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Research Article

A comparative study of regional climate trends in the Keoladeo and Bhitarkanika wetlands, India

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Abstract
The climate trend is one of the most dominant factors likely to affect the structure and function of the wetlands of Keoladeo and Bhitarkanika. This study compares the climate conditions and trends of two Ramsar sites in India, the Bhitarkanika and Keoladeo wetlands. Forty-year climate data (1980-2020) were used to identify and measure the strength of possible climate change in these habitats. Mann-Kendall's test, Sen's slope estimates and Sequential Mann-Kendall's (SQMK) test were used to study the long-term and short-term trends of rainfall and climate of Bhitarkanika and Keoladeo. The results of this study matched those of earlier studies conducted at a larger geographical scale. The study indicated significant changes in the parameters of rainfall and temperature trends. A significant increase in annual rainfall (Sen's slope = 5.24E+00, New *p* value = 2.75E-02) was observed at Bhitarkanika, while the trend at Keoladeo was positive but insignificant. Both ecosystems are getting warmer. Seasonal changes were also identified in the rainfall and temperature. The summer temperature rise was comparatively stronger at Keoladeo (T_{max}: Sen's slope=2.33E-02, New *p* value=2.45E-02; T_{min}: Sen's slope=2.68E-02, New *p* value=1.39E-02). An increase in monsoon temperature was also recorded in both ecosystems. Both wetland ecosystems are vulnerable to climate change, but the Keoladeo wetland is at higher risk because stronger temperature changes have occurred in the past four decades. The SQMK test also suggests a more erratic climate in the Keoladeo wetlands. The study highlights the comparative changes occurring in both ecosystems. This is the first study identifying both long-term and short-term changes in these wetlands at a smaller geographical scale.

Keywords: Long-term and short-term climate trend, Wetland, Keoladeo, Bhitarkanika, SQMK test

INTRODUCTION

Wetlands are ecosystems with water-saturated soil either throughout the year or seasonally. Wetlands are extremely useful ecosystems with high benefits to humans and biodiversity (Salimi *et al.*, 2021). Although their total area is very small throughout the planet, their importance cannot be neglected. Wetlands provide unique and highly productive habitats for a variety of biodiversities, such as waterfowl and other aquatic fauna. Wetlands are also economically important because of their economic utility, such as rice production, fisheries and other aquaculture. However, wetlands are a very fragile ecosystem and vulnerable to climate change. The structure and function of wetland ecosystems are largely dependent on the hydrological regime of an area and are hence susceptible to climate change. Climate change can alter the biogeochemistry, water availability, aquatic fauna, plant community and overall productivity of wetlands (Weltzin *et al.*, 2000, Laine *et al.*, 2014, Dieleman *et al.*, 2015, Salimi *et al.*, 2021).

India is a large country with several unique wetland ecosystems (Prasad *et al.*, 2002). Wetlands in India are located in various landscapes, including the Himalayas, arid regions, river plains, Deccan Plateau and coastal regions (Prasad *et al.*, 2002). Many of these are man-made and managed, but most are natural and dependent on natural climatic conditions. Rainfall and temperature changes have been identified in many regions of India (Mondal *et al.*, 2015), which can threaten all wetlands. Both man-made and natural wetlands face climate change problems directly or indirectly (Salimi *et al.,* 2021). It is vital to identify climate change-vulnerable wetlands and prepare a management plan for each of these wetlands.

Keoladeo and Bhitarkanika are the two most important Ramsar wetland sites in India. Both ecosystems are unique and different from each other in terms of their geolocation. These ecosystems are home to unique waterfowl and other biodiversity, such as saltwater crocodile (*Crocodylus porosus*), which is of conservation importance (Pradhan and Kar, 2018, Sugandh and Joshi, 2018, Gopi and Pandav, 2007, Ali and Vijayan, 1980). This study compares the climate trends in these two wetlands to determine whether these two ecosystems are changing in climate conditions. However, large geographical studies have tested the climate trend in the region of the two wetlands mentioned above (Mondal *et al.,* 2012, 2015, Pal *et al.,* 2019, Ramarao *et al.,* 2019, Singh *et al.,* 2019). Few studies have focused on the small-scale climate of the mentioned wetlands (Bal and Banerjee, 2019, Ramnathan *et al.,* 2010). The present study aimed to compare the regional climatic conditions of Keoladeo National Park (Keoladeo) and Bhitarkanika National Park (Bhitarkanika) located in the different climatic zones of India. A comparative approach was used to study the rainfall and temperature to identify long-term and short-term climate trends in these wetlands at a small geographical scale.

MATERIALS AND METHODS

Study area

The wetlands Keoladeo National Park (Keoladeo) and Bhitarkanika National Park (Bhitarkanika) are located in the different climatic zones of India (Fig. 1). Both of these ecosystems are unique and comprise very different ecosystem conditions. Both protected areas have been recognized as wetlands of international importance under the Ramsar convention (1972). Both Bhitarkanika and Keoladeo are home to the two of India's largest aggregations of heronries. Nearly 15 species of heronry birds breed in these two ecosystems.

Keoladeo is a semi-arid zone and a combination of deciduous, scrub, grasses, shrubs and a few evergreen vegetation habitats (Ali and Vijayan 1985). It is located in the semi-arid area (27°7.6¢–27°12.2N and 77°29.5¢ –77°33.2E) of district Bharatpur in the state of Rajasthan, India. It is spread in 28 sq. ft. (7100 Acres) of area. Bhitarkanika is a coastal ecosystem dominated by mangrove vegetation (Gopi and Pandav 2007). It is the second-largest mangrove after the Sundarbans, covering 675 sq. km of area. It is located on the eastern coast in the district of Kendrapara in the state of Orissa (20°04'-20°08'N and 86°45'-87°50'E). (20°04'-20°08'N and 86°45'-87°50'E).

Climate data

Rainfall and temperature were used as variables of

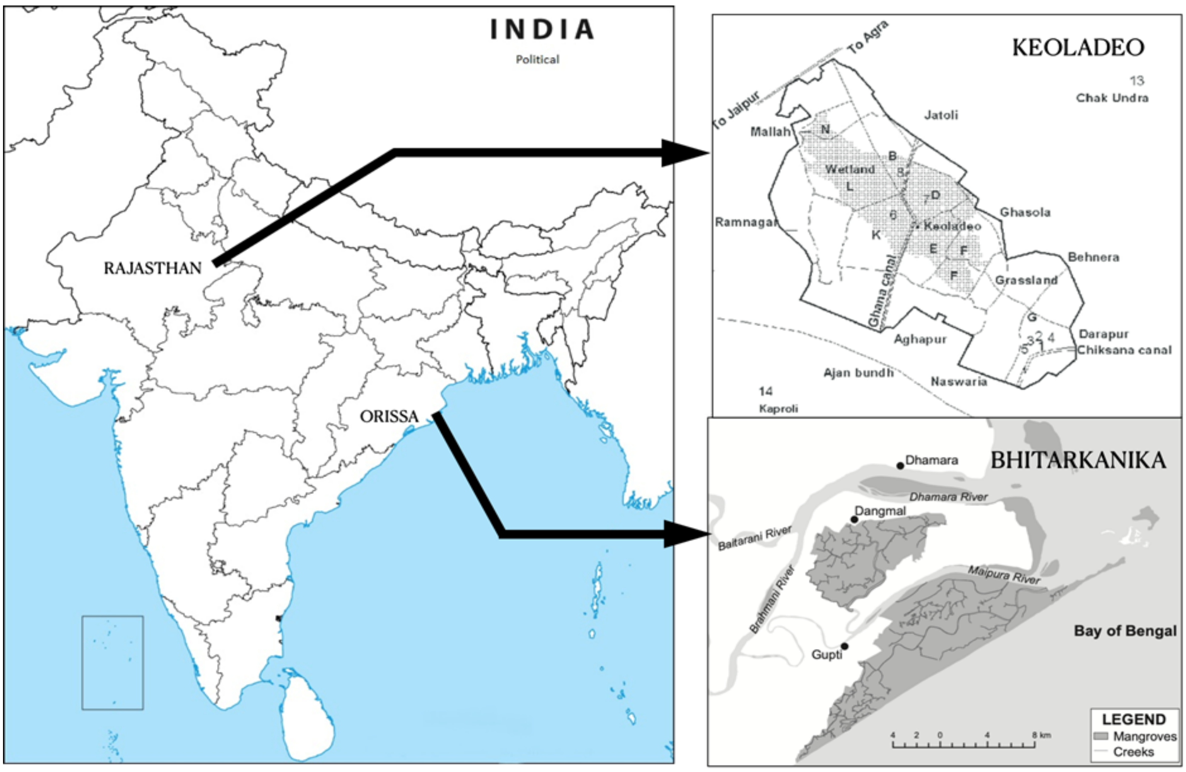

Fig. 1. *Map of India showing the location of the Keoladeo and Bhitarkanika wetlands (Map not to scale) (adapted from Verma and Prakash 2007, Prasad et al., 2015)*

climate. These were further classified according to the season. Temperature, both maximum and minimum, was used in the analysis. Temperature and rainfall data (1980-2020) were downloaded using the Indian Meteorological Department (IMD) website (https://dsp.imdpune.gov.in). Geographical locations on the IMD website were searched for both ecosystems. A grided file at 1 x 1 degrees and 0.5 x 0.5 degrees resolution was downloaded to obtain temperature and rainfall data (https://dsp.imdpune.gov.in). For analysis purposes, rainfall data were subdivided into two variables, summer rainfall (March-May) and monsoon rainfall (June - September). Temperature data were categorized according to the season into maximum and minimum monsoon and summer temperature. The annual mean was also considered separately for description purposes. A final list of climate variables tested for the trend is given in Table 1. Significant changes between both ecosystems were compared using a pairwise t test or a test depending on the statistical distribution of climate variables. The study was limited to the past four decades, as the objective was to see the recent changes in the climate.

Identification of long-term climate trends

Modified Mann-Kendall (MK) test statistics and sequential Mann-Kendall (SQMK) plot results were used to study the climate of the Keoladeo and Bhitarkanika ecosystems. Modified Mann-Kendall's (MK) test was applied to test the long-term trends of climate parameters. The modified MK test is not affected by autocorrelated data (Hamed and Rao 1998). Zc statistics were calculated for the identification of monotonic trends. If the Zc value was >1.96 (at the 95% confidence level), the null hypothesis was rejected, i.e., there was no trend. At the 90% confidence level, the null hypothesis was rejected if the Zc value was >1.645. Apart from Z statistics, Sen's slope was also calculated to check the magnitude of change (Hamed and Rao 2008). Sen's slope is a nonparametric test and robust in the quantification of the magnitude of change (Radziejewski and Kundzewicz 2004). The positive and negative values of Sen's slope indicate increasing and decreasing trends, respectively. The MK test is useful in detecting long-term trends, but it is not adequate to detect short-term trends in a long data series. Sequential Mann-Kendall's (SQMK) plot was applied to detect the point of a trend change (Salehi *et al.,* 2020). Although Sen's slope is a good estimate to identify long-term trends, it cannot point to changes between the time series. A short-term trend can also be easily identified using a sequential MK plot in a long series of data. This test utilizes the calculation of a progressive time series u(t) and a backwards series u'(t) to identify changes in the values of a variable (Partal and Kahaya 2007). If a progressive series u(t) crossed the 95% confidence limit and did not return, it indicated the occurrence of either a significant increasing or decreasing trend. The sudden change could also be statistically significant provided u (t) and u'(t) cross with each other after straight lines at ± 1.96 (95% confidence limit) in the SQMK plot. SQMK could also be applied in detecting insignificant trend changes. All analyses were performed using program *R.*

RESULTS AND DISCUSSION

Climate of Bhitarkanika and Keoladeo

The present study showed that both Keoladeo and Bhitarkanika ecosystems differed in climatic conditions. Annual rainfall in both ecosystems was significantly different (t = -19.146, p value = 0.0000). Bhitarkanika receives more annual rainfall than Keoladeo (Table 1, Fig. 2). Expectedly, total rainfall in both wetland habitats was highly correlated with monsoon rainfall ($COR_{BHITARKANIKA}$ = 0.87, $COR_{KEOLADEO}$ = 0.98). Most of the rainfall was received during the monsoon, and

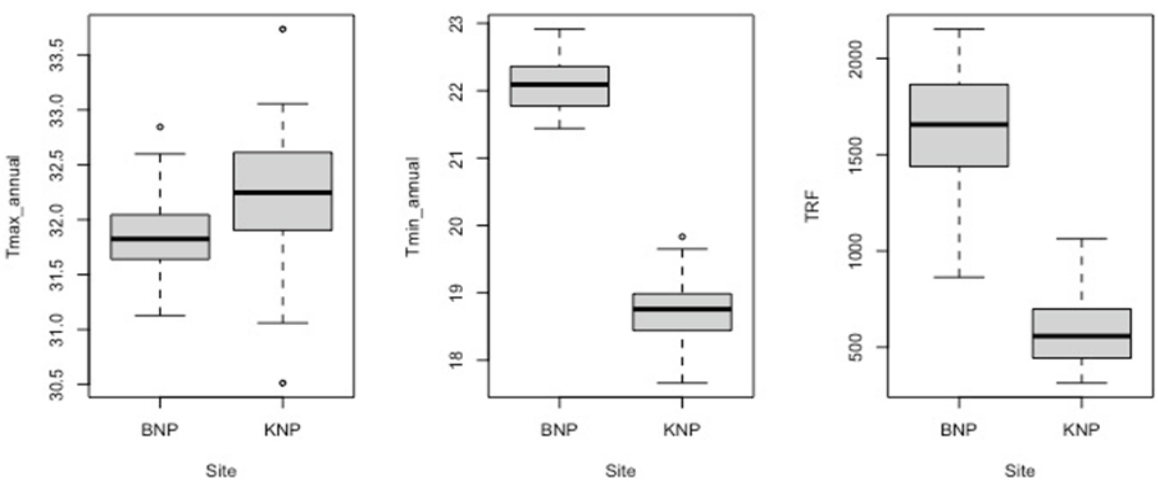

Fig. 2. *Boxplot showing differences between annual climate conditions: a) maximum temperature (degree Celsius), b) minimum temperature (degree Celsius), and c) total rainfall (TRF) (mm)*

Table 1. Descriptive statistics of climate parameters of the wetlands

Variable/Site	BHITARKANIKA			KEOLADEO		
	Mean (SE)	**Stnadard Deviation**	**Range**	**Mean**	**Stnadard Deviation**	**Range**
Annual Temperature (max)	31.87	0.38	1.72	32.23	0.58	3.22
Annual Temperature (min)	22.09	0.39	1.47	18.71	0.48	2.17
Summer temperature (max)	35.12	0.7	3.8	36.77	1.2	6.54
Monsoon temperature (max)	32.34	0.45	1.62	35.52	0.76	4.28
Summer temperature (min)	24.2	0.57	2.66	20.66	0.85	4.46
Monsoon temperature (min)	24.88	0.39	1.68	24.75	0.45	1.71
Annual Rainfall	1630.47	302.38	1289.03	582.99	176.85	748.82
Summer Rainfall	184.13	107.03	446.47	25.86	22.81	109.49
Monsoon Rainfall	1352.85	306.07	1281.45	531.23	180.51	735.477

Note: Values of temperature and rainfall are in degrees Celsius and millimeters

hence, the strong positive correlation was between total annual rainfall and the monsoon rainfall. Monsoon rainfall and summer rainfall were significantly higher at Bhitarkanika (Fig. 3, Table 1). Keoladeo faced a scarcity of rainfall and remained dry in summer. Overall, Bhitarkanika received approximately 200% more rainfall than Keoladeo (Table 1).

At both Bhitarkanika and Keoladeo, summer was highly variable in temperature (Table 1, Fig. 3). Keoladeo was slightly warmer but also experienced lower temperatures. Summer at Bhitarkanika was also comparatively static in temperature (Table 1, Fig. 3) and cooler than Keoladeo (Table 1). The monsoon in Keoladeo was warmer than that in Bhitarkanika. Overall, Keoladeo was warmer and drier than Bhitarkanika (Table 1). In the long-term climate, Keoladeo experienced more variation in rainfall and erratic temperature conditions (Fig. 2, Table 1).

Trend in rainfall and temperature

Annual rainfall at Bhitarkanika showed an increasing trend (Table 2), and no significant changes were detected in rainfall trends (annual, monsoon or summer) at Keoladeo. Although annual rainfall showed an increasing trend, a significant increase was not recorded in monsoon or summer rainfall at Bhitarkanika, indicating a possible rainfall change in other seasons. Mondal *et al.* (2015) also found a significant increasing trend of rainfall (1871-2011) during summers and winters in the east coast region of India, confirming the results of this study. After 1987, Bhitarkanika experienced an overall increase in rainfall (Fig. 4); however, a decreasing trend was recorded in the last decade (after 2010). As expected, a similar pattern was recorded in summer and monsoon rainfall. A small insignificant declining trend of rainfall was observed at Keoladeo (Table 2). Similar to Bhitarkanika, Keoladeo also underwent an increasing trend from 1987 to 2000, after which there was a decline in the rainfall trend (Fig. 4).

Temperature (max) significantly increased in the Bhitarkanika region. The annual, summer and monsoon temperatures (max) increased, suggesting an impact of

Table 2. Modified MK trend test results of rainfall and temperature (1980-2020)

Variable	BHITARKANIKA		KEOLADEO	
	Sen's slope	**New p value**	**Sen's slope**	**New p value**
Annual Rainfall	5.24E+00	**2.75E-02**	1.46E+00	6.13E-01
Summer Rainfall	5.64E-01	5.22E-01	4.03E-01	1.02E-01
Monsoon Rainfall	5.336596	0.2043665	1.19E+00	6.78E-01
Annual Temperature (Max)	1.72E-02	**1.84E-04**	2.94E-04	9.19E-01
Summer Temperature (Max)	1.93E-02	**3.02E-02**	2.33E-02	**2.45E-02**
Monsoon Temperature (Max)	2.31E-02	**3.40E-04**	4.96E-03	5.52E-01
Annual Temperature (Min)	3.50E-03	5.50E-01	2.19E-02	**1.02E-05**
Monsoon Temperature (Min)	6.71E-03	1.11E-01	2.24E-02	**1.07E-03**
Summer Temperature (Min)	5.53E-03	4.38E-01	2.68E-02	**1.39E-02**

*Significant trend changes are marked in bold

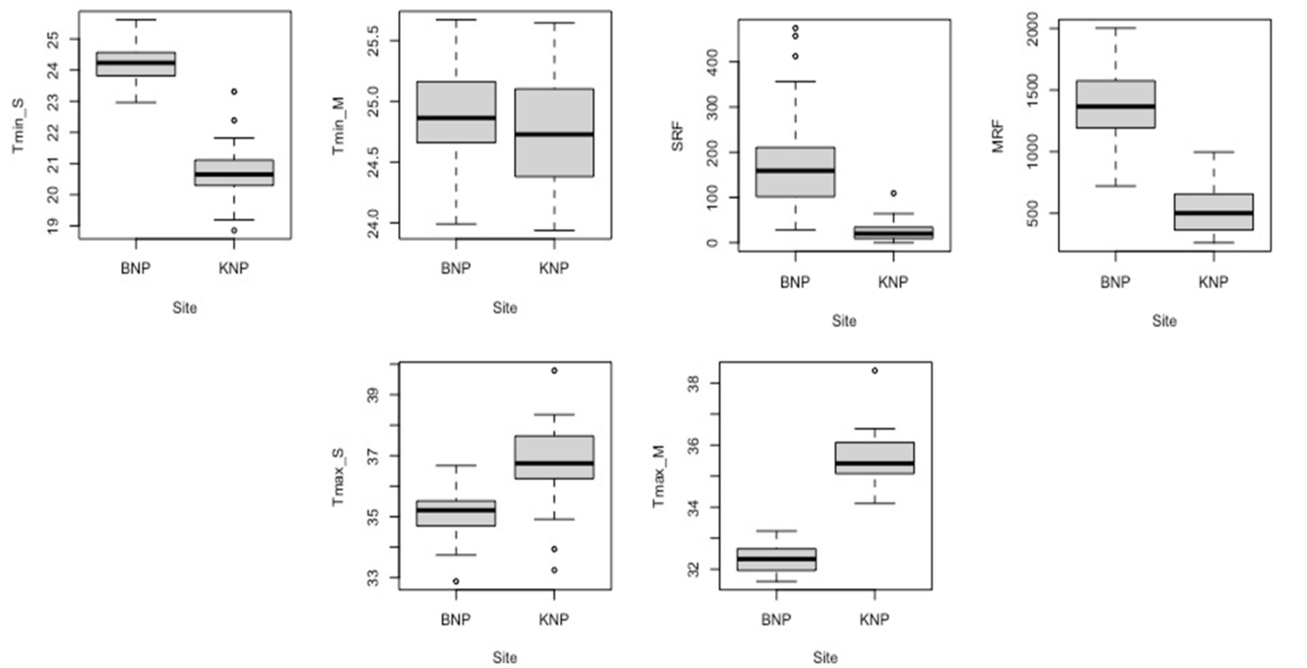

Fig. 3. *Seasonal climate differences between Bhitarkanika and Keoladeo (minimum summer temperature = Tmin_S, maximum summer temperature = Tmax_S, minimum monsoon temperature = Tmin_M, maximum monsoon temperature = Tmax_M, summer rainfall = SRF, monsoon rainfall = MRF) (values of temperature and rainfall are in degrees Celsius and millimeters)*

warming in the region. It is evident from Table 2 that the mean monsoon temperature (max) and mean annual temperature (max), both, have significantly increased in the past four decades at Bhitarkanika. Although insignificant, temperatures (min) during summer, monsoon, and annual also showed an increasing trend at Bhitarkanika. The annual temperature (max) at Keoladeo indicated no significant trend. The monsoon period temperature (max) showed a similar pattern. The temperature (min) trends at Keoladeo were similar to those at Bhitarkanika. The point of temperature (min) change (1998) for both seasons, summer and monsoon, was the same (Fig. 5). The temperature change started to occur after 1994.

Summer temperature (max) increased significantly and more strongly at Keoladeo, as indicated by the value of Sen's slope in Table 2. The summer temperature (min) also showed a significant increase only at Keoladeo and not at Bhitarkanika. Summer temperatures started increasing significantly post-1998 at Keoladeo (Fig. 6). Although the monsoon temperature (max) remained static, the minimum temperature recorded during the monsoon increased significantly at Keoladeo. Overall, there was a significant increase in minimum and maximum temperatures at Keoladeo and Bhitarkanika, respectively.

Coastal areas have experienced considerable warming in India (Mondal *et al.,* 2012). Orissa has seen significant changes in the rainfall pattern for more than 100 years (Patra *et al.,* 2012). The present study confirms the increasing trend in rainfall at Bhitarkanika in the last four decades, matching the rest of Orissa state (Patra *et al.* 2012). A mangrove habitat is even more susceptible to changes in the climate. Sippo *et al.* (2018) pointed out that mangroves can experience higher mortality because of extreme climate events such as extreme heat. The present study confirms the occurrence of higher temperatures and hence the vulnerability of Bhitarkanika mangroves.

The present study has concluded similar trends in rainfall in semi-arid zones, matching other studies (Mehta and Yadav, 2021, Ramarao *et al*., 2019, Singh *et al*., 2019, Pingale *et al*., 2016). Pingale *et al*. (2016) did not find a significant trend in rainfall at Ajmer. A 144-year long-term climate analysis of eastern and western Rajasthan concluded similar results (Mehta and Yadav, 2021). A vulnerability assessment of Rajasthan to climate change categories District Bharatpur, location of Keoladeo, as vulnerable to climate change (Singh *et al.,* 2019). The present study and other earlier studies (Mehta and Yadav, 2021, Jhurawat *et al.,* 2020, Ramarao *et al.,* 2019, Singh *et al.,* 2019 and Pingale *et al.,* 2014) of the region indicate that the Keoladeo region is vulnerable to climate change, even though there is no significant trend of rainfall. However, studies do indicate high interannual variability in rainfall (Pingale *et al.* 2014). Moreover, a few more studies on aridity index analysis have confirmed this region's increasingly drier conditions, making this habitat more vulnerable to climate change (Jhurawat *et al.,* 2020, Ramarao *et al.,*

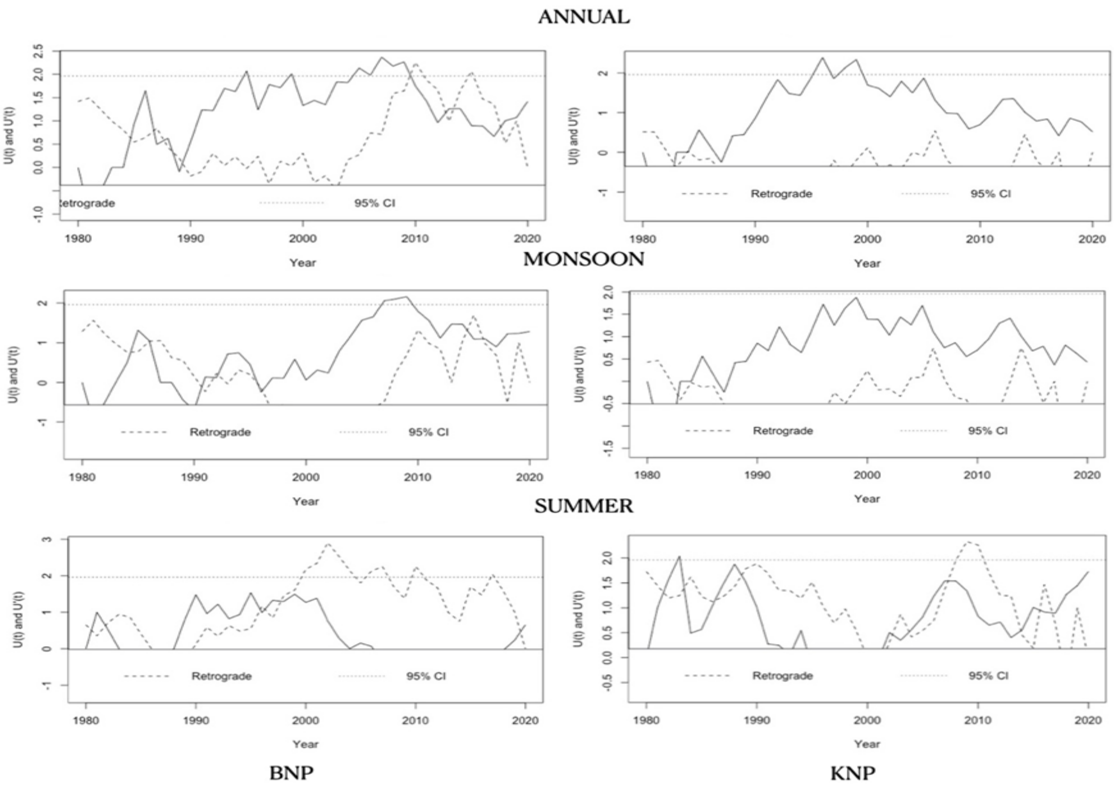

Fig. 4. *Sequential Mann-Kendall plot showing seasonal rainfall trends at Bhitarkanika and Keoladeo*

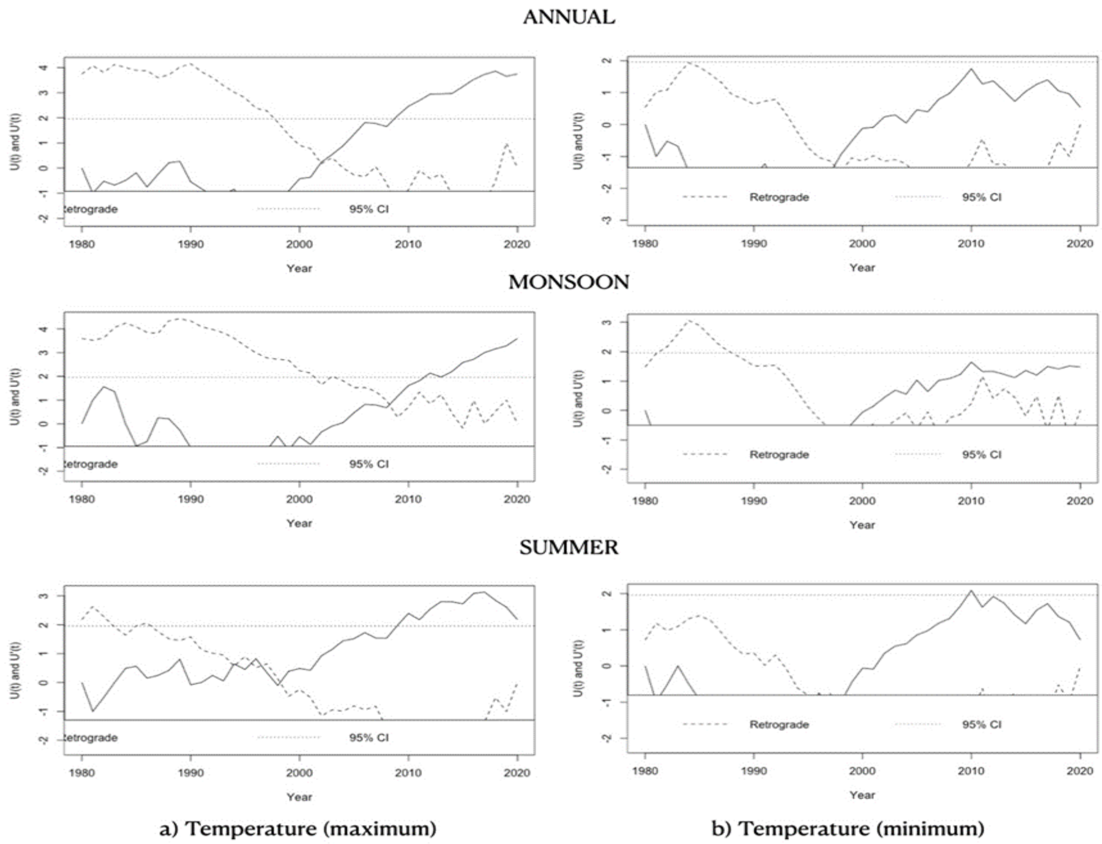

Fig. 5. *Sequential Mann-Kendall plot showing the seasonal temperature trend at Bhitarkanika*

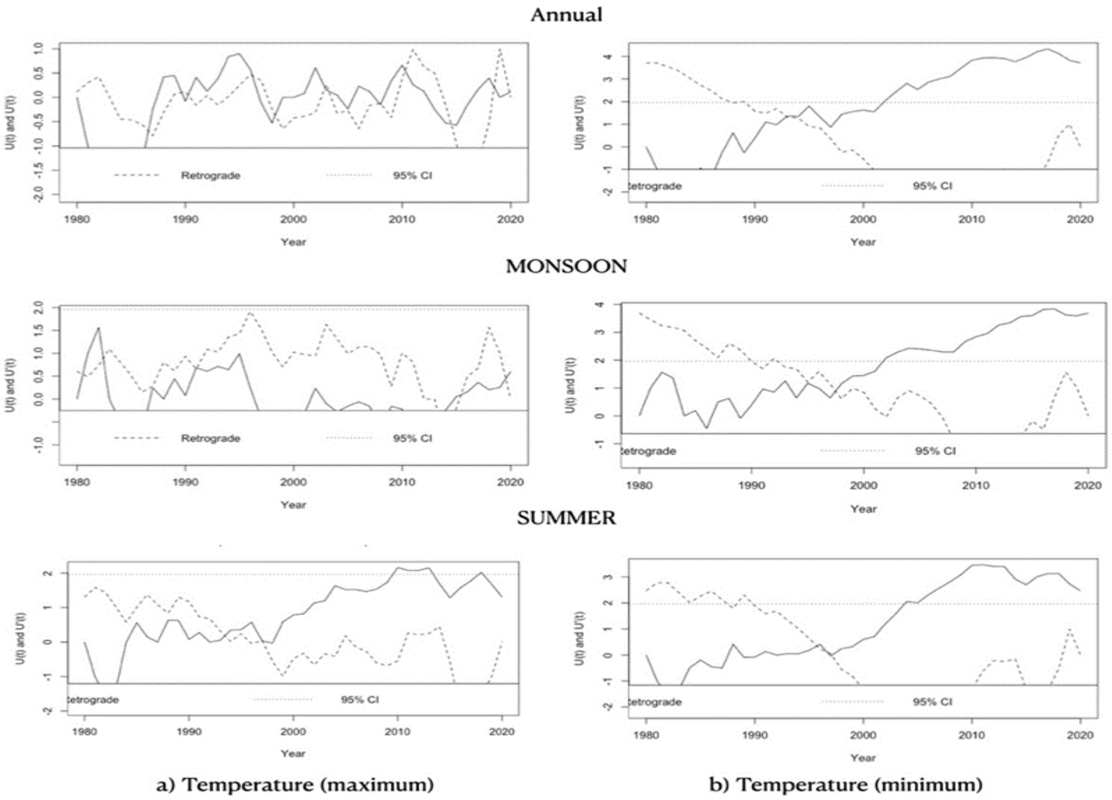

Fig. 6. *Sequential Mann-Kendall plot showing the seasonal temperature trend at Keoladeo*

2019).

The expected results in this study indicate very different climate conditions at Keoladeo and Bhitarkanika. Previous studies (Mondal *et al.,* 2012, 2015, Pal *et al.,* 2019, Ramarao *et al.,* 2019, Singh *et al.,* 2019) and the present study showed that both ecosystems are experiencing changing rainfall and temperature patterns. Both ecosystems are located at unique locations and hence have different climate impact scenarios. The Keoladeo region is getting warmer during summers, with temperatures (min) rising in all seasons. The warmer and drier conditions can cause a decline in the habitat quality of Keoladeo; hence, a management plan is needed according to the climate change patterns. Notably, Bhitarkanika is also getting warmer with more rainfall. This changing climate will also affect the habitat quality of the Bhitarkanika wetland. Authorities should be more careful in monitoring the situation at Bhitarkanika because of its mangrove nature. Mangroves are even more sensitive to climate change (Sippo *et al.,* 2018)

The present study is limited in exploring all the parameters of climate and hence limited in understanding the full situation climate impact. Other parameters, such as wet day frequency, cloud cover, potential evapotranspiration, and reference evapotranspiration, will provide a better understanding of climate conditions. It is also important to further expand the scope of this study to link the long-term monitoring of biodiversity in these two wetlands with climate change (Dwevedi *et al.,* 2021). Although both are monitored to some extent (Dwevedi *et al.,* 2021, Pradhan and Kar 2018, Kumar 2009), the inclusion of some parameters on biodiversity will improve the understanding of the impact of climate change on wetlands. Presently, some biodiversity data are available, but there are some data gaps (Dwevedi *et al.,* 2021, Pradhan and Kar 2018). Although the data gaps can be overcome by applying suitable statistical methods (Dwevedi *et al.,* 2021), complete data sets are always recommended. In the light of earlier and present studies, an integrated long-term monitoring and management plan for Bhitarkanika and Keoladeo is recommended to allow better planning and conservation of these wetlands. Similar studies must be applied to other wetlands.

Conclusion

The present study compares climate conditions in India's Keoladeo and Bhitarkanika regions over the past 40 years. Both ecosystems have gone under significant changes in climatic conditions. They are getting warmer with erratic short-term patterns of temperature. The rainfall conditions are static and increasing at Keoladeo and Bhitarkanika, respectively. Semi-arid conditions in eastern Rajasthan make Keoladeo more vulnerable to warming and hence threaten the ecology of the ecosystem. Bhitarkanika, although warming, is receiving more rainfall. However, changing climate conditions need to be studied with other aspects, such as the local hydrology and biodiversity of the ecosystem, to understand the impact of climate change. More specific studies on ecology will help in framing the climate-resilient management plan for both ecosystems. This study is the first attempt to look at the short-term and long-term climate trends at the regional scale of both ecosystems. It is suggested that a sustainable monitoring plan of different aspects of the ecosystem be implemented to link the climate condition with abiotic and biotic factors of both ecosystems.

Conflict of interest

The authors declare that they have no conflict of interest.

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