Assessing climatic change impacts on mangrove structural dynamics on the northern coasts of the Persian Gulf

Mahdieh Shirmohammadi[†1], Davood Mafi-Gholami[†2], Saied Pirasteh[†1*], Fahimeh Youssefi[1], Jie Shen[3,4,5], Weilian Li[6], Jonathan Li[7]

[1] Institute of Artificial Intelligence, Shaoxing University, Shaoxing, 508 West Huancheng Road, Yuecheng District, Zhejiang Province, Postal Code 312000, China, mshirmohammadi.khu@gmail.com, sapirasteh1@usx.edu.cn, fahimeh.y@gmail.com

[2] Department of Forest Sciences, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord, 8818634141, Iran, d.mafigholami@sku.ac.ir

[3] School of Geography, Nanjing, Normal University, China, shenjie@njnu.edu.cn

[4] Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing, China;

[5] Key Laboratory of Virtual Geographic Environment (Nanjing Normal University), Ministry of Education, Nanjing, China;

[6] Computational Methods Lab, HafenCity University Hamburg, Germany, li.weilian@hcu-hamburg.de

[7] Geospatial Sensing and Data Intelligence Lab, Department of Geography and Environmental Management, University of Waterloo, Waterloo, ON N2L 3G1, Canada, junli@uwaterloo.ca

Corresponding author: sapirasteh1@usx.edu.cn

[†] Equal contribution

Keywords: Drought, Patchiness, Satellite images, Climate change adaptation.

Abstract

Monitoring long-term trends in structural changes within mangrove ecosystems is essential for understanding their response to climate change and devising effective adaptation strategies in coastal regions. This study examines changes in mangrove patchiness within the Hara Biosphere Reserve (HBR) along the northern coasts of the Persian Gulf (PG) over a 31-year period (1986-2017), focusing on variations in rainfall patterns and drought occurrences. Employing a 35-year time series of monthly Standardized Precipitation Index (SPI) values alongside satellite imagery analysis, trends in both the number of patches (NP) and the Largest Patch Index (LPI) were assessed at the mangrove stand level. The analysis reveals a significant correlation between structural changes in mangroves and drought events. Pre-1998, characterized by wetter conditions, witnessed a decrease in both NP and LPI, indicating patch expansion and habitat extension. Conversely, post-1998, during drought periods, both indices increased, indicating habitat degradation due to heightened drought intensity. Pre-1998 structural changes in the HBR signify habitat expansion, with increased patch extent and core areas reflecting enhanced structural integrity. However, post-1998, a concerning trend of habitat degradation emerged, with increased NP and LPI attributed to intensified droughts. These findings highlight a transitional period marked by favourable conditions for mangrove growth followed by habitat degradation linked to increased drought intensity. This underscores the vulnerability of mangrove ecosystems to climate change impacts, particularly exacerbated droughts, necessitating urgent efforts for conservation and management to preserve biodiversity and ecosystem services in coastal regions.

1. Introduction

Due to the close relationship between mangrove swamp conditions and rainfall occurrence, any changes in rainfall patterns will significantly impact the growth and spatial distribution of mangroves (Chan and Qin, 2017; Pirasteh et al., 2020). According to conducted studies, reduced rainfall and the occurrence of drought through increased evaporation and salinity stress will result in decreased net primary production, reduced growth and survival of seedlings, and changes in interspecies competition within mangrove ecosystems, ultimately leading to undesirable structural changes and increased vulnerability of mangroves to other human and natural stresses. Therefore, analyzing the observed changes in mangroves and examining their relationship with drought occurrence can provide valuable insights into the adverse effects of climate change on mangroves. Among these detrimental natural and human factors, the occurrence of long-term droughts and severe reduction in rainfall amounts along the southern coasts of Iran has been identified as one of the most significant stressors and disturbances affecting the vulnerability of Iranian mangroves (Mafi-Gholami et al., 2021; Pirasteh et al., 2021; Ghosh et al., 2022; Pirasteh et al., 2024). Despite the importance of this issue, no study has been conducted in Iran regarding the relationship between long-term droughts over past decades and the changes in mangrove integrity (fragmentation). Hence, the aim of this study is to investigate the observed changes in the integrity status (fragmentation) of mangrove reserves in the Hara Biosphere Reserve (HBR) in response to changes in rainfall amounts and the occurrence of droughts over a 31-year period (1986-2017). To achieve this, a 31-year time series of satellite images and rainfall data were utilized.

2. Material and Methods

2.1 Study Area

The HBR, spanning 85,686 hectares, is situated geographically between 26° and 43' to 26° and 59' north latitude, and 55° and 32' to 55° and 48' east longitude, stretching from the coastal lands of Bandar Khamir district to the coastal lands of Lāft and Tabl districts on Qeshm Island (Figure 1). Due to its international significance, this area was designated as a Ramsar Site in 1975 and joined the UNESCO Man and Biosphere (MAB) Programme as the Hara Biosphere Reserve in 1976.

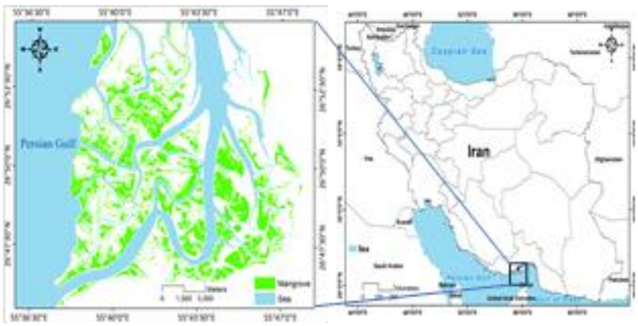

Figure. 1. Geographic location of the HBR on the northern coasts of the Persian Gulf.

2.2 A 31-Year Time Series (1986-2017) of SPI Values

Studies have shown that the survival and resilience of mangrove ecosystems to cope with high salinity are dependent on the amount of rainfall and the volume of freshwater input from upstream catchment areas (Ellison, 2015). Furthermore, annual fluctuations in rainfall and freshwater input to mangrove environments lead to changes in mangrove ecosystems (Dubayah et al., 2017). Therefore, this study investigates the relationship between drought occurrence and changes in mangrove coherence by calculating annual Standardized Precipitation Index (SPI) values. To this end, monthly precipitation data spanning 31 years (1986 to 2017) from the synoptic station located near the Hara Biosphere Reserve was utilized.

2.3 Mapping Fragmentation Changes of Mangroves During a 31-year (1986-2017) Period

Given the high geometric accuracy of Landsat 8 satellite images, other images covering the 31-year period (1986-2017) were also geometrically corrected in a similar manner. Radiometric corrections of the images were performed using ENVI software. This study employed the supervised maximum likelihood classification method for image classification and mangrove vegetation cover extraction (Huang et al., 2022). For validation of the classification maps derived from the 2017 images, a total of 48 ground truth samples with dimensions of 30m*30m (900 square meters) were collected in 2017 from the mangrove surface as well as from the boundaries of mangroves facing the sea and land. Additionally, aerial photographs and QuickBird images from 1993 and 2010 were utilized for the validation of maps derived from images from other years in the study period. This study used a stratified random sampling method to validate the final maps, and user accuracy, producer accuracy, overall accuracy, and kappa coefficient were calculated for mangrove vegetation cover maps (Nguyen et al., 2013). Two indices, namely the Number of Patches (NP) and Largest Patch Index (LPI), which best represent changes in the fragmentation of these ecosystems, were selected to investigate temporal and spatial changes in the coherence of Hara Biosphere Reserve mangroves in response to long-term drought events. Finally, the trends of SPI values and NP and LPI indices over the 31-year period were examined.

3. Results and Discussion

The analysis of drought trends revealed an increase in SPI values from 1986 to 1998 (positive SPI values indicating wet periods), followed by a continuous decrease in SPI values during the 19-year period after 1998, indicating drought conditions. Mapping of mangroves in the HBR over the 31-year period (1986-2017) showed that during the 12-year period prior to 1998 (wet period), various sections of the HBR experienced advancement and expansion towards both inland and coastal areas. Conversely, during the 19-year period after 1998 (drought period), due to reduced rainfall, mangroves experienced retreat and reduction in extent along coastal and inland margins (Figures 2 and 3).

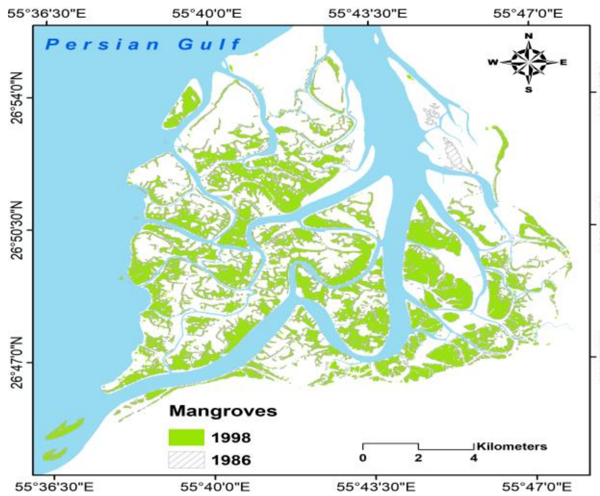

Figure 2. The changes in the extent of the largest patch in the HBR over the 12-year period (1986-1998).

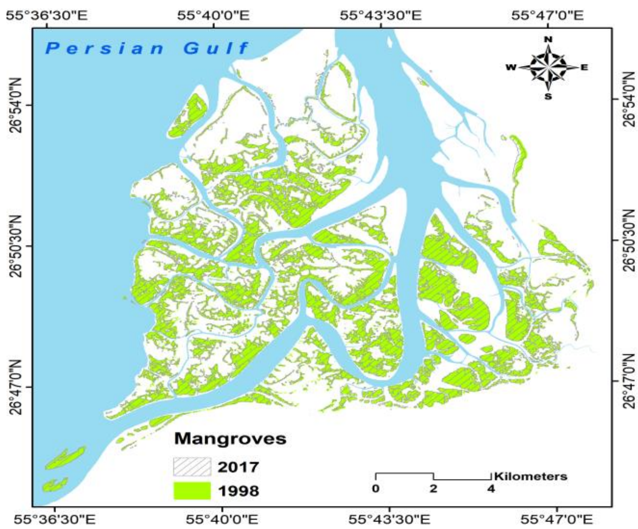

Figure 3. The changes in the extent of the largest patch in the HBR over the 19-year period (1998-2017).

Changes in the extent of the largest patch in the HBR indicated an increase in its extent during the period prior to 1998 (wet period), followed by a gradual decrease until the end of the 31-year period (Figure 4).

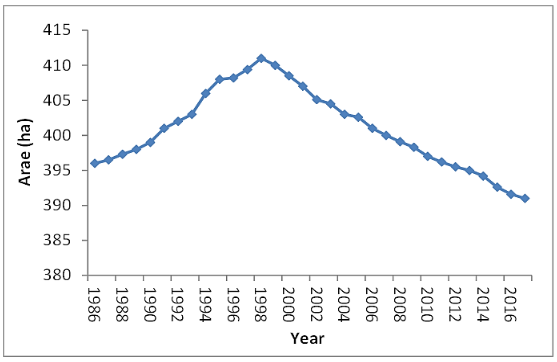

Figure 4. The changes in the extent of the largest patch in the HBR over the 31-year period (1986-2017).

Results showed that the trend of changes in LPI over the 31-year period (1986-2017) differed from the trend of changes in the extent of the largest patch (Figures 5 and 6). Specifically, LPI values decreased gradually from 1986 to 1998 (wet period) and then increased until the end of the 31-year period (drought period) (Figure 5). Additionally, the NP decreased during the 12-year period (1986-1998), with the NP of the reserve being 1281 and 911 in 1986 and 1998, respectively. However, the number of mangrove patches increased during the period after 1998 (drought period), reaching 1639 by the end of the 31-year period in 2017 (Figure 6).

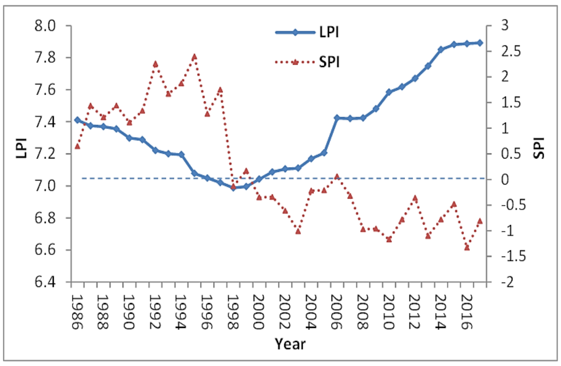

Figure 5. Comparison of the trends in changes in LPI and SPI in the HBR over the 31-year period (1986-2017).

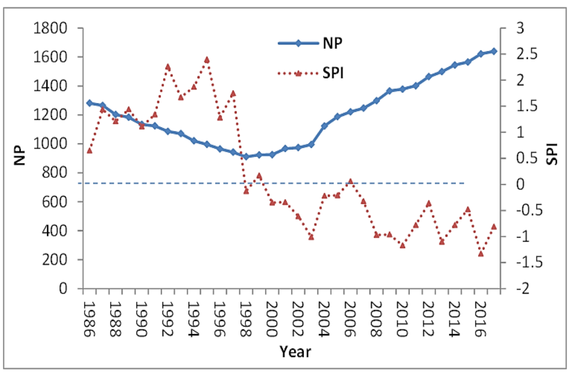

Figure 6. Comparison of the trends in changes in NP and SPI in the HBR over the 31-year period (1986-2017).

4. Conclusion

The examination of patch numbers and the extent of the largest patch in the HBR over the 31-year period (1986-2017) indicated that during the years from 1986 to 1998 (wet period), despite a decrease in the number of mangrove patches, there was an increase in the extent of the largest patch. This increase in the extent of the largest patch in the Hara Biosphere Reserve, accompanied by a decrease in the NP and a decrease in the LPI in this reserve, occurred before 1998. These structural changes in the HBR before 1998 indicate an increase in the extent of existing patches and, ultimately an expansion of mangrove habitats during this period. Indeed, increased coherence in the Hara mangrove stands significantly affects the distribution and diversity of mangrove-associated fauna, and the increase in patch numbers, reduction in the extent of large patches, and the presence of gaps between mangrove patches disrupts biological exchanges at the habitat level and reduces gene flow among populations within patches. Therefore, higher rainfall amounts and continuous wet periods before 1998 have led to increased coherence in the HBR. According to landscape ecology principles, an increase in patch numbers, along with a decrease in the extent of large patches and the total extent of an ecosystem over time, indicates degradation (Riitters et al., 2002). The reduction in patch extent and increase in patch numbers in the HBR also indicate the degradation of this habitat during recent long-term drought periods. However, these results are not unexpected, as other researchers worldwide have also noted that any changes in rainfall amounts, surface water flows, and drought occurrences can lead to undesirable changes in nutrient levels, water salinity, and sediment inputs into mangrove beds, resulting in reduced growth potential and structural decline in mangroves (Ellison, 2015). Undoubtedly, other environmental factors such as local geomorphological characteristics, surface water hydrological dynamics, and changes in coastal sediment deposition rates also affect changes in mangroves within the HBR. Investigating the impact of each of these factors on the occurrence of degradation in the Hara Biosphere Reserve can be a focus of future studies.

References

Chan, K.L., Qin K., 2017. Biomass burning related pollution and their contributions to the local air quality in Hong Kong. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W7, 29-36. doi.org/10.5194/isprs-archives-XLII-2-W7-29-2017.

Dubayah, R.O., Swatantran, A., Huang, W., Duncanson, L., Tang, H., Johnson, K., Dunne, J.O., Hurtt, G.C., 2017. CMS: LiDAR-derived Biomass, Canopy Height and Cover, Sonoma County, California, 2013. ORNL DAAC, Oak Ridge, Tennessee, USA. doi.org/10.3334/ORNLDAAC/1523.

Huang, Z., Tian, Y., Zhang, Q., Huang, Y., Liu, R., Huang, H., Liu, H., 2022. Estimating mangrove above-ground biomass at Maowei Sea, Beibu Gulf of China using machine learning algorithm with Sentinel-1 and Sentinel-2 data. *Geocarto Int.*, 37(27), 15778-15805.

Ellison, J.C., 2015. Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetl. Ecol. Manag.*, 23(2), 115-137.

Ghosh, S., Proisy, C., Muthusankar, G., Hassenrück, C., Helfer, V., Mathevet, R., Andrieu, J., Balachandran, N., Narendran, R., 2022. Multiscale Diagnosis of Mangrove Status in Data-Poor

Context Using Very High Spatial Resolution Satellite Images: A Case Study in Pichavaram Mangrove Forest, Tamil Nadu, India. *Remote Sens.*, 14(10):2317. https://doi.org/10.3390/rs14102317.

Mafi-Gholami, D., Pirasteh, S., Ellison, J.C., Jaafari, A., 2021. Fuzzy-based vulnerability assessment of coupled social-ecological systems to multiple environmental hazards and climate change. *J. Environ. Manag.*, 299, 113573.

Nguyen, H.H., McAlpine, C., Pullar, D., Johansen, K., & Duke, N.C., 2013. The relationship of spatial–temporal changes in fringe mangrove extent and adjacent land-use: Case study of Kien Giang coast, Vietnam. *Ocean Coast. Manag.*, 76, 12-22.

Pirasteh, S. ,Zenner, E.K., Mafi-Gholami, D., Jaafari, A., Nouri Kamarie, A., Liu, G., Zhu, Q., Li, J., 2021. Remote sensing of multi-decadal spatial extents and biomass changes of mangroves in response to climate change and anthropogenic impacts, *Int. J. Appl. Earth Obs. Geoinfo.*, Vol. 102, https://doi.org/10.1016/j.jag.2021.102390.

Pirasteh, S., Mollaee, S., Fatholahi, S.N., Li J., 2020. Estimation of Phytoplankton Chlorophyll-a Concentrations in the Western Basin of Lake Erie Using Sentinel-2 and Sentinel-3 Data, *Canadian J. Remote Sens*., DOI: 10.1080/07038992.2020.1823825.

Pirasteh, S., Mafi-Gholami, D., Li, H., Fang, Z., Nouri-Kamari, A., Khorrami, B., 2024. Precision in Mapping and Assessing Mangrove Biomass: Insights from the Persian Gulf Coasts. *Int. J. Appl. Earth Obs. Geoinfo.*, 128: 103769. doi:10.1016/j.jag.2024.103769.