Long-term rainfall variability along the west coast of India and its teleconnections

B.R. Manjunatha[1,2]*, Jithin Jose[1], K. Prashantha Kumar[1] and H.K. Ramaraju[2]

[1]*Department of Marine Geology, Mangalore University, Mangalagangothri-574199, India.*

[2]*Department of Civil Engineering, Dayananda Sagar College of Engineering, Bengaluru- 560078 India.*

*E-mail mail of the lead presenter: manjzircon@gmail.com

Abstract

The west coast of India and the adjoining Western Ghats serve as major watershed regions for both west- and east-flowing rivers of Peninsular India. This study investigates the long-term variability of seasonal and interannual rainfall over a 145-year period across three coastal sectors: northern Konkan–Goa, central Karnataka, and southern Kerala. An increasing trend in annual rainfall is observed over the northern Konkan–Goa coast, no significant change in the Karnataka coast, and a decreasing trend in the southern Kerala coast. These variations are influenced by atmospheric processes, such as, enhanced convection linked to desert dust in the troposphere, particularly in the northern sector, and are further amplified by global warming. Principal Component Analysis (PCA) reveal that the Southern Oscillation Index (SOI) significantly affecting the rainfall variability over the Konkan–Goa and Karnataka coasts. Rainfall in these regions exhibits an inverse relationship with Niño 3.4 sea surface temperatures during summer and SOI values during winter season. In addition to the dominant influence of the Southern Oscillation Index (SOI) on summer monsoon rainfall over the Konkan and Goa coastal regions, variability in Northeast (NE) Atlantic temperatures during winter, spring, and summer also appears to play a significant role. While the teleconnection of the SOI with summer monsoon rainfall is well established, the NE Atlantic temperature influence is noteworthy across multiple seasons (winter, spring, and summer). However, this influence is inversely related to the Arctic Oscillation during winter and the Azores High during spring, suggesting that the North Atlantic temperature variability is teleconnected with monsoonal rainfall over the west coast of India.

Introduction

India receives most of its rainfall during the summer monsoon, followed by the fall and spring inter-monsoons, and the least during the winter monsoon (Parthasarathy et al., 1993; Kothawale and Rajeevan, 2017). However, the southeastern region receives 40–50% of its annual rainfall in winter (Parthasarathy et al., 1993; Manjunatha et al., 2015). The Himalayan region and Western Ghats are the two major watershed areas. The western region, including the west coast and Ghats, is a key water source for west-flowing rivers. These areas receive 200–400 cm of rainfall annually, with some pockets receiving up to 800 cm mostly during the summer monsoon, which contributes 70–85% of the annual total 2 to 4 times the national average. Together with the northwestern coastal plain, this region accounts for about 20% of India's total rainfall and supports both east- and west-flowing river systems in Peninsular India.

This study focuses on the long-term rainfall variability to document droughts and floods along the Kerala, Karnataka, and Konkan-Goa coasts from the latter part of the 19th century till 2018. In addition, the long-term teleconnections affecting the rainfall have been studied along with the Principal Component Analysis. The rainfall along this region occurs mainly during the summer southwest monsoon season; however, to some extent, the southern part of Kerala gets meager rainfall during the northeast monsoon (Kothawale and Rajeevan, 2016; Premlet, 2018; Preethy et al., 2018; Krishnan et al., 2020). The calculations of droughts and rainstorms/floods during the monsoon season have been studied for the past 148 years. This study indicates that the southwest monsoon has been a prime source of water for the hydrological cycle, especially the coastal region, which is important for agriculture, fisheries, and water resources. Kerala is blessed with copious rainfall during the monsoon season, which is significant for agricultural and fisheries resources. However, extreme rainfall in Kerala has been quite evident for years 84 (Preethy et al., 2018).

Data and Methods

The rainfall data are mainly collected from the IITM and the Indian Meteorological Division (IMD; Kothawale and Rajeevan, 2017). These data have been considered as highly precipitation–highly-resolved observational data integration. the SST- Indian Ocean, SST –Global, Global temperature anomaly, dipole mode index (standard), annual global average SST and North Atlantic Oscillation (NAO) have been taken from the public domain monthly atmospheric and ocean time series provided by the NOAA/NASA (http://data.giss.nasa.gov/ http://data.giss.nasa.gov/). Further details are provided at https://www.worldclimateservice. com/ 2021/08/26/north-atlantic- oscillation. Based on four seasons in a year, namely Winter, Spring, Summer and Fall/Autumn (October and November), the data have been categorized and PCA has been carried out. The five PCs considered here are significant which fall above the inflection point between Eigenvalues and the number of components as scree plot (not shown here).

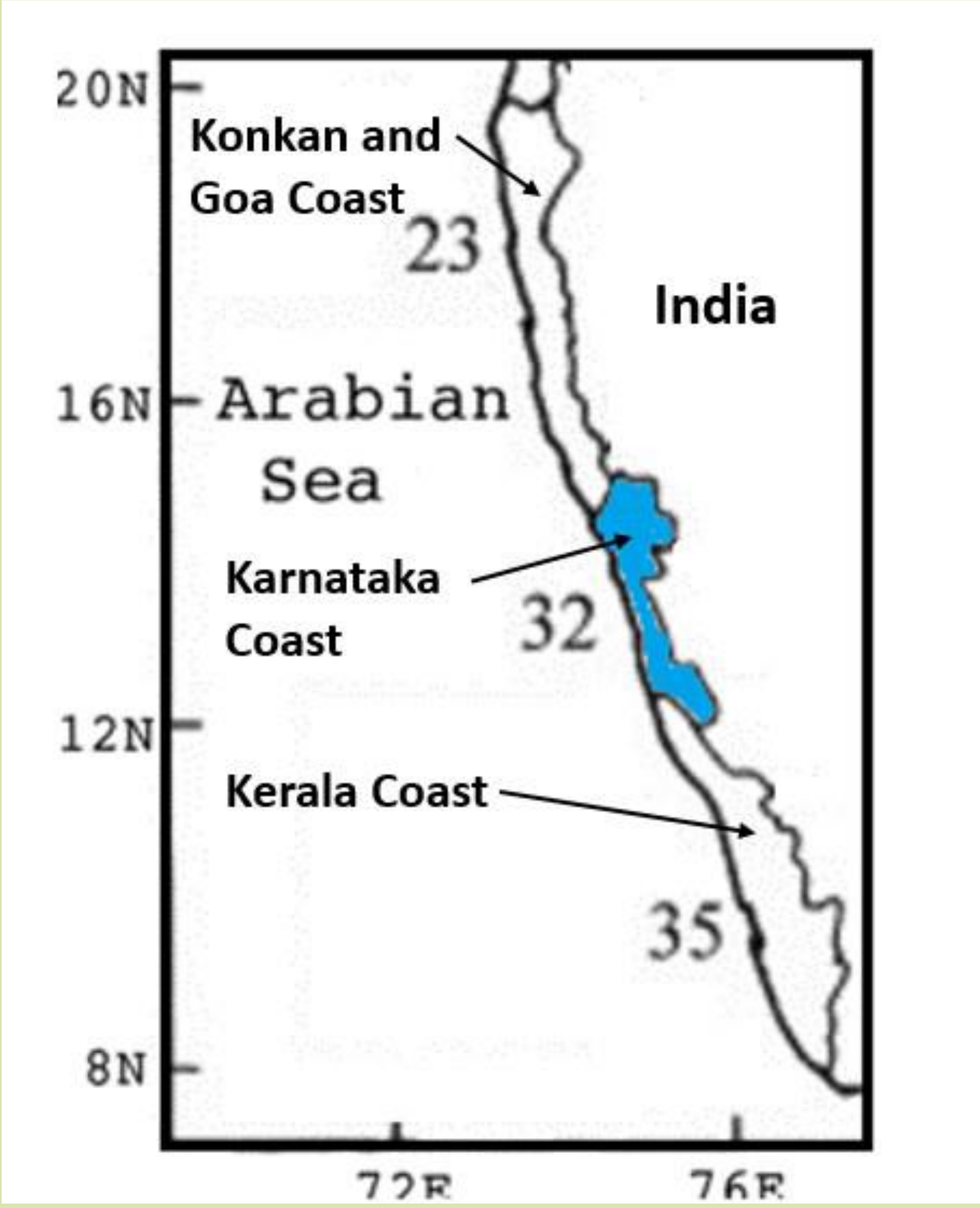

Figure 1. Map of the west coast of India showing three regions.

Results and discussion

Here, the data reduction technique of Principal component analysis (PCA) has been carried out to assess the impact of long-term tele connecting forces on rainfall of the study from 1871 to 2018 (Table 1). The rainfall is controlled not only by local meteorological variations, but also links with teleconnecting forces including human impacts (Holton and Tan, 1980; Rosenfeld, 2000; Han et al., 2022). In component-1, Konkan-Goa Coast and Karnataka Coast, the summer monsoon rainfall data are significantly positively loaded. Other co-positively loaded parameters are the Southern Oscillation Index (SOI) during summer, all Indian average summer monsoon rainfall (ISMR), summer rainfall of NW India, Western Rajasthan, Gujarat, Saurashtra, but negatively loaded on Niño 3.4 temperature of the tropical Central Pacific Ocean during the summer, and SOI during the winter season. This indicates that the SOI is the major control of the summer monsoon rainfall of the Konkan-Goa and Karnataka Coast.

The long-term climatic variations result from the positive(negative) SOI data coincide with abnormally cold (warm) ocean waters across the eastern tropical Pacific Ocean, which is typical of La Niña(El Niño) episodes(ncei.noaa.gov/access/monitoring/enso/soi). This has a chief bearing on the Indian Summer Monsoon rainfall of the study area, in particular the Konkan, Goa, and Karnataka Coastal regions. However, the warming of the tropical central Pacific Ocean (ONI/Niño 3.4 region) has an adverse effect on the study area as the Niño 3.4 temperature is negatively loaded on component-1. The ENSO is the shortest climatic cycle operating at the time scale of 2 to 7 years, where the SOI negative (positive) indicates El Niño (La Niña). Therefore, here, the positive loading of SOI in PC-1 shows that during La Niña, the Indian subcontinent receives a significant amount of rainfall than the long-term averages that often causes flooding of rivers noticed in different regions of India (Manjunatha et al., 2015). In the PCA-2, the summer rainfall of the Kerala Coast is quite unique in that it is positively loaded with Niño 3.4 temperature during winter, spring, and summer seasons, but correspondingly negative with SOI. The summer rainfall along the Kerala Coast is also negative with ISMR—however, there is a positive relationship with the North Atlantic temperature during the spring season. In components 3 and 4, none of the parameters studied significantly loaded; however, in component 5, only Konkan and Goa Coastal (summer monsoon) rainfall statistically loaded along with very positive high loadings for NE Atlantic temperature during the Winter, Spring, and Summer, but negatively on Arctic Oscillation data during the Winter and Azores High during the Spring season. All these observations suggest that the role of the North Atlantic temperature changes in regulating the summer monsoon of the Konkan and Goa coast; however, it is not prominent along the two southern regions of the study area.

Table 1. Principal Component Analysis of the data.

Parameter	Component 1	2	3	4	5	6	7	8
1	-0.01	0.16	-0.01	0.05	**-0.28**	0.02	**0.77**	**-0.30**
2	0.00	-0.09	-0.02	0.01	0.14	0.03	**0.77**	**0.21**
3	0.06	-0.09	**0.89**	0.17	-0.12	-0.09	0.01	0.02
4	0.00	-0.16	0.08	**0.81**	**-0.20**	-0.01	0.03	0.04
5	0.03	0.11	**-0.90**	-0.08	0.11	-0.08	-0.01	-0.03
6	-0.04	0.03	-0.13	**-0.88**	0.14	0.03	-0.03	0.08
7	0.09	-0.10	**0.82**	-0.06	-0.06	0.09	-0.02	-0.14
8	-0.05	0.06	0.16	**0.72**	**-0.27**	-0.01	-0.02	0.17
9 NINO-W	0.13	**0.82**	-0.15	0.01	0.16	**0.23**	-0.09	**-0.19**
10 NINO-Sp	-0.01	**0.92**	-0.13	-0.03	0.13	0.04	0.09	-0.03
11 NiNO-S	**-0.43**	**0.61**	-0.07	0.08	-0.08	**-0.25**	0.09	**0.20**
12 SOI- Winter	**-0.23**	**-0.77**	0.10	0.03	-0.07	**-0.19**	0.03	0.14
13 SOI - Spring	0.08	**-0.84**	0.00	0.00	-0.04	0.01	0.02	-0.04
14 SOI- Summer	**0.32**	**-0.51**	-0.01	-0.15	0.09	**0.33**	-0.10	**-0.46**
15	0.14	0.01	-0.15	-0.08	**0.89**	0.02	-0.03	0.03
16	0.09	**0.21**	-0.12	-0.25	**0.89**	0.06	-0.03	-0.08
17	0.02	0.11	0.01	**-0.29**	**0.83**	-0.06	0.02	-0.16
18	-0.01	-0.04	**0.95**	0.13	0.03	0.05	-0.03	0.04
19	0.10	0.16	-0.04	**0.89**	0.02	0.01	0.01	-0.05
20 NAO	0.14	-0.15	-0.05	0.00	-0.15	**0.18**	-0.01	**0.79**
21 ISMR	**0.81**	**-0.18**	-0.01	0.02	0.14	**0.39**	0.02	0.00
22	**0.97**	-0.03	-0.01	-0.02	0.00	0.12	-0.02	0.02
23	**0.84**	-0.05	0.03	-0.08	-0.13	0.07	0.01	-0.05
24	**0.90**	0.06	0.04	0.10	0.13	-0.03	-0.06	0.02
25	**0.78**	**0.17**	0.06	0.13	0.12	0.03	0.01	0.17
26	**0.52**	0.03	0.04	-0.01	**0.21**	**0.41**	**0.29**	-0.11
27	**0.35**	0.07	0.09	0.00	0.02	**0.79**	0.16	-0.03
28	0.07	**0.18**	0.06	-0.03	-0.07	**0.82**	-0.10	**0.22**
Eigenvalue	4.56	3.76	3.34	3.01	2.75	1.97	1.34	1.25
% of Variance	16.28	13.43	11.92	10.77	9.81	7.03	4.78	4.46
Cumulative %	16.28	29.71	41.63	52.39	62.20	69.23	74.01	78.47

1 Year, 2 Sun's spots in Summer, 3 Arctic Oscillation (AO) in Winter, 4 (AO) in Spring, 5 Iceland low (IL) in Winter, 6 IL in Spring, 7 Azores High (AH) in Winter, 8 AH in Spring, 9 NiNO 3.4 in Winter (NINO-W), 10 NiNO 3.4 in Spring (NINO-Sp), 11 NiNO 3.4 in Summer (NINO-S) (NiNO-S), 12 SOI in Winter, 13 SOI in Spring, 14 SOI in Summer, 15 NE Atlantic temperature (NEA) in Winter, 16 NEA in Spring,17 NEA in Summer, 18 NAO Oscillation in Winter, 19 NAO Oscillation in Spring, 20 NAO Oscillation in Summer, 21 All India Summer Monsoon Rainfall (ISMR) , 22 Rainfall NW India in Summer, 23 West Rajastan in Summer, 24 Gujarath in Summer, 25 Saurashtra in Summer, 26 Konkan Goa in Summer, 27 Coastal Karnataka in Summer, and 28 Kerala in Summer.

Summary and conclusions

The PCA of the long-term rainfall data of the study area along with teleconnection forces indicates that the rainfall of the Konkan-Goa and Karnataka Coasts are prominently linked to the Southern Oscillation Index (SOI), all Indian summer rainfall average, NW India, Western Rajasthan, Gujarat, and Saurashtra. The Niño 3.4 temperature in the Pacific Ocean during the summer and SOI during the winter season are inversely affecting the rainfall of the Konkan-Goa and Karnataka Coasts. In contrast, the summer rainfall along the Kerala Coast found to be positively associated with the Niño 3.4 temperature and North Atlantic temperature during the spring, winter, and summer seasons, however, negatively related with SOI and ISMR. In addition to the dominance of the SOI on the summer monsoon rainfall of the Konkan and Goa Coastal regions, the influence of NE Atlantic temperature during the winter, spring, and summer seems significant. However, this is inversely related to the Arctic Oscillation during the winter and Azores High during the Spring season, suggesting that the North Atlantic temperature influences rainfall over Konkan and Goa during the summer monsoon season.

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Selected references

Han, Y., Xie, F., Cui, F., Wang, F., Li, X., Feng, W., 2022. Extreme change events of stratospheric HCl and N2O in the mid-latitude region of the Northern Hemisphere. Remote Sens., 14, 6114. https://doi.org/10.3390/rs14236114.

Holton, J.R., Tan, H.-C., 1980. The influence of the equatorial quasi-biennial oscillation on the global circulation at 50 mb. J. Atmos. Sci., 37, 2200–2208.

Kothawale, D.R., Rajeevan, M., 2017. Monthly, seasonal and annual rainfall time series for all-India, homogeneous regions and meteorological subdivisions: 1871-2016. I.I.T.M. Research Reports, Pune, India.

Manjunatha, B.R., Balakrishna, K., Krishnakumar, K.N., Manjunatha, H.V., Avinash, K., Mulemane, A.C., Krishna, K.M., 2015. Increasing trend of rainfall over Agumbe, Western Ghats, India in the scenario of global warming. The Open Oceanography Journal, 8, 39-44.

Parthasarathy, B., Kumar, K.R., Munot, A.A., 1993. Homogeneous Indian monsoon rainfall—variability and prediction. Proceedings of the Indian Academy of Science, 102, 121–155.

Rao, K.L., 1973. India's water wealth. Orient Longman, New Delhi.

Rosenfeld, D., 2000. Suppression of rain and snow by urban and industrial air pollution. Science, 287, 1793–1796. https://doi.org/10.1126/science.287.5459. 1793..