5-21-2017

Precipitation and Indian Ocean Climate Variability-ACase Study on Pakistan

Kazi Ali Tamaddun
University of Nevada, Las vegas, tamaddun@unlv.nevada.edu

Ajay Kalra
Southern Illinois University, kalraa@siu.edu

Waqas Ahmed
Mehran University of Engineering and Technology, wapathan.uspcasw@faculty.muet.edu.pk

Ghulam Hussain Dars
Mehran University of Engineering and Technology, ghdars.uspcasw@faculty.muet.edu.pk

Steve Burian
University of Utah, steve.burian@utah.edu

See next page for additional authors

Citation Information

Tamaddun, K. A., Kalra, A., Ahmed, W., Dars, G. H., Burian, S., Ahmad, S. (2017). Precipitation and Indian Ocean Climate Variability-ACase Study on Pakistan. 526-535. Sacramento, California: World Environmental and Water Resources Congress 2017.
https://digitalscholarship.unlv.edu/fac_articles/445

Authors
Kazi Ali Tamaddun, Ajay Kalra, Waqas Ahmed, Ghulam Hussain Dars, Steve Burian, and Sajjad Ahmad

Precipitation and Indian Ocean Climate Variability – A case study on Pakistan

Kazi Ali Tamaddun[1], Ajay Kalra[2], Waqas Ahmed[3], Ghulam Hussain Dars[4], Steve Burian[5], Sajjad Ahmad[6]

[1]Department of Civil and Environmental Engineering and Construction, University of Nevada, 4505 S. Maryland Parkway, Las Vegas, NV 89154-4015, USA; Phone: (702) 490-1284; email: tamaddun@unlv.nevada.edu

[2]Department of Civil and Environmental Engineering, Southern Illinois University, 1230 Lincoln Drive, Carbondale, IL 62901-6603; Phone: (618) 453-7008; email: kalraa@siu.edu

[3]US-Pakistan Center for Advance Studies in Water, Mehran University of Engineering and Technology, Jamshoro, Pakistan; Phone: +92 22 2772250 Ext: 6506; email: wapathan.uspcasw@faculty.muet.edu.pk

[4]US-Pakistan Center for Advance Studies in Water, Mehran University of Engineering and Technology, Jamshoro, Pakistan; Phone: +92 22 2772250 Ext: 6506; email: ghdars.uspcasw@faculty.muet.edu.pk

[5]Department of Civil and Environmental Engineering, University of Utah, Salt Lake City, UT 84112-0561, USA; Phone: (801) 585-5721; email: steve.burian@utah.edu

[6]Department of Civil and Environmental Engineering and Construction, University of Nevada, 4505 S. Maryland Parkway, Las Vegas, NV 89154-4015, USA; Phone: (702) 895-5456; email: sajjad.ahmad@unlv.edu

ABSTRACT

The study evaluated the relationship between two climate variability indicators – sea-surface temperature (SST) and 500-mbar geopotential height (HGT/Z_{500}) – and the monsoonal precipitation pattern of Pakistan. Data from 30 precipitation gauges were obtained and were analyzed over a period of 35 years from 1980 to 2014. Singular-valued decomposition (SVD) technique was used to determine the association of previous year's SST and HGT with the current year's monsoonal precipitation. The results indicated that the association of SST and HGT with precipitation varied depending on the lead-times selected. Multiple regions of the North Indian Ocean were identified that showed significant association in affecting Pakistan's precipitation. The long term trend and abrupt shift patterns of precipitation were also evaluated across the selected gauges to determine the generic change patterns. The findings of the study can be useful predictors of forecasting models for water management in Pakistan.

INTRODUCTION

Improved predictions of hydrologic variables such as precipitation and resulting streamflow can help in better management of water resources. Climate variability impacts both precipitation and stream flow. Understanding the relationships between climate variability and hydrologic variables can improve rainfall and streamflow forecasting (Carrier et al. 2013; Thakali et al. 2016; Zhang et al. 2016). Many studies have focused on understanding these relationships to predict the hydrologic consequences associated with climate variability (Choubin et al. 2014; Carrier et al. 2016). Several studies have focused on understanding the association between oceanic-atmospheric climate variability, e.g., temperature and pressure fluctuations, and hydrologic variables (Kalra et al. 2008; Sagarika et al. 2015a).

Periodic oscillations observed in different oceans, such as El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Atlantic Multi-Decadal Oscillation (AMO), and North Atlantic Oscillation (NAO) have been recognized in previous studies as influential climate indices that affect regional and global hydroclimatic variables (Kalra and Ahmad 2011; Pathak et al. 2016a; Tamaddun et al. 2016a). Change in sea-surface temperature fluctuation can alter the moisture component of the air above the ocean surface, which might impact the storm tracks and eventually cause climate extremes (Sagarika et al. 2015b; Kalra et al. 2013 a & b). Previous studies have evaluated the effect of climate indices on hydrologic variables at many different spatial and temporal scales (Barlow et al. 2001; Hidalgo and Dracup 2003; Kalra et al. 2012). Even though these specific zones of the oceans represented by climate indices have been used to understand the hydrology of different regions around the globe, some studies have argued that the climate variability of different locations of the oceans have unlikely effects on different basins that are in close proximity (McCabe and Dettinger 2002; Kalra et al. 2013c).

Some studies have also reported variability in certain locations of the oceans that can strengthen or weaken the effect of variability of another location (Ashok et al. 2004; Hussain et al. 2016). Different phases of ENSO (originated from the Pacific Ocean) were considered to be a primary factor in causing climate extremes in the Indian subcontinent and in Southeast Asia (Kumar et al. 1999) till Indian Ocean Dipole (IOD) became popular (Ashok et al. 2001), which has the potential to strengthen or weaken the effect of ENSO on the monsoon cycle (Saji et al. 1999). Hussain et al. (2016) studied the effect of IOD on Pakistan's precipitation and found a significant correlation between IOD and monsoonal precipitation. The recent climate extremes in Pakistan (Adnan et al. 2016) have brought the attention to understanding the association between climate variability of the Indian Ocean and the hydrologic processes of Pakistan.

Another atmospheric variable is 500-mbar geopotential height (HGT/Z_{500}) that has been found to be associated with hydrologic variability (Sagarika et al. 2015a). Movements in jet streams that result from rapid alteration of HGT have been found to be directly related to precipitation (Xoplaki et al. 2000; Chen and Georgakakos 2014). Studies also suggest that use of HGT as an input parameter (predictor) for a forecasting model can potentially improve the model performance (Soukup et al. 2009).

The current study determined the trend and shift patterns of Pakistan's precipitation over a study period of 35 years (from 1980 to 2014) and evaluated the association of Indian Ocean SST and HGT variations with Pakistan's precipitation patterns. The results may help understand the precipitation patterns of Pakistan across different seasons and can provide insights regarding how the Indian Ocean climate variability affects Pakistan's precipitation.

STUDY AREA AND DATA

The monthly mean data for each year from 1980 to 2014 (ranging a total of 35 calendar years) for 30 precipitation stations (gauges) across Pakistan were used in this study (Figure 1). The topography of these stations also varies significantly across the different regions (Figure 1), which have affected the precipitation patterns of these regions over the years. The data were obtained from Pakistan Meteorological Department. The monsoonal precipitation (total rainfall during the monsoon season) was obtained by summing of the monthly means for the month of June through September for each year.

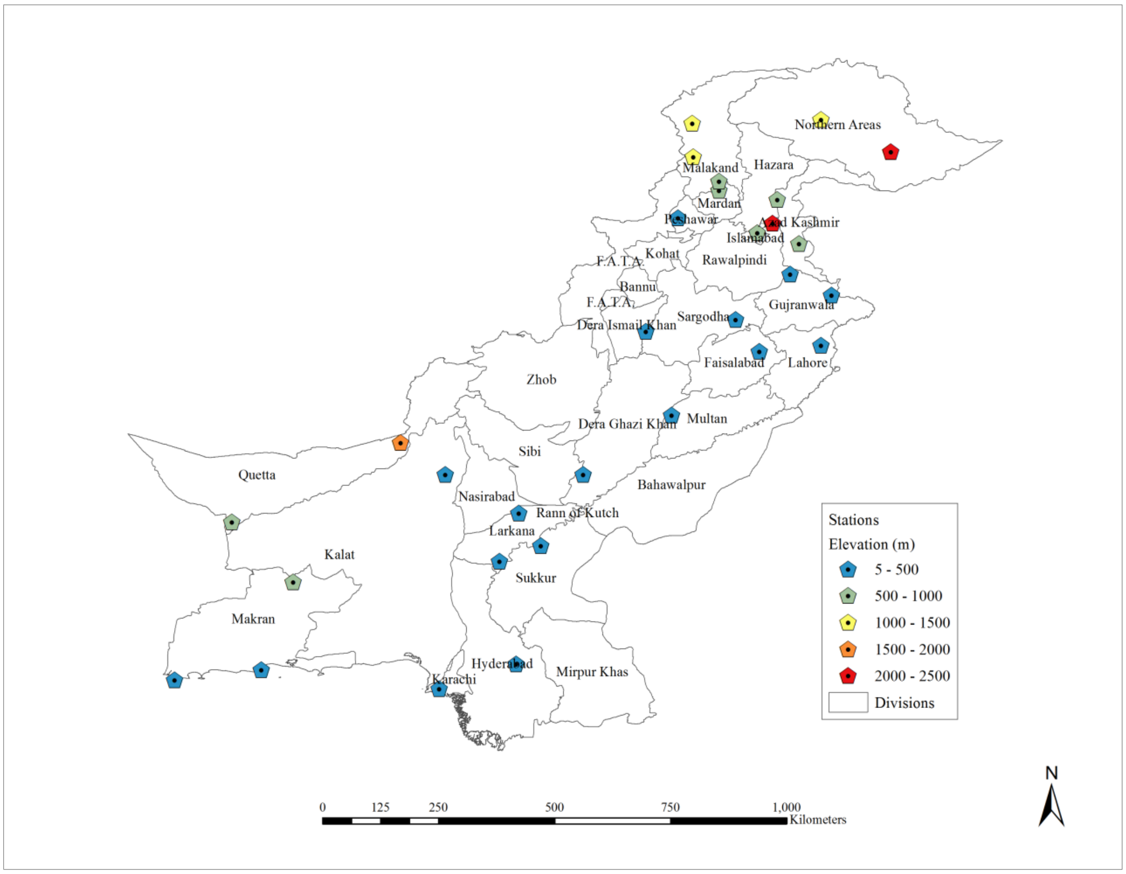

Figure 1. Map showing the locations and the elevations of the stations selected for the study across Pakistan.

The monthly SST data were obtained from the Earth System Research Laboratory online database provided by National Oceanic and Atmospheric Administration (NOAA). The data comprise of monthly mean SSTs at 2° x 2° gridded cells. The region of the Indian Ocean selected for this study was 40°E to 105° E and 15°S to 40°N, which resulted in a total of 506 cells (excluding the land areas). The monthly HGT data were obtained from NOAA's Physical Sciences Center online database. The data are provided at 2.5° x 2.5° gridded cells. The same region of the Indian Ocean (40°E to 80° E and 15°S to 40°N) was selected for the HGT data, which resulted in a total of 575 cells.

METHODOLOGY

Trend and Shift Tests

To determine the presence of trends and shifts in each station over the study period, the Mann-Kendall (MK) trend test (Mann 1945; Kendall 1975) and the Pettitt's test (Pettitt 1979) were used in this study. The advantages of using non-parametric tests in analyzing non-stationary hydroclimatic data have made both the tests popular and widely accepted (Lins and Slack 1999; Burn 2008; Villarini et al. 2009). A detailed discussion of the methods along with their advantages over other methods can be found in the works of Pathak et al. (2016b), Sagarika et al. (2014), and Tamaddun et al. (2016b). Readers may also refer to the original papers for the underlying theories and formulation of the methods.

Singular Value Decomposition

SVD has been used quite effectively in evaluating spatiotemporal relationships between hydroclimatic variables in many different regions across the world (Wang and Ting 2000; McCabe and Wolock 2014; Sagarika et al. 2015b). SVD involves factorization of the data matrix to obtain two orthogonal and one diagonal matrix, which are then used to determine the cross-covariance among the matrices using SVD decomposition. A detailed description of the SVD method can be found in the works of Newman and Sardeshmukh (1995) and Strang (1998). An SVD model to be statistically applicable, the first three elements (also known as the first three modes) of the diagonal matrix, obtained from the factorization of the data matrix, needs to explain a considerable amount of the total variance in the data (Newman and Sardeshmukh, 1995). Based on the works of Bretherton et al. (1992), the square covariance fraction (SCF) index was calculated, which represented the amount of variability explained by the model.

In this study, SVD was used to determine the association between Indian Ocean SST and HGT with the monsoonal precipitation of Pakistan. The Indian Ocean SST and HGT for DJF and SON were used against the total monsoonal (June through September) precipitation, which resulted in lags of 6 to 9 months. Hence, the correlations obtained were between SST/HGT (DJF and SON) and monsoonal precipitation (June through September).

RESULTS

The results obtained from the MK and the Pettitt's tests have been tabulated in Tables 1 & 2. The correlation maps for the first two modes of SON/DJF SST with monsoonal precipitation and SON/DJF HGT with monsoonal precipitation are provided in Figures 2 & 3, respectively. Positive (red) regions represent the regions that were found to be directly associated (in-phase) with monsoonal precipitation, while negative (blue) regions represent the regions with an anti-phase relationship with monsoonal precipitation.

Trend and Step Results

From the MK trend test result (Table 1), it was observed that on 29 occasions, stations experienced an increase in one of the months over the study period. The maximum number of stations experiencing an increase was observed in the month of September (36.7%), while June had the second highest number of stations with increasing trend (26.7%). July, October, November, and December did not show the presence of any increase during the study period.

Table 1. Number of stations showing increasing or decreasing trends under the MK test.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	Number of Stations											
Increasing	1	5	1	1	1	8	0	1	11	0	0	0
Decreasing	1	1	9	0	0	0	1	0	0	0	0	3

A decrease in trend was observed on 15 occasions across the study period with the month of March having the maximum number of stations (30%) with a decrease among the other months (Table 1). January, February, and July had one station each with a decrease, while December had three. The rest of the months did not show the presence of any decrease in trend.

An increase in shift was observed on 31 occasions across the different months during the study period (Table 2). The month of January, June, and September experienced more increase compared to the other months with 23.3%, 33.3%, and 23.3% stations with an increase, respectively. March, July, October, November, and December did not show the presence of any increase in shift.

Table 2. Number of stations showing increasing or decreasing shift under the Pettitt's test.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	Number of Stations											
Increasing	7	3	0	1	1	10	0	2	7	0	0	0
Decreasing	0	1	9	0	1	0	1	0	0	0	0	5

A decrease in shift was observed on 17 different occasions across the different months during the study period in Pakistan. The maximum number of stations with decrease was observed in the month of March (30%). February, May, and July had one station each with the decrease, while December had five. The rest of the months did not show the presence of any decrease in shift during the study period.

From the trend and shift results, it was observed that June and September have experienced the maximum increase over the years, while March has experienced the maximum decrease during the study period. Among the months, October and November were found to be not showing any instances of change during the study period.

SVD Results

From the SVD analyses between the SON SST and the monsoonal precipitation, it was observed that the SCF of the first mode was 59.6%, while the SCF of the second mode was 12.8% (Figure 2). The first mode consisted of 415 cells, while the second mode consisted of 39 cells out of the 506 cells representing the SST variations.

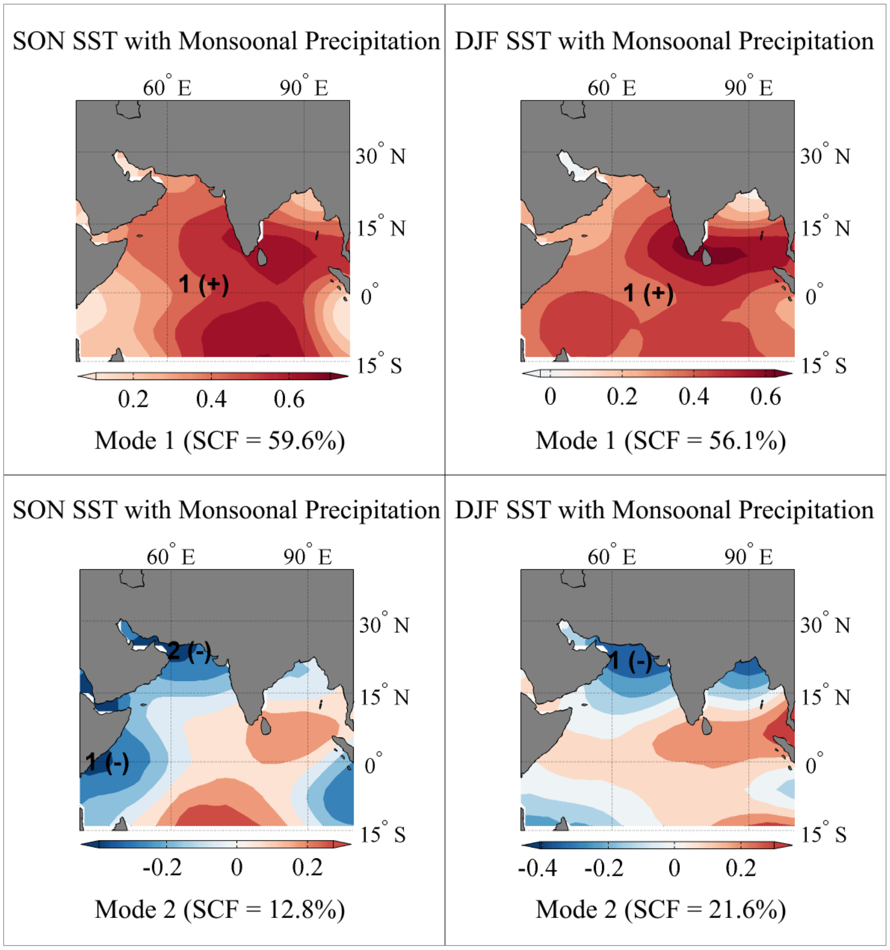

Figure 2. SVD maps showing the regions of Indian Ocean with significant correlation (modes 1 and 2) between the SON/DJF SST and the monsoonal precipitation.

The SCF of the first mode for the DJF SST and the monsoonal precipitation was found to be 56.1%, while the SCF of the second mode was 21.6% (Figure 2). The number of cells that comprised modes 1 and 2 were 437 and 36, respectively, out of the 506 cells representing the SST variation for the study.

The SVD analyses of the SON HGT and the monsoonal precipitation revealed that the SCF of the first mode was 66.9%, while the SCF of the second mode was 16.8% (Figure 3). The first and the second mode consisted of 507 and 54 cells, respectively, out of the 575 cells considered for HGT variation in this study.

The SCFs of the first and second mode for the DJF HGT and the monsoonal precipitation were found to be 62.7% and 20.2%, respectively (Figure 3). The number of cells comprising the first and the second modes was found to be 190 and 39, respectively, out of the 575 cells considered in the study.

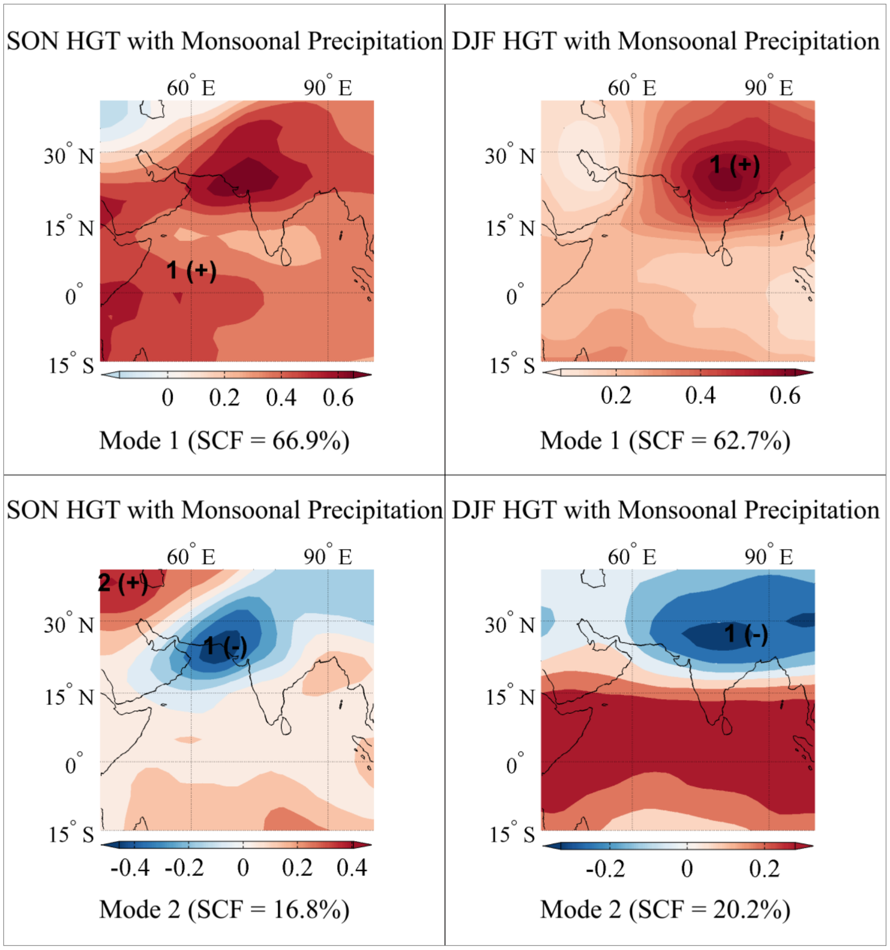

Figure 3. SVD maps showing the regions of Indian Ocean with significant correlation (modes 1 and 2) between the SON/DJF HGT and the monsoonal precipitation.

DISCUSSIONS AND CONCLUSION

The current study obtained continuous monthly mean data of 35 calendar years (from 1980 to 2014) for 30 precipitation stations (along a wide range of elevations) across Pakistan to determine the presence of trend and shift patterns during this study period and to evaluate the association between the monsoonal precipitation and the Indian Ocean climate variability. SST and HGT data on a monthly basis were obtained to correlate these changes with monsoonal precipitation. The trend and shift patterns of each month revealed that the months of June and September have experienced the maximum increase of precipitation over the study period, while March has experienced the maximum decrease. The significant increase during June and September can be attributed to the initiation and recession of the monsoon season.

From the comparison between the SON and DJF SST with the monsoonal precipitation correlation results, it was inferred that the first mode of SON SST explained the higher variability of the data analyzed in the study even though the first mode of DJF SST consisted of a higher number of cells. Opposite results were obtained from the SON and DJF HGT correlation results, where only 190 cells from the DJF HGT explained 62.7% of the variability, while 507 cells (2.7 times the number of cells in DJF HGT) from the SON HGT explained 66.9% variability. The results showed that SST and HGT had a different association with the monsoonal precipitation depending on the lags, which varied from 6 to 9 months for SON and DJF. Less number of cells explaining higher variability implies that smaller zones of influence of the Indian Ocean may have a higher association with certain regions of Pakistan.

The results also indicated that the Bay of Bengal SST variation, compared to the Arabian Sea SST variation, had a higher positive (in-phase) association with the Pakistan monsoonal precipitation in both the significant modes. On the other hand, the HGT variation across the land areas of Pakistan and India had a higher positive association with Pakistan's precipitation. For both the SST and the HGT correlation results, negative (anti-phase) correlations were observed only in the second modes. Future studies can evaluate these correlations at the regional level with a higher number of stations in each region for a better understanding of the associations present between climate variability and hydrologic variables using longer record length.

The study provided a case study that explains how spatiotemporal association between hydrologic variables (e.g., precipitation) and oceanic variability can be determined using SVD analyses. The results also show how the trend and shift patterns of monthly precipitation have changed during the study period. The results can be helpful in understanding Pakistan's precipitation pattern across different seasons and also may help to develop hydrologic forecasting models based on correlation with climate variabilities with time lags.

ACKNOWLEDGEMENT

This research was supported by the United States Agency for International Development (USAID) grant to establish the U.S.-Pakistan Centers for Advanced Studies in Water. The contents are the sole responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government.

REFERENCES

Adnan, S., Ullah, K., & Shouting, G. (2016). "Investigations into precipitation and drought climatologies in south central Asia with special focus on Pakistan over the period 1951-2010." *Journal of Climate*, 29(16), 6019–6035. http://doi.org/10.1175/JCLI-D-15-0735.1

Ashok, K., Guan, Z., & Yamagata, T. (2001). "Impact of the Indian Ocean dipole on the relationship between the Indian monsoon rainfall and ENSO." *Geophys. Res. Lett*., 28, 4499–4502.

Ashok, K., Guan, Z., Saji, N.H., & Yamagata, T. (2004). "Individual combined influences of the ENSO and Indian Ocean Dipole on the Indian summer monsoon." *J. Clim*. 17, 3141–3155.

Barlow, M., Nigam, S., & Berbery, E. (2001). "ENSO, pacific decadal variability, and U.S. summertime precipitation, drought, and stream flow." *J. Clim*. 14(9): 2105–2128, doi: 10.1175/1520-0442 (2001)014<2105:EPDVAU>2.0.CO;2.

Bretherton, C. S., Smith, C., Wallace, J. M. (1992). "An inter-comparison of methods for finding coupled patterns in climate data." *J. Clim*. 5(6): 541–560, doi: 10.1175/15200442(1992)005<0541: AIOMFF>2.0.CO;2.

Burn, D.H. (2008). "Climatic influences on streamflow timing in the headwaters of the Mackenzie River Basin." *J. Hydrol*., 352, 225–238.

Carrier, C., Kalra, A., & Ahmad, S. (2013). "Using Paleo Reconstructions to Improve Streamflow Forecast Lead Time in the Western United States." *Journal of the American Water Resources Association*, 49(6), 1351–1366. doi:10.1111/jawr.12088.

Carrier, C., Kalra, A., & Ahmad, S. (2016). "Long-range precipitation forecast using paleoclimate reconstructions in the western United States." *Journal of Mountain Science,* 13 (4), 614–632. doi:10.1007/s11629-014-3360-2.

Chen, C. J., Georgakakos, A. P. (2014). "Hydro-climatic forecasting using sea surface temperatures: methodology and application for the southeast US." *Clim. Dyn.* 42(11-12): 2955–2982, doi: 10.1007/s00382- 013-1908-4.

Choubin, B., Khalighi-Sigaroodi, S., Malekian, A., Ahmad, S., & Attarod, P. (2014). "Drought forecasting in a semi-arid watershed using climate signals: a neuro-fuzzy modeling approach." *J. Mt. Sci*. 11(6): 1593–1605, doi: 10.1007/s11629-014-3020-6.

Hidalgo, H. G., Dracup, J.A. (2003). "ENSO and PDO effects on hydroclimatic variations of the Upper Colorado River Basin." *J. Hydrometeorol.* 4(1): 5–23, doi: 10.1175/1525-7541(2003)004 <0005:EAPEOH>2.0.CO;2.

Hussain, M. S., Kim, S., & Lee, S. (2016). "On the relationship between Indian Ocean Dipole events and the precipitation of Pakistan." *Theoretical and Applied Climatology*, 1–13. http://doi.org/10.1007/s00704-016-1902-y.

Kalra, A., Piechota, T. C., Davies, R., & Tootle, G. A. (2008). "Changes in US streamflow and western US snowpack." *Journal of Hydrologic Engineering*, 13(3), 156-163.

Kalra, A., & Ahmad, S. (2011). "Evaluating changes and estimating seasonal precipitation for the Colorado River Basin using a stochastic nonparametric disaggregation technique." *Water Resour. Res*. 47, W05555. http://dx.doi.org/10.1029/ 2010WR009118.

Kalra, A., & Ahmad, S. (2012). "Estimating annual precipitation for the Colorado River Basin using oceanic-atmospheric oscillations." *Water Resources Research*, 48(6), W06527. doi:10.1029/2011WR010667.

Kalra, A., Li, L., Li, X., & Ahmad, S. (2013a). "Improving streamflow forecast lead time using oceanic-atmospheric oscillations for Kaidu river basin, Xinjiang, china." *J. Hydrological Eng*. 18 (8), 1031–1040.

Kalra, A., Miller, W. P., Lamb, K. W., Ahmad, S., & Piechota, T. (2013b). "Using large-scale climatic patterns for improving long lead time streamflow forecasts for Gunnison and San Juan River Basins." *Hydrological Processes*, 27(11), 1543–1559. doi:10.1002/hyp.9236.

Kalra, A., Ahmad, S., & Nayak, A. (2013c). "Increasing streamflow forecast lead time for snowmelt-driven catchment based on large-scale climate patterns." *Advances in Water Resources*, 53, 150–162. doi:10.1016/j.advwatres.2012.11.003

Kendall, M.G. (1975). "Rank Correlation Methods." Charles Griffin: London, UK.

Kumar, K., Rajagopalan, B., Cane, M. (1999). "On the weakening relationship between the Indian monsoon and ENSO." *Science* (New York, N.Y.), 284(5423), 2156–9. doi:10.1126/science.284.5423.2156.

Lins, H., Slack, J. (1999). "Streamflow trends in the United States." *Geophys. Res. Lett*., 26, 227–230.

Mann, H.B. (1945). "Nonparametric tests against trend. Econom." *J. Econom. Soc*. 13, 245–259.

McCabe, G.J., Dettinger, M. D. (2002). "Primary modes and predictability of year-to-year snowpack variations in the western United States from teleconnections with Pacific Ocean climate." *J. Hydrometeorol*. 3(1): 13–25.

McCabe, G. J., Wolock, D. M. (2014). "Variability common to global sea surface temperatures and runoff in the Conterminous United States." *J. Hydrometeorol*. 15(2): 714–725.

Newman, M., Sardeshmukh, P. D. (1995). "A caveat concerning singular value decomposition." *J. Clim*. 8(2): 352–360, doi: 10.1175/1520- 0442(1995)008<0352:ACCSVD>2.0.CO;2.

Pathak, P., Kalra, A., Ahmad, S., & Bernardez, M. (2016a). "Wavelet-Aided Analysis to Estimate Seasonal Variability and Dominant Periodicities in Temperature, Precipitation, and Streamflow in the Midwestern United States." *Water Resources Management*, 30(13), 4649–4665. http://doi.org/10.1007/s11269-016-1445-0.

Pathak, P., Kalra, A., & Ahmad, S. (2016b). "Temperature and precipitation changes in the Midwestern United States: implications for water management." *International Journal of Water Resources Development*, 1–17. http://doi.org/10.1080/07900627.2016.1238343.

Pettitt, A. (1979). "A non-parametric approach to the change-point problem." Appl. Stat, 28, 126–135.

Sagarika, S., Kalra, A., & Ahmad, S. (2014). "Evaluating the effect of persistence on long-term trends and analyzing step changes in streamflows of the continental United States." *Journal of Hydrology* 517,36–53. doi:10.1016/j.jhydrol.2014.05.002.

Sagarika, S., Kalra, A., & Ahmad, S. (2015a). "Interconnection between oceanic-atmospheric indices and variability in the US streamflow." *Journal of Hydrology* 525, 724–736. doi:10. 1016/j.jhydrol.2015.04.020.

Sagarika, S., Kalra, A., & Ahmad, S. (2015b). "Pacific Ocean and SST and Z500 climate variability and western U.S. seasonal streamflow." *International Journal of Climatology 36*, 1515– 1533. doi:10.1002/joc.4442.

Saji, N.H., Goswami, B.N., Vinayachandran, P.N., & Yamagata, Y. (1999). "A dipole mode in the tropical Indian Ocean." *Nature* 401, 360–363.

Soukup, T. L., Aziz, O. A., Tootle, G. A., Piechota, T. C., & Wulff, S. S. (2009). "Long lead-time streamflow forecasting of the North Platte River incorporating oceanic–atmospheric climate variability." *J. Hydrol*. 368(1): 131–142, doi: 10.1016/j.jhydrol.2008.11.047.

Strang, G. (1998). "Introduction to Linear Algebra, 2nd edn." Addison-Wesley: Reading, MA.

Tamaddun, K. A., Kalra, A., & Ahmad, S. (2016a). "Wavelet analysis of western U.S. streamflow with ENSO and PDO." *Journal of Water and Climate Change*, 1–15. http://doi.org/10.2166/wcc.2016.162.

Tamaddun, K., Kalra, A., & Ahmad, S. (2016b). "Identification of Streamflow Changes across the Continental United States Using Variable Record Lengths." *Hydrology*, 3(2), 24. http://doi.org/10.3390/hydrology3020024

Thakali, R., Kalra, A., & Ahmad, S. (2016). "Understanding the Effects of Climate Change on Urban Stormwater Infrastructures in the Las Vegas Valley." *Hydrology*, 3(4), 34. http://doi.org/10.3390/hydrology3040034.

Villarini, G., Serinaldi, F., Smith, J. A., Krajewski, W. F. (2009). "On the stationarity of annual flood peaks in the continental United States during the 20th century." *Water Resour. Res*., 45.

Wang, H., Ting, M. (2000). "Covariabilities of winter U.S. precipitation and Pacific Sea surface temperatures." *J. Clim*. 13(20): 3711–3719, doi: 10.1175/1520-0442(2000)013<3711:COWUSP>2.0.CO;2.

Xoplaki, E., Luterbacher, J., Burkard, R., Patrikas, I., & Maheras, P. (2000). "Connection between the large-scale 500 hPa geopotential height fields and precipitation over Greece during wintertime." *Clim. Res*. 14(2): 129–146.

Zhang, F., Ahmad, S., Zhang, H., Zhao, X., Feng, X., & Li, L. (2016). "Simulating low and high streamflow driven by snowmelt in an insufficiently gauged alpine basin." *Stochastic Environmental Research and Risk Assessment*, 30(1), 59–75. http://doi.org/10.1007/s00477-015-1028-2.