Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Impact of climatic parameters on the extent of mangrove forests of southern Iran

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ABSTRACT

Mangrove forests play a valuable role in maintaining the coastal ecosystem. Global warming alongside human activities has caused reduced extent and health of these ecosystems in recent years. This study aimed to examine the variability of the extent of mangrove forests and the sea surface area in response to changes in climatic parameters in the south of Iran. To achieve this, the climatic data recorded at Bandar Abbas Synoptic Weather Station and Landsat series of satellite images were used. To detect the trends of meteorological parameters during 1987-2017, the modified Man-Kendall test and the Sen's slope estimator were employed. We investigated the regression relationship between climatic parameters as well as the sea surface area and the mangrove forest extent. The results showed that mangrove forest extent was about 73.08 km^2 in the first year of study (1987), which increased to 88.73 km^2 (21%) in 2017. The minimum temperature ($Z = 2.77$, $\beta = 0.0186$), maximum temperature ($Z = 2.066$, $\beta = 0.0362$), and the extent of the mangrove forests ($Z = 2.58$, $\beta = 0.0405$) displayed significantly growing trends. In contrast, the mean temperature, precipitation, relative humidity, and the sea surface area had no significant trends during the study period. The minimum temperature presented the highest correlation coefficient with the mangrove forest extent (61%). It is expected, therefore, along with global warming and increasing minimum temperature, the extent of mangrove forests would have a growing trend in the south of Iran in the future. The results of this study can be used by natural resources and forest managers to determine the best place for afforestation in order to perform better protection of these forests.

Keywords: Climate change; Coastal ecosystem; Hormozgan; Landsat; Minimum temperature.
Article type: Research Article.

INTRODUCTION

Mangroves are forest formations estimated to cover about 12 to 20 million hectares worldwide (Food and Agriculture Organization of the United, 2007). These forests exhibit a great degree of community persistence and ecological stability in front of environmental inconstancy (Alongi 2015). Mangrove forests help decrease atmospheric carbon dioxide, protect coastal lines, and provide food and shelter for ecosystems. However, they are among the top threatened habitats worldwide caused by human activities, climate change, and coastal-related natural disasters such as flood, heavy rainfall, tsunami, etc. (Pham *et al*. 2019). Research showed that in South Asia (Giri *et al.* 2014), South and Southeast Asia (Parida *et al.* 2014; Richards & Friess 2016), West Africa (Carney *et al.* 2014), Amazon in Brazil (Barros & Albernaz 2014), Indonesia (Murdiyarso *et al*. 2015), India (Giri *et al*. 2014; Srivastava *et al*. 2015), Myanmar, Malaysia, Cambodia, Indonesia and Guatemala (Hamilton & Casey 2016), South American countries (López-Angarita *et al.* 2016), Southwest Australia (Lovelock *et al.* 2017) and Myanmar (Estoque *et al.* 2018), mangrove forests extent have shrunk by human activities and climate change. Studies have shown that global mangrove deforestation rates range from 0.16% to 0.39% per year, with

Publisher: University of Guilan, Iran

Southeastern of Asia being an area of concern with mangrove deforestation rate between 3.58% and 8.08 (Hamilton & Casey 2016). Literature has also confirmed that approximately 36,000 ha of mangrove forest has been destroyed since the 1960s, with nearly 70% of reported mangrove loss due to climate change (Sippo *et al.* 2018). It is expected that the impacts of climate change on the mangrove ecosystem services would challenge-dependent livelihoods (Uddin *et al.* 2014). Changes in climate parameters, such as sea levels rise (SLR), increasing temperature and droughts, rising the frequency or severity of storms and especially precipitation and minimum temperature, affect the species richness of mangrove forests and its abundance (Jennerjahn *et al.* 2017; Osland *et al.* 2017). Additionally, the global sea level has risen by 3.2 mm per year over the last decades (Church & White 2011; Wolanski & Elliott 2015) and is likely to increase by 0.28 to 0.98 m by 2100 (Pachauri *et al*. 2014). A recent study in southern Iran at Jask and Chabahar stations also confirmed that the sea level has risen between 2.88 to 5.47 mm per year in recent decades (Etemadi *et al.* 2018). Although climate change often threatens the ecosystem function of mangrove forests, these changes have sometimes expanded the extent of these forests. For example, the results of some studies related to mangrove forests on the coast of Texas, USA, in the western Gulf of Mexico (Armitage *et al.* 2015), north Australia (Asbridge *et al.* 2016), and south of Iran (Etemadi *et al.* 2018) have indicated that the extent of mangrove forests have increased in recent decades as a result of sea level rise and climate parameters change as well as increasing the minimum annual temperature. Guo *et al.* (2013) showed that as conditions became unfavorable at lower latitudes, such as rising temperature, many species expanded their distribution to higher latitudes due to the lower temperature in these areas. About 93.37 km^2 of the shorelines of Iran were covered with mangrove forests in 2002. The largest extent (67.5 km^2) occurs between the northwest region of the Qeshm Island and the Khamir Port (Zahed *et al.* 2010). In recent years, Iranian authors, e.g., Etemadi *et al.* (2018) have examined the changes of mangrove forest extent in southern Iran (Hormozgan Province, east and west of Jask) using aerial photographs and satellite imagery. They have concluded that during the 1956-2012 period, the extent of mangrove forests increased significantly. In addition, Toosi *et al.* (2019) have reported that the extent of mangrove forests in the northwest region of Qeshm Island and Khamir port increased by 8.9% and 4%, respectively, using satellite imagery. Mafi-Gholami *et al.* (2019) have presented a relationship between Leaf Area Index (LAI) and Standardized Precipitation Index (SPI) in mangrove forests of southern Iran; the LAI health index decreased as drought intensified. Although the trend of changes in mangrove forests in Iran has frequently been studied in recent decades, however, the relationship between the changes of the time-series of forest extent alterations and the climatic parameters, as well as the sea level changes have not been considered. The present study investigated the relationship between the time series of mangrove forests located in the Khamir Port as well as the northwest of Qeshm Island and time-series variations of climatic parameters such as temperature, precipitation, and SLR using satellite imagery and statistical analysis.

MATERIALS AND METHODS

Iran's natural mangrove forests extend along the north of the Oman Sea and the Persian Gulf, with *Avicennia marina* being the dominant species in these forests (Mafi-Gholami *et al*. 2019; Zahed *et al*. 2010). The mangrove forests are located between the Khamir Port and the Qeshm Island in Hormozgan Province, constituting the largest part of Iran's mangrove forests (Fig. 1). This region has a warm and humid climate (Mafi-Gholami *et al.* 2019). Bandar Abbas Synoptic Weather Station recorded an average temperature of 27.0 °C with average maximum and minimum temperatures of 32.3 °C and 21.9 °C, respectively, from 1987 to 2017. In addition, yearly relative humidity and precipitation were recorded at 62.3% and 171 mm, respectively. There are two tides in the area every day with significant fluctuations. During the high tide, the northern coast is submerged, while during the low one, the site is marshy. In the south-western regions of the mangrove forests, changes in the sea surface areas rise up to 5 m (Toosi *et al*. 2019).

Satellite data and image preprocessing

Landsat satellite imagery was used to study the trend of changes in the extent of the mangrove forest cover. For this purpose, spectral bands of Landsat 5, 7, and 8 were taken from the US Geological Survey (USGS). Of the 31 images received between 1987 and 2017, 15 images were from Landsat 5 (TM) satellite, 12 images from Landsat 7 (ETM+), and 4 images from Landsat 8 (OLI). All images were taken in August, with 160 path and 41 rows. The existence of atmospheric, geometric, and radiometric errors was evaluated to control the data quality. The accuracy of the images was checked and verified. The radiometric correction was performed on all images. The FLAASH module was used for atmospheric correction to ensure accurate spectral data retrieval. The purpose of atmospheric corrections is to convert the TOA radiation of objects into reflections from the Earth's surface (Wolanski & Elliott 2015; Almahasheer *et al*. 2016; Attafi *et al*. 2021). An additional challenging issue in the pre-processing of ETM+ sensor images is the error correction of the black bars (the chapping of bar lines) known as Scan Line Corrector (SLC). To fix this error, the Landsat Gap-fill extension was used in ENVI 5.3.

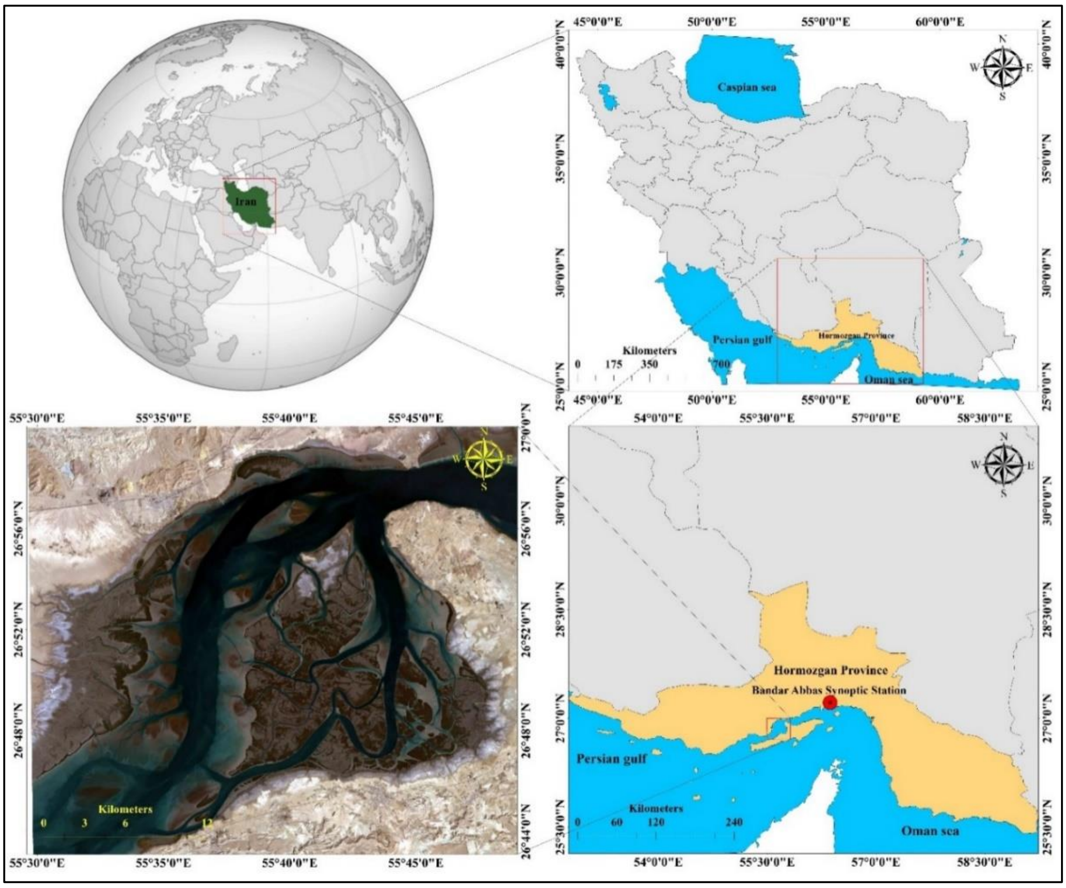

Fig. 1. Location of the Mangrove forest in Khamir port and Qeshm Island of Hormozgan province, south of Iran.

Images classification

One of the most well-known supervised classification algorithms widely used in the studies of land use classifications and mangrove forest cover is the Maximum Likelihood classification (MLC; Srivastava *et al*. 2015; Asbridge *et al*. 2016; Mafi-Gholami *et al*. 2017; Etemadi *et al.* 2018; Lee *et al*. 2018; Alemi Safaval *et al*. 2018). The MCL algorithm examines the covariance and variance of the group spectral response patterns when classifying an unknown pixel. For this purpose, it is assumed that the distribution of cloud points that form the training data for that group is Gaussian (normal distribution). Based on this assumption, the distributional behavior of each group with a spectral response pattern can be usefully described by mean vector and covariance matrices (Srivastava *et al*. 2015). Thus, each pixel is classified into a class with the highest probability. This probability can be classified as an indicator of classification certainty, while classifying the pixels with the maximum likelihood below the defined threshold is rejected (Gomariz-Castillo *et al.* 2017). Given the spectral characteristics of images and recognition of land use in the study area (Thakkar *et al.* 2017), four land use classes including, mangrove (M), shrub (Sh), bare lands (Bl), and water (W) were considered. The false-color composite as well as Google Earth images, were used to capture training points for MLC classification. After classifying the images, to enhance the separation of the classes, especially the class of the mangrove forest, using the ARC GIS and Google Earth Historical Images, the errors of map classification were corrected (Jayanthi *et al*. 2018; Soltaninejad *et al*. 2020). Finally, the classification map was prepared with optimum accuracy.

Caspian J. Environ. Sci. Received:
DOI: Article type: Research

Climatic data

Daily climate data collected by Bandar Abbas Synoptic Weather Station were used to investigate the effect of climatic parameters on the mangrove forest cover in the study area. The station is located 59 km far away from the study area at latitude 48° 12' 27" North and longitude 56° 22' 06" East. Time series of mean, minimum and maximum temperatures, relative humidity, and precipitation were extracted during the 1987-2017 period, with the trend of changes and their relationships with forest cover changes were also examined. MATLAB and SPSS software were used to measure the significance of the trends.

Modified Mann–Kendall test

The modified Mann-Kendall test was used to study the trend of time-series variations of climate parameters, the extent of mangrove forests, and the sea level. The Mann-Kendall test is a non-parametric test generally used to detect evolutionary trends in environmental, climatic, hydrological, and meteorological datasets. This test statistically examines the monotonic upward or downward trends (Asfaw *et al*. 2018). The Mann-Kendall test was first introduced by Mann in 1945 and then developed by Kendall in 1966 (Mann 1945; Kendall 1975). Negative and positive Z statistics values in this test indicate descending and ascending trends, respectively (Huang *et al*. 2017; Yevenes *et al*. 2018). In this test, the difference between each observation is first calculated with all observations, and then the parameter S is calculated as below (Mann 1945; Kendall 1975):

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \mathrm{sgn}\left(x_j - x_i\right) \quad \textbf{(1)}$$

Where, x_j is the value of the j^{th} data, n represents the number of data, and sgn (θ) denotes the sign function and calculated as:

$$\mathrm{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases} \quad \textbf{(2)}$$

Mann and Kendall showed that when n > 8, the S statistic is almost normally distributed and its mean is zero, where its standard deviation can be obtained by Eq. 3 (Mann 1945; Kendall 1975).

$$\mathrm{Var}(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_i-1)(2t_i+5)}{18} \quad \textbf{(3)}$$

where, t_i indicates the number of tie data with the i^{th} group. Finally, the Z statistic of the Mann–Kendall test can be obtained as:

$$Z = \begin{cases} \frac{s-1}{\sqrt{\mathrm{var}(s)}} & s > 0 \\ 0 & s = 0 \\ \frac{s+1}{\sqrt{\mathrm{var}(s)}} & s < 0 \end{cases} \quad \textbf{(4)}$$

The Z statistic has the standard normal distribution with unit variance and zero mean. The null hypothesis (H_0) is based on the randomness or absence of any trend in the data series. In contrast, the alternative hypothesis (H_1) indicates the existence of a trend in the data series (Moazed *et al*. 2012). Since most hydrological and meteorological time series may have significant autocorrelation, it should be ensured that the studied time series have no significant autocorrelation before using the Mann–Kendall test (Ahmadi *et al*. 2018). The modified Mann–Kendall test was proposed by Hamed & Ramachandra Rao (1998). In this method, all significant autocorrelation coefficients are removed from a dataset before using the Mann–Kendall test. Initially, modified variance V(s)* was used as Eqs. 5 & 6.

$$V(S)^* = V(S)\frac{n}{n^*} \quad \textbf{(5)}$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)n-2)}\sum_{i=1}^{n-1} \quad (n-i)(n-i-1)\,(n-i-2)r_i \quad \textbf{(6)}$$

where, V(S) is estimated using Eq. 3 and r_i is the delayed autocorrelation coefficient. To calculate the Z statistic in the modified version of the Mann-Kendall test in Eq. 4, V(S) is substituted by V(S)*.

Sen's estimator

The slope of the trend line of the data series is calculated using the nonparametric Sen's slop estimator method presented by Theil (1992) and Sen (1968) using Eq. 7:

$$\beta = \text{Median}\left[\frac{X_j - X_i}{j-i}\right] \forall i < j \qquad \textbf{(7)}$$

where, β is the slope estimator of the trend line, while X_j and X_i represent the observed values of j and i, respectively. Negative values of β indicate a diminishing trend, while positive ones show an ascending one.

Statistical analysis of the relationship between mangrove forest cover extent and climatic parameters as well as sea surface area

To study the statistical relationship between mangrove forest cover plus sea surface area and climatic parameters such as minimum temperature, mean temperature, relative humidity, maximum temperature, and precipitation over 31 years (1987-2017), simple and multiple linear regression analyses were used using Excel software. In the simple linear regression, the correlation coefficients of independent climatic variables with the dependent variables of mangrove forest cover were investigated. On the other hand, in the multiple regressions, the linear relationship between the independent variables (e.g., climatic parameters and sea surface area) and a dependent variable (e.g., mangrove forest extent) was investigated.

To achieve this, stepwise regression was used. In this method, all independent variables were introduced into the model. When computing the independent variable, in case it has no significant effect on the dependent variable, it would be removed from the analysis.

RESULTS AND DISCUSSION

After initial image processing and land use classification, the trend of mangrove forest extent changes between Qeshm Island and Khamir Port was examined. In addition, the extent of mangrove forest cover and the sea surface area level was calculated during 1987-2017 period (Table 1). Fig. 2 displays the annual changes in the mangrove forest extent during 1987-2017. The results indicated significant increasing trends for both minimum and maximum temperatures (Z = 2.77, β = 0.0188; Z = 2.066, β = 0.0362) at 1% and 5% level of significance. The extent of mangrove forest showed an ascending trend (Z = 2.58, β = 0.405), while the sea surface revealed no significant trend (Table 2). The significant relationship between the mangrove forest extent and climatic parameters during the studied period showed that although there was an inverse relationship between relative humidity along with the sea surface area and the mangrove forests extent, the correlation between these relationships was very weak (Fig. 3). Furthermore, the regression relationship between the relative humidity along with precipitation and the extent of mangrove forests was not significant. However, the regression relationship of minimum, maximum, and mean temperatures with the extent of mangrove forests at the level of 1% was significant. Meanwhile, the minimum temperature with 61% correlation demonstrated the greatest effect on increasing and decreasing the extent of mangrove forests. Fig. 5 revealed that the extent of mangrove forests grew over 31 years; it was about 73.9 km^2 in 1987, and increased by 21% (15.6 km^2) to 88.7 km^2 in 2017. Notably, the trend of changes in the extent of mangrove forests was increasing but not continuous over the years (Fig. 4). In a 31-year period, the mangrove forest showed both ascending and descending trends over the study area. For example, the mangrove forests showed a steady increase in the Mardo Forest located in the northwest of the study area forests over the 31-year period (Fig. 5).

The results showed that the minimum, maximum, and mean annual temperatures have a significant ascending trend among the studied climatic parameters during the 1987-2017 period. This result was in line with Etemadi *et al.* (2018), who reported that the temperature increased by 14.3 C° in the last 42 years in southern Iran. The mangrove forests in the study area exhibited also a significant ascending trend during this period, as the extent of these forests has grown by about 21% during the 31 years.

Caspian J. Environ. Sci. Received:
DOI: Article type: Research

Table 1. Climatic parameters and mangrove forest extent and sea surface area during the period 1987-2017.

Year	Mangrove forest extent (Km^2)	Sea surface area (Km^2)	Min air temperature (°C)	Max air temperature (°C)	Mean air temperature (°C)	Relative humidity (%)	Annual precipitation (mm)
1987	73.1	251.5	21.4	32.3	26.8	64.0	159.3
1988	81.4	288.9	21.9	32.1	26.9	65.5	207.9
1989	63.6	380.7	21.2	31.5	26.1	64.2	261.4
1990	67.2	401.5	21.9	32.0	26.8	66.4	138.9
1991	63.4	404.2	21.2	31.4	25.9	69.4	244.4
1992	63.3	399.6	20.7	30.7	25.6	66.7	375.8
1993	74.8	400.1	21.8	32.1	26.7	64.9	246.5
1994	65.7	271.7	21.8	32.2	26.8	66.8	33.8
1995	72.4	250.6	21.7	31.8	26.6	67.4	256.1
1996	66.7	234.0	21.7	31.8	26.5	67.2	348.3
1997	76.0	229.7	21.9	31.0	26.2	69.4	357.6
1998	73.4	330.1	22.3	33.1	27.4	64.8	215.4
1999	74.1	307.1	22.2	33.1	27.3	63.1	110.6
2000	78.4	230.7	21.8	32.9	27.1	63.6	213.7
2001	69.6	223.1	21.9	32.8	27.4	65.0	47.9
2002	77.9	237.5	22.4	32.6	27.4	62.8	112.0
2003	82.3	272.5	22.1	32.4	27.2	61.6	82.1
2004	84.8	304.5	22.3	32.9	27.5	61.6	71.0
2005	67.9	373.1	22.0	32.4	27.1	62.4	153.9
2006	71.8	382.2	22.1	32.3	27.2	63.9	158.5
2007	72.4	405.6	22.1	32.8	27.5	63.0	69.5
2008	63.6	400.5	21.3	31.9	26.5	62.4	101.5
2009	72.9	321.3	22.1	32.6	27.3	63.4	200.8
2010	67.4	399.2	22.0	33.3	27.5	60.6	24.4
2011	77.2	240.2	22.2	32.6	27.2	62.3	138.4
2012	79.0	239.5	22.0	32.8	27.3	59.7	89.4
2013	75.1	311.0	22.0	31.8	26.8	64.0	62.2
2014	75.0	397.0	21.8	32.1	26.8	65.7	314.4
2015	76.0	367.3	22.5	33.2	27.7	64.0	224.6
2016	82.4	356.0	22.0	32.9	27.4	65.5	56.6
2017	88.7	228.4	22.1	33.4	27.7	63.5	229.0

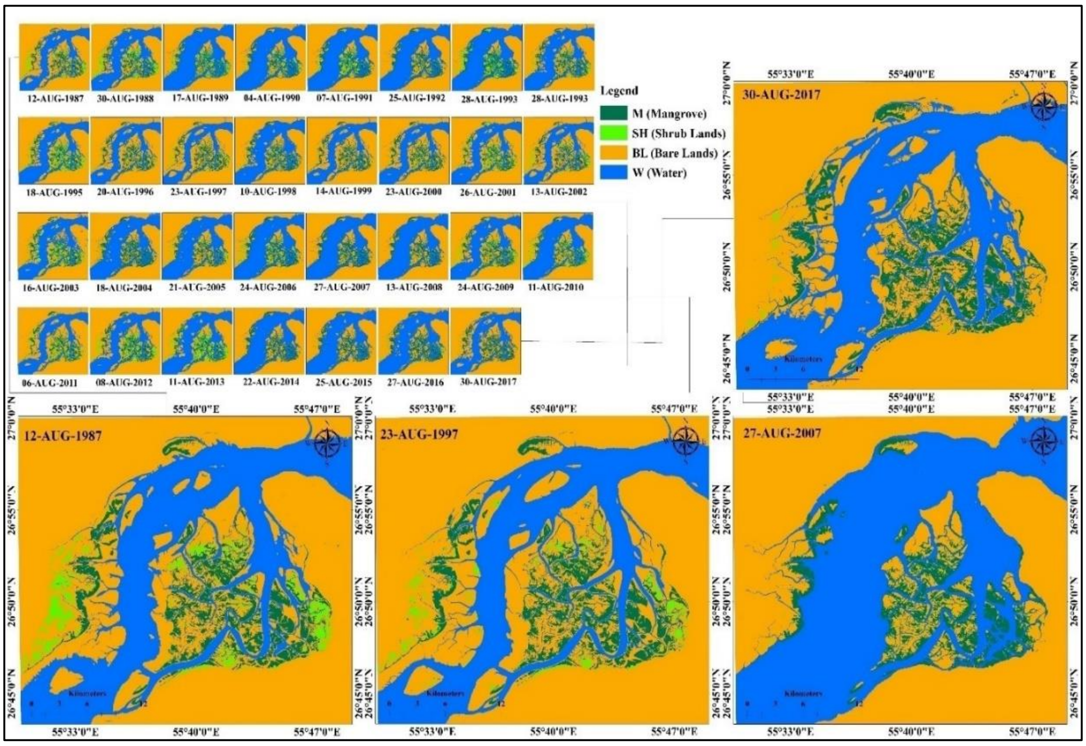

Fig. 2. Yearly changes in mangrove forest extent during 1987-2017.

Table 2. Results of Man-Kendall (MK) test and Sen's slop estimator tests for trends of climatic parameters, mangrove forest extent and sea surface area.

Variables	Z (MK)	β
Min air temperature (C°)	2.770**	0.0186**
Max air temperature (C°)	2.066*	0.0362*
Mean air temperature (C°)	1.930	0.0300
Relative humidity (%)	-1.211	0.1174
Precipitation (mm)	-1.870	-3.4520
Mangrove extent (km^2)	2.583**	0.04054**
Sea surface area (km^2)	-0.120	-0.1155

* 1 % level of significance **5 % level of significance.

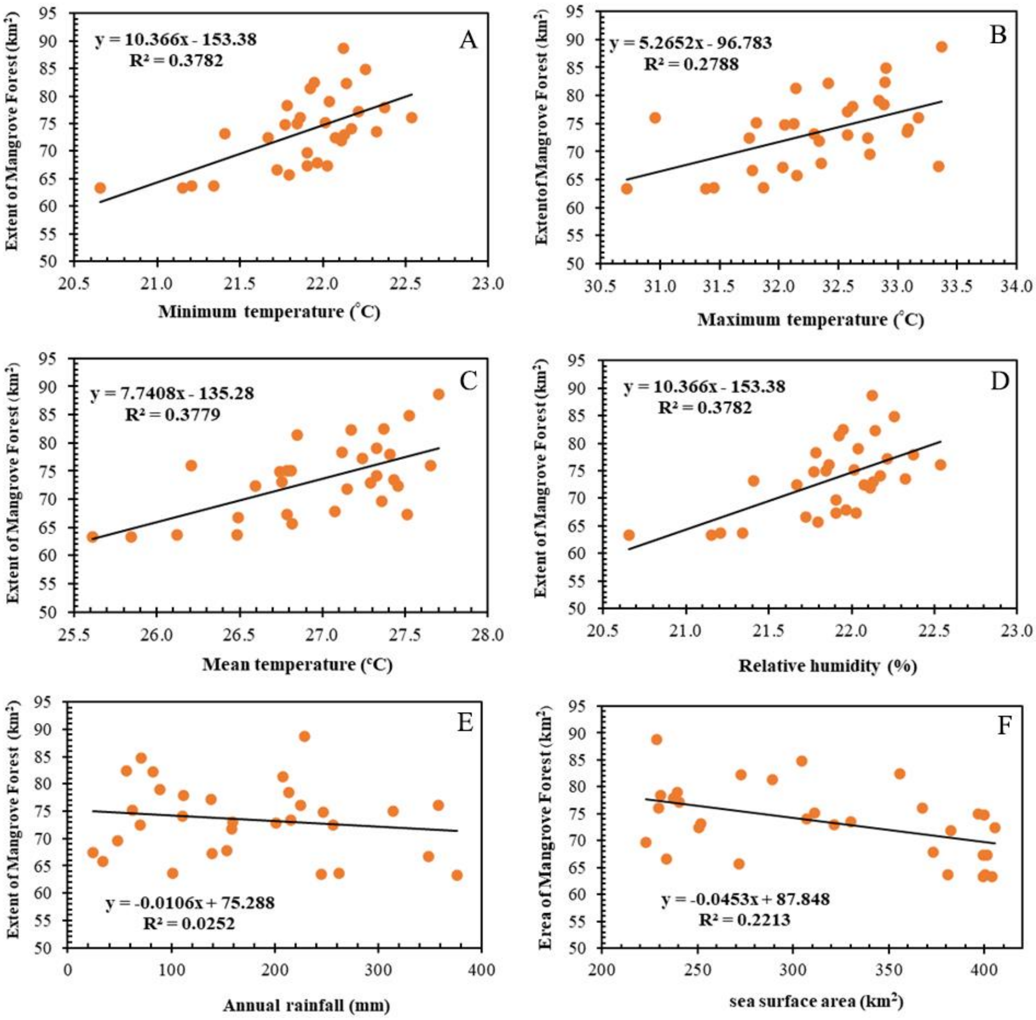

Fig. 3. The relationships between Mangrove forest extent with minimum temperature (A) maximum temperature (B) mean temperature (C) relative humidity (D) precipitation (E) sea surface area (F).

The trend of the mangrove forests extent demonstrated the highest slope compared to other parameters. In other words, the regression relationship between the extent of mangrove forests with the minimum, maximum, and mean annual temperatures revealed a positive linear relationship between the climatic parameters and the extent of mangrove forests; the highest correlation coefficient was related to the minimum and maximum temperatures. The slope of the regression line of the minimum temperature and the extent of the mangrove forest (α) was the highest. This suggests that increasing the minimum temperature showed the highest impact on the increased mangrove forests extent. This finding was even more critical as Etemadi *et al.* (2018) predicted that the minimum temperature in southern Iran would increase up to 38 °C in hot seasons in the future (2080-2099).

Caspian J. Environ. Sci. Received:
DOI: Article type: Research

Although very little information is available about the effect of warming on the physiology and phenology of mangrove trees, the optimum temperature for the photosynthetic process of mangrove trees is 32-28 °C , where this process is affected by temperature elevation (40-38 °C; Lacerda *et al*. 2002). Given that the highest and lowest minimum temperatures during the 1987-2017 period in the study area (Bandar Abbas Synoptic Weather Station) are 22.5°C and 20.7 °C, respectively, it is expected that by the elevated minimum temperature in the upcoming years, the extent of mangrove forests will grow in the study area. However, many studies suggested that the extent of mangrove forests is declining (Barros & Albernaz 2014; Carney *et al*. 2014; Estoque *et al*. 2018; Giri *et al*. 2014; Hamilton & Casey 2016; Lovelock *et al*. 2017; Murdiyarso *et al*. 2015; Parida *et al*. 2014; Richards & Friess 2016), while many other studies, especially at higher latitudes, have shown that the extent of mangrove forests has increased (Almahasheer *et al*. 2016, Armitage *et al*. 2015, Etemadi *et al*. 2018). Indeed, the elevated regional average temperature of air or/and sea can result in the expansion of the extent of some mangrove species to higher latitudes.

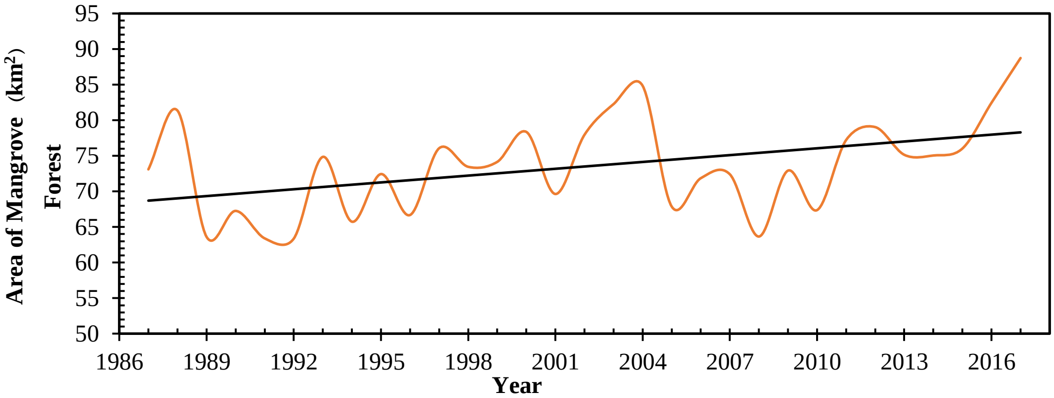

Fig. 4. The increasing trend in the extent of mangrove forests during 1987-2017.

The concentration of mangrove forests is currently limited by temperature (Barros & Albernaz 2014). In other words, the direct effects of increased CO_2 levels and rising temperature are likely to increase mangrove productivity, changing the phenological patterns such as the timings of flowering and fruiting, and expanding the ranges of mangroves vegetation into higher latitudes (Ellison 2000). The spread of mangrove forests has frequently been recorded in bays or basins of high latitudes. For example, Guo *et al.* (2013) reported that the mangrove covers expanded to higher latitudes in the northern Gulf of Mexico coast, the USA in freeze-free winters. Similarly, Armitage *et al.* (2015) reported that relatively mild winters on the Texas (USA) coast have led to the expansion of mangrove forests into extent populated by salt marsh plants over the past few decades. They concluded that climate change is expected to accelerate both the sea level rise as well as mangrove expansion. Cavanaugh *et al.* (2018) by examining the relationship between EVI index and climatic parameters in mangrove forests of North and South America concluded that there was a direct relationship between EVI index and annual minimum temperature; the mangrove forest extended to the nearby swamp or new habitat by the elevated annual minimum temperature. Some studies have shown that mangrove forests will possibly experience slight changes in regions by increasing precipitation, such as Southeast Asia and the west and central coasts of Africa (Alongi 2015). However, in our study area, annual precipitation did not experience any significant alteration and we detected no regression relationship between the annual precipitation and the mangrove forests extent. Thus, the annual precipitation had no significant effect on the changes in the mangrove forests extent in the southern regions of Iran.

Although the level of mangrove forests is inversely related to the increased sea surface area, mangrove forests are most affected by temperature during this period due to the sea-level fluctuations, which showed no changes over the past 31 years. Etemadi *et al.* (2018) also showed that the increase in mangrove forests did not coincide with the elevated sea surface area in southern Iran in the east and west of Jask. They indicated that the sea surface area has risen by 2.88 and 5.47 mm during 1990-2009 in Chabahar and 1997-2011 in Jask, respectively. The results indicated that in short periods, an elevated sea surface area was observed, however, this area did not exhibit a significant upward or downward trend over the last 31 years.

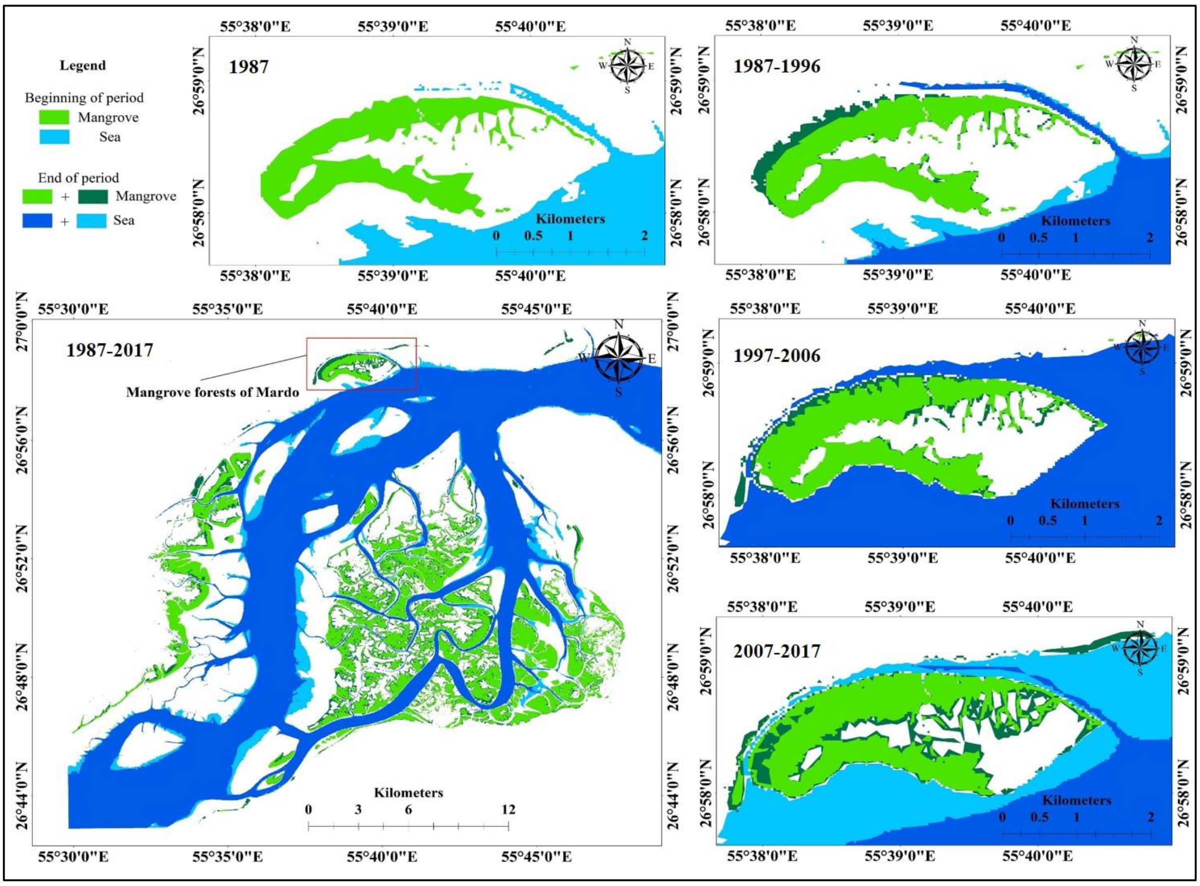

Fig. 5. Changing the extent of mangrove forests from 1987 to 2017 and the range Mangrove forest of Mardo over the past three decades (1987-1996, 1997-2006, and 2007-2017).

Notably, the first tree planting program was carried out in 2001-2002 in the Khamir port (Khoorani *et al*. 2015), which can possibly affect this research results. Although separating the influence of human activities in environmental processes from natural events is often difficult (Asbridge *et al*. 2016), the increasing trend in extent of mangrove forests area have been started before 2001-2002. The ascending trend of mangrove forests extent continued consistently in all decades within the study period (2017-1987). Meanwhile, the forestation initiatives have been carried out only in the Khamir Port. In contrast, the elevated mangrove forest extent in the northwestern forests of Qeshm Island has been reported (Khoorani *et al*. 2015). The results also showed that despite unfavorable conditions such as increasing temperature, which caused a reduction in the extent of mangrove forests, it provided favorable conditions for species to spread in new habitats at higher latitudes. According to our findings, the extent of mangrove forests in Iran exhibits a significant growing trend along with elevating minimum temperature over the past three decades.

CONCLUSION

The results showed that the minimum, maximum, and mean temperatures, as well as the extent of mangrove forests had a significant upward trend in the study area. Furthermore, the regression relationship between mangrove forest extent and climatic parameters exhibited that minimum temperature had the highest correlation coefficient. Indeed, more favorable conditions are provided by rising temperature, especially the minimum temperature in mangrove forest's development at higher latitudes. It is expected, therefore, together with global warming and increasing minimum temperature, the extent of mangrove forests would have a growing trend in the south of Iran in the future. The results of this study can be used by natural resources and forest managers to determine the best place for afforestation in order to perform better protection of these forests.

REFERENCES

Ahmadi, F, Nazeri Tahroudi, M, Mirabbasi, R, Khalili, K & Jhajharia, D 2018, Spatiotemporal trend and abrupt change analysis of temperature in Iran. *Meteorological Applications*, 25: 314-321.

Caspian J. Environ. Sci. Received:
DOI: Article type: Research

Alemi Safaval, P, Kheirkhah Zarkesh, M, Neshaei, SA & Ejlali, F 2018, Morphological changes in the southern coasts of the Caspian Sea using remote sensing and GIS. *Caspian Journal of Environmental Sciences*, 16: 271-285.

Almahasheer, H, Aljowair, A, Duarte, C.M & Irigoien, X 2016, Decadal stability of Red Sea mangroves. Estuarine, *Coastal and Shelf Science*, 169: 164-172.

Alongi, DM 2015, The impact of climate change on mangrove forests. *Current Climate Change Reports*, 1: 30-39.

Armitage, AR, Highfield, WE, Brody, SD & Louchouarn, P 2015, The contribution of mangrove expansion to salt marsh loss on the Texas Gulf Coast. *PloS one*, 10: 0125404.

Asbridge, E, Lucas, R, Ticehurst, C & Bunting, P, 2016, Mangrove response to environmental change in Australia's Gulf of Carpentaria. *Ecology and Evolution*, 6: 3523-3539.

Asfaw, A, Simane, B, Hassen, A & Bantider, A 2018, Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and Climate Extremes*, 19: 29-41.

Attafi, R, Darvishi Boloorani, A, Fadhil Al-Quraishi, AM & Amiraslani, F 2021, Comparative analysis of NDVI and CHIRPS-based SPI to assess drought impacts on crop yield in Basrah Governorate, Iraq. *Caspian Journal of Environmental Sciences*, 19: 547-557.

Barros, DF & Albernaz, ALM 2014, Possible impacts of climate change on wetlands and its biota in the Brazilian Amazon. *Brazilian Journal of Biology*, 74: 810-820.

Carney, J, Gillespie, TW & Rosomoff, R 2014, Assessing forest change in a priority West African mangrove ecosystem: 1986–2010. *Geoforum*, 53: 126-135.

Cavanaugh, KC, Osland, MJ, Bardou, R, Hinojosa‐ Arango, G, López‐ Vivas, JM, Parker, JD & Rovai, AS 2018, Sensitivity of mangrove range limits to climate variability. *Global Ecology and Biogeography*, 27: 925-935.

Church, JA & White, NJ 2011, Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, 32(4): 585-602.

Ellison, JC 2000, How South Pacific mangroves may respond to predicted climate change and sea-level rise. In: Climate change in the South Pacific: Impacts and responses in Australia, New Zealand, and small island states (pp. 289-300). Springer, Dordrecht.

Estoque, RC, Myint, SW, Wang, C, Ishtiaque, A, Aung, TT, Emerton, L, Ooba, M, Hijioka, Y, Mon, MS, Wang, Z & Fan, C 2018, Assessing environmental impacts and change in Myanmar's mangrove ecosystem service value due to deforestation (2000–2014). *Global Change Biology*, 24: 5391-5410.

Etemadi, H, Smoak, JM Sanders, C.J 2018, Forest migration and carbon sources to Iranian mangrove soils. Journal of Arid Environments, 157: 57-65.

Food and Agriculture Organization of the United Nations 2007, The world's mangroves, 1980-2005. FAO Forestry paper, 153 p.

Friess, DA, Krauss, KW, Horstman, EM, Balke, T, Bouma, TJ, Galli, D & Webb, EL, 2012, Are all intertidal wetlands naturally created equal? Bottlenecks, thresholds and knowledge gaps to mangrove and saltmarsh ecosystems. *Biological Reviews*, 87: 346-366.

Giri, S, Mukhopadhyay, A, Hazra, S, Mukherjee, S, Roy, D, Ghosh, S, Ghosh, T & Mitra, D 2014, A study on abundance and distribution of mangrove species in Indian Sundarban using remote sensing technique. Journal of Coastal Conservation, 18: 359-367.

Gomariz-Castillo, F, Alonso-Sarría, F & Cánovas-García, F 2017, Improving classification accuracy of multi-temporal Landsat Images by Assessing the Use of different algorithms, textural and ancillary information for a Mediterranean semiarid area from 2000 to 2015. *Remote Sensing*, 9: 1058.

Guo, H, Zhang, Y, Lan, Z & Pennings, SC 2013, Biotic interactions mediate the expansion of black mangrove (*Avicennia germinans*) into salt marshes under climate change. Global change biology, 19: 2765-2774.

Hamed, KH & Rao, AR 1998 A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology*, 204: 182-196.

Hamilton, SE & Casey, D 2016 Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC‐ 21). *Global Ecology and Biogeography*, 25: 729-738.

Hu, L, Li, W & Xu, B 2018, Monitoring mangrove forest change in China from 1990 to 2015 using Landsat-derived spectral-temporal variability metrics. *International Journal of Applied Earth Observation and Geoinformation*, 73: 88-98.

Huang, J, Islam, AT, Zhang, F & Hu, Z 2017, Spatiotemporal analysis the precipitation extremes affecting rice yield in Jiangsu province, southeast China. *International Journal of Biometeorology*, 61: 1863-1872.

Jayanthi, M, Thirumurthy, S, Nagaraj, G, Muralidhar, M & Ravichandran, P 2018, Spatial and temporal changes in mangrove cover across the protected and unprotected forests of India. *Estuarine, Coastal and Shelf Science*, 213: 81-91.

Jennerjahn, TC, Gilman, E, Krauss, KW, Lacerda, LD, Nordhaus, I & Wolanski, E 2017, Mangrove ecosystems under climate change. In Mangrove ecosystems: a global biogeographic perspective (pp. 211-244). Springer, Cham.

Kendall, MG 1975, Rank correlation methods, Charles Griffin, Landon, UK.

Khoorani, A, Biniaz, M & Amiri, HR 2015, Investigating the changes of mangrove forests between Khamir Port and Gheshm Iseland and its correlation with climatic elements. *Journal of Aquatic Ecology*, 5: 100-111.

Lee, CKF, Duncan, C, Owen, HJF & Pettorelli, N 2018, A new framework to assess relative ecosystem vulnerability to climate change. *Conservation Letters*, 11: 12372.

López-Angarita, J, Roberts, CM, Tilley, A, Hawkins, JP & Cooke, RG 2016, Mangroves and people: Lessons from a history of use and abuse in four Latin American countries. *Forest Ecology and Management*, 368: 151-162.

Lovelock, CE, Feller, IC, Reef, R, Hickey, S & Ball, MC 2017, Mangrove dieback during fluctuating sea levels. *Scientific Reports*, 7: 1-8.

Mafi-Gholami, D, Mahmoudi, B & Zenner, EK 2017, An analysis of the relationship between drought events and mangrove changes along the northern coasts of the Persian Gulf and Oman Sea. *Estuarine, Coastal and Shelf Science*, 199: 141-151.

Mafi-Gholami, D, Zenner, EK, Jaafari, A & Ward, RD 2019, Modeling multi-decadal mangrove leaf area index in response to drought along the semi-arid southern coasts of Iran. *Science of the Total Environment*, 656: 1326-1336.

Mann, HB 1945, Nonparametric tests against trend. *Econometrica*, 13: 245-259.

Moazed, H, Salarijazi, M, Moradzadeh, M & Soleymani, S 2012, Changes in rainfall characteristics in Southwestern Iran. *African Journal of Agricultural Research*, 7: 2835-2843.

Murdiyarso, D, Purbopuspito, J, Kauffman, JB, Warren, MW, Sasmito, SD, Donato, DC, Manuri, S, Krisnawati, H, Taberima, S & Kurnianto, S 2015, The potential of Indonesian mangrove forests for global climate change mitigation. *Nature Climate Change*, 5: 1089-1092.

Osland, MJ, Feher, LC, Griffith, KT, Cavanaugh, KC, Enwright, NM, Day, RH, Stagg, CL, Krauss, KW, Howard, RJ, Grace, JB & Rogers, K 2017, Climatic controls on the global distribution, abundance, and species richness of mangrove forests. *Ecological Monographs*, 87: 341-359.

Pachauri, RK, Allen, MR, Barros, VR, Broome, J, Cramer, W, Christ, R, et al., 2014, Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), p. 151.

Parida, AK, Tiwari, V & Jha, B 2014, Impacts of climate change on Asian mangrove forests. In: Mangrove ecosystems of Asia, Springer, New York, NY, p. 233-256.

Pham, LT, Vo, TQ, Dang, TD & Nguyen, UT 2019, Monitoring mangrove association changes in the Can Gio Biosphere Reserve and implications for management. *Remote Sensing Applications: Society and Environment*, 13: 298-305.

Richards, DR & Friess, DA 2016, Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. Proceedings of the National Academy of Sciences, 113(2): 344-349.

Sen, PK 1968, Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, 63(324): 1379-1389.

Sippo, JZ, Lovelock, CE, Santos, IR, Sanders, CJ & Maher, DT 2018, Mangrove mortality in a changing climate: An overview. *Estuarine, Coastal and Shelf Science*, 215: 241-249.

Caspian J. Environ. Sci.
DOI:
Received:
Article type: Research

Soltaninejad, M, Jafari, M, Noroozi, A & Javadi, SA 2020, Evaluation of vegetation changes in desertification projects using remote sensing techniques in Bam, Shahdad and Garmsar regions, Iran. *Caspian Journal of Environmental Sciences*, 19: 47-51.

Srivastava, PK, Mehta, A, Gupta, M, Singh, SK & Islam, T 2015, Assessing impact of climate change on Mundra mangrove forest ecosystem, Gulf of Kutch, western coast of India: A synergistic evaluation using remote sensing. *Theoretical and Applied Climatology*, 120: 685-700.

Thakkar, AK, Desai, VR, Patel, A & Potdar, MB 2017, Post-classification corrections in improving the classification of Land Use/Land Cover of arid region using RS and GIS: The case of Arjuni watershed, Gujarat, India. *The Egyptian Journal of Remote Sensing and Space Science*, 20: 79-89.

Theil, H 1992, A Rank-Invariant Method of Linear and Polynomial Regression Analysis. In: B, Raj & J, Koerts (Eds.), Henri Theil’s Contributions to Economics and Econometrics: Econometric Theory and Methodology. Springer, Dordrecht Netherlands, pp. 345-381

Toosi, NB, Soffianian, AR, Fakheran, S, Pourmanafi, S, Ginzler, C & Waser, LT 2019, Comparing different classification algorithms for monitoring mangrove cover changes in southern Iran. *Global Ecology and Conservation*, 19: 00662.

Uddin, MS, Shah, MAR, Khanom, S & Nesha, MK 2013, Climate change impacts on the Sundarbans mangrove ecosystem services and dependent livelihoods in Bangladesh. *Asian Journal of Conservation Biology*, 2(2): 152-156.

Ward, RD, Friess, DA, Day, RH & MacKenzie, RA 2016, Impacts of climate change on mangrove ecosystems: a region by region overview. *Ecosystem Health and Sustainability*, 2: 01211.

Wolanski, E & Elliott, M 2015, Estuarine ecohydrology: an introduction. Elsevier.

Yevenes, MA, Figueroa, R, Parra, O & Research, P 2018, Seasonal drought effects on the water quality of the Biobío River, Central Chile. *Environmental Science and Pollution Research* 25(14): 13844-13856.

Zahed, MA, Rouhani, F, Mohajeri, S, Bateni, F & Mohajeri, L 2010, An overview of Iranian mangrove ecosystems, northern part of the Persian Gulf and Oman Sea. *Acta Ecologica Sinica*, 30: 240-244.

Bibliographic information of this paper for citing:

Rostami, F, Attarod, P, Keshtkar, H, Nazeri Tahroudi, M 2022, Impact of climatic parameters on the extent of mangrove forests of southern Iran. Caspian Journal of Environmental Sciences, 20: 671-682.