Multi-hazards threat assessment of mangroves using remote sensing and geographic information system

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1. INTRODUCTION

In mangroves assessing the threat of multiple environmental hazards is important to inform effective management decisions to protect these habitats and to reduce or prevent damage as a result of environmental impacts (REF). In this study, the threat of multiple environmental hazards including drought, reducing surface runoff of upstream catchments, strong winds, extreme temperatures, fishing activities and extent of loss of mangroves in the northern coast of the Persian Gulf and Oman Sea in Iran are assessed and mapped.

2. MATERIALS & METHODS

2.1 Study area

The study area comprises 10025.55 ha located on the northern coast of the Persian Gulf and the Oman Sea. Natural mangrove forests on the coastal areas of Hormozgan range between 25° 34′ 13″ N in Gabrig (Jask town) to 27° 10′ 54″ in Koulaghan (Bandar Abbas town) and 58° 34′ 07″ E in Himan (Jask town) to 55° 22′ 06″ E in Bandar Lenge town. Mangroves on the northern coast of the Persian Gulf and the Oman Sea are classified according to geographical location, habitat structure and geomorphology of the coast and are found in four areas: Khamir, Tiab, Sirik and Jask.

2.2 Mapping environmental hazards

In this study a Mann-Kendall (MK) test was employed using MAKESENSE 1.0 to detect trends in soil potential index (SPI) values at a confidence level of 95% and 99%. Based on changes in Z values and implementation of the natural break command in ArcGIS, a map of changes as a result of drought was categorized into four classes of low (code 1), moderate (code 2), high (code 3) and very high (code 4), based on the values of Z | ≥ 1.96 (increasing trend of drought severity). This was used to assess the threat to mangroves.

In order to map changes in surface runoff from upstream catchments during the 30-year period (1986-2016), the time series of changes in runoff coefficient values were evaluated. A30-year time series of land use / land cover changes (LULC) in upstream catchments of mangroves was also prepared using data from 210 Landsat images. Using the LULC map, the Runoff coefficient of the catchment is calculated from the runoff coefficient for permeable areas (Cper). Cper was calculated from a weighted sum of land use, soil type and slope factors, respectively, the first, second, and third term in the right-hand side of Eq. 1:

$$C_{per} = w1\left(\frac{0.02}{n}\right) + w2\left(\frac{\theta_w}{1-\theta_w}\right) + w3\left(\frac{s}{10+s}\right) \qquad (1)$$

In equation (1), n is the Manning's roughness coefficient dependent on the LULC, θ_w is the volumetric soil water content at wilting point, and S is the land surface slope in percentage land surface slope in percentage. The value of $\left(\frac{\theta_w}{1-\theta_w}\right)$ was calculated using the soil texture map of upstream catchments of mangroves obtained from Iranian Forests, Range and Watershed Management Organization (FRWMO). The values of the coefficients W1, W2 and W3 were considered as 0.4, 0.3 and 0.3 respectively. Using a 30-year time series of runoff coefficients and annual precipitation values, a 30-year time series of surface runoff changes in catchments was prepared. The time series of the changes in surface runoff values was used to create a map of the reduction of catchments using four classes of

low (code 1), moderate (code 2), high (code 3) and very high (Code 4) to assess the threat to mangroves. Classification was undertaken using the natural break command in ArcGIS.
Changes in the intensity of fishing activities in mangrove habitats were mapped using the location of the fishing ports and the number of active launches and boats, determined by reviewing the satellite imagery of Google Earth Pro (© DigitalGlobe Inc., © GeoEye Inc.) and visiting the coasts. The coastal waters area was divided into 4×4 km GIS grid cells (598 cells) and in each of the grid cells, the intensity of the fishing activity was calculated using equations (2) and (3) and finally a map of the intensity of the fishing activity in coastal waters was prepared.

$$F_B = \sum_{i=1}^{N} fd_{Pi} \times n_{BP_i} \quad (2)$$

$$F_L = \sum_{i=1}^{N} fd_{Pi} \times n_{LP_i} \quad (3)$$

In equations (2) and (3), N is Number of fishing ports, fd_{Pi} is linear distance factor (0 to 1), n_{BP_i} is the total number of boats in each port and n_{LP_i} is total number of launches in each of the ports. The map of the Fishing Index (FI) was derived from sum of equations (2) and (3). Using the Fishing Index (FI) map, fishing activity intensity was classified using the natural break command in ArcGIS as low (code 1), moderate (code 2), high (code 3) and very high (Code 4), this was used to assess the threat to the mangroves.
In this study, the threat from wind speeds greater than 8 m/s was mapped, this cut off was used as this velocity is considered as potentially damaging to the structure and function of these mangroves (REF). A 30-year time series (1986-2016) of daily wind speed data from synoptic stations adjacent to the mangroves was used. In this study, the Weibull function was used to calculate the probability of wind speeds greater than 8 m/s. Wind speeds greater than 8 m/s were extracted and their average was calculated and multiplied by the probability of occurrence for each of stations during the thirty year period. A risk map of winds speeds greater than 8 m /s was prepared and classified using the natural break command in ArcGIS, the four classes were low (code 1), moderate (code 2), high (code 3) and very high (Code 4), and these were used to assess the threat to mangroves.
Based on previous studies (REFs) and for the analysis of spatial variations in the occurrence of extreme temperatures, a temperature of 38° C was selected as the threshold temperature for mangrove damage. All daily temperatures equal to and greater than 38° C were extracted from the long-term dataset of daily temperatures for the 30-year period (1986-2016). By dividing the number of days with a temperature equal to and greater than 38° C by the total number of daily temperature records in the 30-year period, the probability of occurrence of temperatures above this threshold was calculated for each of the synoptic stations. At each synoptic station, the mean value of all temperatures equal to and greater than 38°C was calculated and multiplied by the probability of occurrence calculated for that station. Finally, using ArcGIS, a risk map of temperatures equal to and greater than 38 °C was prepared within the coastal areas and classified using the natural breaks command as low (code 1), moderate (code 2), high (Code 3) and very high (code 4) to assess the threat to the mangroves.
In this study, Landsat images of 1986, 2000, and 2016 were used to analyse the rate of decrease in the extent of mangroves over the 30-year period (1986-2016). To separate mangroves from surrounding water and coastal land areas and to identify the final borders of the study sites, an NDVI vegetation index was used. In this study, 2701 transects 30 m apart were mapped using the DSAS software to calculate the rate of decrease in the extent of the mangroves. As with previous studies, the linear regression rate (LRR) method was used to measure the rate of decrease in the extent of mangroves (REFs). These were used to create a map of changes in the rate of decrease in extent of mangroves classified as: no loss (code 1), low rate of loss (code 2), moderate rate of loss (code 3) and high rate of loss (code 4) using the natural break command in ArcGIS, to assess the threat to the mangroves.

2.3. Calculation of Threat Index (TI) and its classification in Mangrove habitats
At this stage, classified hazard maps were combined using the functions in the ArcGIS and equation (4):

$$TI = \sqrt{\frac{a \times b \times c \times d \times e \times f}{6}} \quad (4)$$

Where TI = Threat Index, a = drought, b = surface runoff, C = wind, d = air temperature, e = fishing activity and f = extent of loss. The TI was used to create a threat map for the mangroves at all four sites classified as: low, medium and high using the natural break command in ArcGIS.

3. RESULTS & DISCUSSION

The results of this study showed that, considering the severity and probability of occurrence of the hazards, Khamir and Jask mangrove habitats are highly threatened by environmental hazards (Figure 1). Investigating the severity of occurrence of environmental hazards in mangrove habitats shows that Khamir and Jask habitats are considered to have a high to very high threat level from drought, reduced runoff from the catchments and extent of loss, significantly higher than the Tiab and Sirik sites. It is likely that the increase in the severity and risk from these hazards has had adverse effects on the structure and functions of these mangrove habitats as found in other studies conducted in other regions of the world that show that reducing rainfall and increasing the risk of drought reduces the extent of mangrove area and increases their vulnerability to other environmental hazards (REFs).

Figure 1: threat level of mangrove habitats (a: Khamir habitat, b: Tiab habitat, c: Sirik habitat and d: Jask habitat)

4. CONCLUSION

The results of this original study can significantly contribute to effective planning for the protection of these ecosystems and reduce their vulnerability to environmental hazards by providing up-to-date and accurate information on the threats to mangrove habitats. The analytical methods used in this study may serve as a basis for assessing environmental threats to other mangrove ecosystems around the world.