11
IOD	-0.39	-0.49

Quantitative assessment of intensity and locations of the high pressure centers over the subtropical Indian Ocean represent by I_p, I_z, I_m. Mathematical equations (Definitions) of these indices are:

$$I_p(t) = \overline{P_{(x,y)}(t)} \quad (1)$$

$$I_z(t) = \overline{Z_{(x)}(t)} \quad (2)$$

$$I_M(t) = \overline{M_{(y)}(t)} \quad (3)$$

Where $I_p(t)$ is spatial average of pressure when monthly MSLP at a grid node $P_{(x,\ y)}$ in a specific time interval equaled or exceed from a given threshold value over the entire spatial domain such that $P_{(x,y)}(t) \geq p_t$. This ensures that the pressure values are considered for only the High pressure system, in this case monthly MSLP values are taken from NCEP reanalysis, $I_Z(t)$ and $I_M(t)$ are spatial average of corresponding positions of longitude and latitude addresses where $P_{(x,y)}(t) \geq p_t$ respectively. *Pt*= 1016 hPa is a threshold value for the Indian Ocean, Z_x(t) and M_y(t) are corresponding addresses of longitude and latitude when $P_{(x,y)}(t) \geq p_t$. The domain of the IOSH for this study was chosen as 10°S to 50°S and 82.5°E to 137.5°E. The domains of the High over Indian Ocean and its threshold value *Pt* was chosen by examining their geographical ranges in NCEP reanalysis data over the period 1951–2011.

4. LARGE SCALE DRIVERS AND ACHERON RIVER FLOW

To analyze the relationship between climate drivers and ARC rainfall and streamflow two techniques, correlation analysis and multi-linear regression analysis, are discussed in this section. Correlation analysis (Table 1 above) suggested ENSO indices, Indian Ocean Dipole (IOD), Southern Oscillation Index (SOI) and Indian Ocean Subtropical High (IOSH) indices showed association with both ARC streamflow and rainfall. Among the indices Indian Ocean subtropical High Longitude (IOSHLN) showed strong inverse association with both the dependent variables of ARC. All correlations (Tables 1, 2) are taken in this manuscript are significant at p<0.05 statistical significance level. The correlations of IOSHPS with rainfall and runoff are -0.46 and -0.33 respectively and IOSHLN are -0.54 and -0.57. Multicolinearity among the climate indices used in this study is shown in Table 2. IOSH indices are mutually independent (Table 2) and therefore two multi-linear regression models are constructed between ARC rainfall and IOSH indices (Rain = 12158 - 11.5 IOSHP - 3.60 IOSHLN) and between ARC streamflow and IOSH indices (Streamflow = 10063 - 9.19 IOSHP - 5.87 IOSHLN). Results obtained by multilinear regression analysis showed IOSH indices describe 38% and 36% variability in rainfall and streamflow (May-August) over ARC while SOI has weaker relationship with variability 15% and 22% rainfall and streamflow. IOSHLN and Nino 3.4 describes 31.5% and 33.6% variability of ARC rainfall and streamflow respectively while IOSHLN and Nino 4 explains 31.5% and 33.3% variability of ARC rainfall and streaflow respectively. IOSH indices also showed strong mutual correlation with rainfall (0.62) and streamflow (0.60). According to correlation and regression analysis, IOSH indices showed strong association with rainfall (May-August) and streamflow (May-August) over ARC.

5. DYNAMICS OF INDIAN OCEAN SUBTROPICAL HIGH PRESSURE AND ACHERON RIVER FLOW

Inverse correlation between IOSH indices with rainfall and streamflow over ARC means when mean central pressure (MCP) over Indian Ocean shifts towards east of Victoria less rainfall receives in ARC and this resulted in less streamflow and on the other hand when MCP remains at west of the state ARC receives more rainfall and resulted in more streamflow in ARC. To justify this relationship four possibilities of IOSH indices are compared with respective observed rainfall and streamflow within the catchment. These possibilities are defined as when MCP over Indian Ocean was maximum and minimum and when MCP was located in the east and west over Indian Ocean. To analyze first two possibilities, 10 years when MCP was minimum are taken from the study era (1951-2011) of IOSHPS index timseries and their mean is calculated this mean is the representative of minimum IOSHPS over Indian Ocean and then respective years of rainfall and streamflow (May-August) also calculated in the same way to compare with minimum IOSHPS. Similarly, representatives of maximum IOSHPS and respective rainfall and streamflow (May-August) are calculated. Obtained results are plotted in Fig. 3. It is evident (Figs. 3 and 4) when MCP (1019.79 mb) was manimum, maximum amounts of rainfall (129.08 mm) and streamflow (145.95 mm) are observed in the catchment and MCP (1020.89 mb) was maximum, less rainfall (75.18 mm) and streamflow (47.78 mm) received in ARC (May-August). Similarly (Figs. 5 and 6) more rainfall (109.63 mm) and streamflow (54.5 mm) observed when MCP shifted towards the west (100.17 longitudes) and less rainfall (56.93 mm) and streamflow (48.2 mm) received in the catchment when MCP observed in the east (113.44) near Victoria over Indian Ocean.

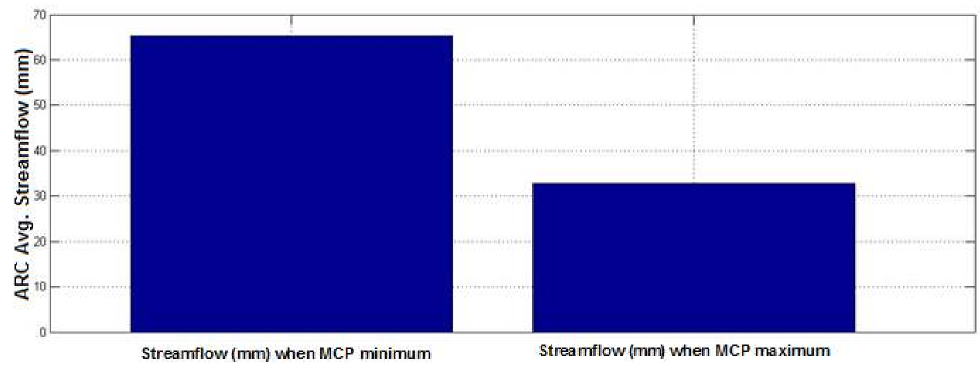

Fig. 3. The average seasonal (May-August) streamflow at ARC normalized by dividing its catchments area during the 10 years with highest pressure and 10 years with lowest pressure

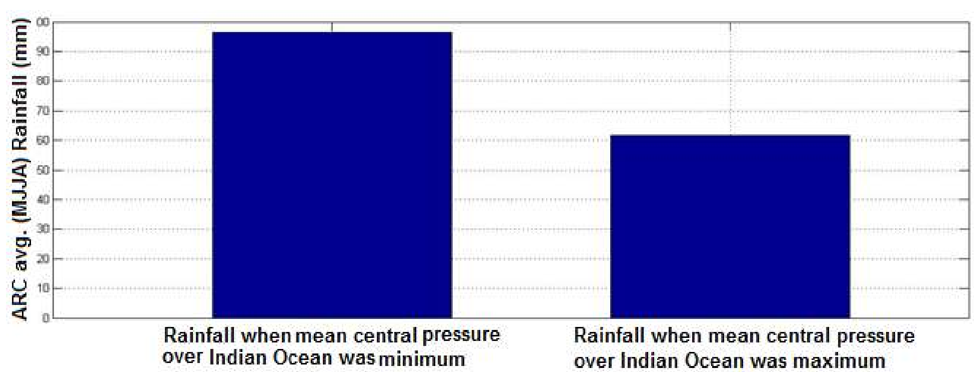

Fig. 4. The 10 years average seasonal (May-August) rainfall at Acheron River during the 10 years with highest pressure and 10 years with lowest pressure

Table 2. Correlation matrix for the large scale climatic drivers

	IOHP	IOHLN	AO	SOI	NINO 3	NINO 3.4	NINO 4	MEI	NAO	EP/NP	PDO	PNA	WP	SAM
IOHLN	0.27													
AO	-0.12	0.01												
SOI	-0.49	-0.43	0.18											
NINO 3	0.44	0.29	-0.26	-0.74										
NINO 3.4	0.41	0.26	-0.25	-0.84	0.91									
NINO 4	0.41	0.25	-0.11	-0.78	0.74	0.91								
MEI	0.47	0.31	-0.22	-0.81	0.92	0.90	0.80							
NAO	-0.10	0.05	0.68	-0.08	-0.07	-0.05	-0.01	-0.01						
EP/NP	0.15	-0.22	-0.24	-0.25	0.20	0.37	0.35	0.26	0.01					
PDO	0.35	0.19	-0.19	-0.40	0.47	0.48	0.49	0.65	-0.02	0.27				
PNA	0.13	0.14	-0.44	-0.11	0.18	0.18	0.18	0.23	-0.19	0.09	0.33			
WP	-0.04	-0.20	-0.04	-0.13	0.06	0.10	-0.04	0.06	0.15	0.16	-0.09	-0.12		
SAM	0.64	0.12	-0.01	-0.08	0.23	0.11	0.07	0.19	-0.10	-0.02	0.11	0.01	-0.05	
IOD	0.41	0.31	0.08	-0.54	0.45	0.42	0.32	0.40	0.18	-0.25	-0.04	-0.15	0.11	0.25

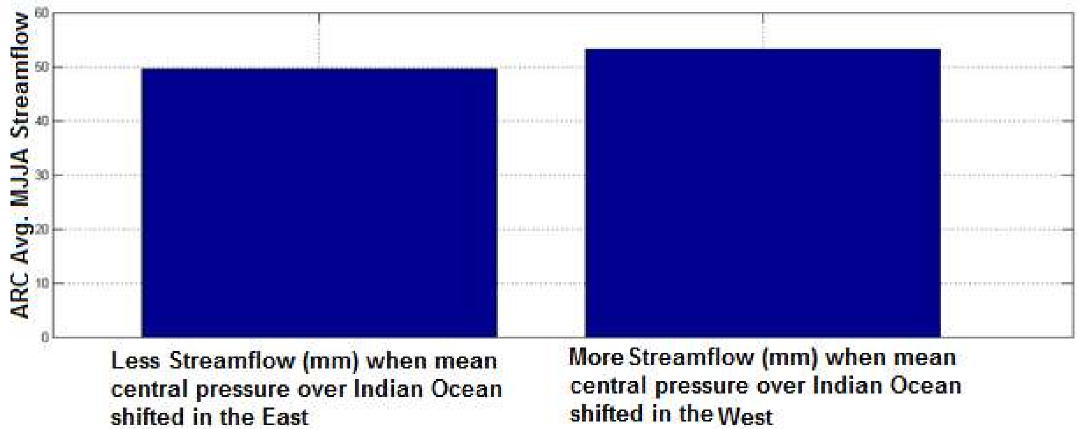

Fig. 5. The average (May-August) streamflow (mm) in Acheron river catchments during the 10 years when Center of IOSHPS located most to West (more streamflow) and 10 years when Center of IOSHPS located most to East (less streamflow) based on records (1951-2011)

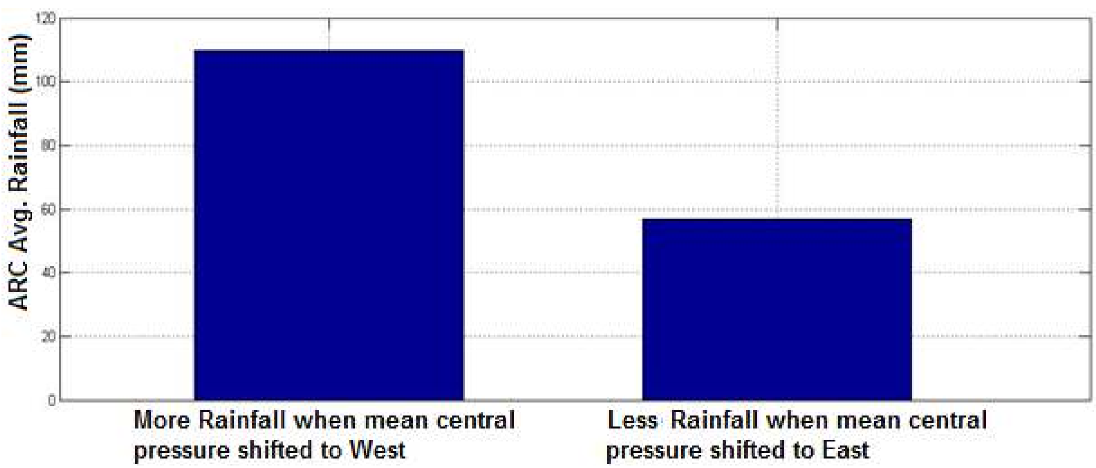

Fig. 6. The average (May-August) rainfall (mm) in Acheron River catchments during the 10 years when Center of IOSHPS located most to West (more rainfall) and 10 years when Center of IOSHPS located most to East (less rainfall) based on records (1951-2011)

6. CONCLUSION

The observations found in the above sections discussed and concluded here as the correlation analysis showed that IOSH indices have association with ARC winter (May-August) rainfall and streamflow (May-August). The correlation coefficients of IOSHPS with rainfall and streamflow were found -0.46 and -0.33 respectively and IOSHLN were -0.54 and -0.57 while Nino 3.4, Nino 4, SOI and IOD also showed significant correlations (Table 1). The correlation between the climate drivers also performed to check which predictors can be combine to form multilinear regression model (Table 2). According to correlation analysis between the predictors (Table 2), IOSHLN is found independent to other predictors except SOI and IOSHPS is found dependent to other predictors except IOHLN so two of the multilinear regression models, one with winter (May-August) rainfall and the other with winter (May-August) streamflow, are chosen which describe more of the winter (May-August) rainfall and winter streamflow (May-August) variability than the other multilinear models of the study. Multilinear analysis showed that IOSH indices describe 38% and 36% variability in rainfall (May-August) and streamflow (May-August) over ARC while SOI showed weak association with 15% and 22% variability in rainfall and streamflow respectively of the ARC. IOSHLN and Nino 4 explains 31.5% and 33.3%

variability of ARC rainfall and streamflow respectively. Correlation and regression analysis both suggest variability in rainfall (May-August) and streamflow (May-August) over ARC is strongly connected to variability in IOSH over the region (82.5° to $137.5^\circ E - 10^\circ$ to $50^\circ S$) of Indian Ocean. Dynamics (East-West shifts) of IOSHPS further clear its association with rainfall and streamflow over ARC. According to dynamics of IOSHPS analysis, when MCP moves in the west ARC receives more rainfall (May-August) and streamflow (Mau-August) on the other hand it receives less rainfall (May-August) and streamflow (May-August). On the basis of above discussion and observed results concluded as IOSH indices strongly associated with Rainfall (May-August) and streamflow (May-August) over ARC than the other climate variables of the study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Steffen W. Climate change 2009: Faster change & more serious risks. Department of Climate Change, Australian Government; 2009. ISBN: 978-1-921298-58-5.
2. Solomon S, Qin D, Manning M, Marquis M, Averyt K, Tignor MMB, Miller HLJ, Chen Z. Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change; 2007. ISBN: 978 0521 88009-1.
3. CSIRO and BOM. Climate change in Australia information for Australia's natural resource management regions: Technical report, CSIRO and Bureau of Meteorology, Australia; 2015;9. ISBN 9781921232947.
4. Jin C, Cant B, Todd C. Climate change impacts on wet lands in Victoria and implications for research and policy. Arthur Rylah Institute for Environmental Research Technical Report Series No.199. Department of Sustain ability and Environment, Heidelberg, Victoria; 2009. ISBN 978-1-74242-358-6.
5. CCV (Climate change in Victoria). Summary, Victorian Government. Department of Sustainability and Environment, Melbourne. 2008;5:9,13.
6. Meneghini B, Simmonds I, Smith IN. Association between seasonal Australian rainfall and the Southern annular mode. Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28. 2006;INPE:311-313.
7. Timbal B, Murphy B, Braganza K, Hendon H, Wheeler M, Clinton R. South Eastern Australia climate initiative. CSIRO; 2007. Final Report for Project 1.1.2.
8. Murphy BF, Timbal B. A review of recent climate variability and climate change in south eastern Australia. International Journal of Climatology; 2007.
   DOI: 10.1002/joc.1627.
9. Kiem SA, Verdon-Kidd CD. Towards understanding hydroclimatic change in Victoria, Australia – Preliminary insights into the "Big Dry", Hydrol. Earth Syst. Sci. 2010;14:433–445.
10. Kiem SA, Verdon-Kidd CD. Climatic drivers of Victorian streamflow: Is ENSO the dominant influence? Australian Journal of Water Resources. 2009;13:17–30.
11. CSIRO. Climate variability and change in south-eastern Australia: A synthesis of findings from phase 1 of the South Eastern Australian Climate Initiative (SEACI). 2010;12-13.
12. Risbey JS, Pook JM, McIntosh CP, Wheeler CM, Hendon HH. 2008, monthly weather review. 2009;137:3233-3253. DOI: 10.1175/2009MWR2861.1.
13. Hope P, Timbala B, Fawcett R. Associations between rainfall variability in the southwest and southeast of Australia and their evolution through time, International Journal of Climatology; 2009. DOI: 10.1002/joc.1964.
14. Rehman S. Influence of Indian Ocean high pressure on streamflow variability over southwestern Australia. Annals of Geophysics. 2014;57(2):2.
    DOI: 10.4401/ag-6398.
15. Hameed S, Iqbal JM, Rehman S, Collins D. Impact of the Indian Ocean high pressure system on winter precipitation over western and southwestern Australia. Australian Meteorological and Oceanographic Journal. 2011;61:159–170.
16. Kalnay E. The NCEP/NCAR 40-year reanalysis project. Bull. Amer. Meteor. Soc. 1996;77:437-471.
17. Wolter K, Timlin MS. Measuring the strength of ENSO - How does 1997/98 rank. Weather. 1998;53:315-324.

18. Rossby CG. Relation between variations in the intensity of the zonal circulation of the atmosphere and the displacement of the semi-permanent centers of actions. J. Marine Res. 1939;2:38–55.

19. Hameed S, Shi W, Boyle J, Santer B. Proceedings of the First International AMIP Scientific Conference, Monterey, California, WCRP. 1995;92:221.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/11668