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Research Article

Identification of shrimp potential fishing zones in the northern part of the Persian Gulf using the Fuzzy Overlay model for integrating satellite and ground-based data

Aeinjamshid K.[1*]; Fazelpoor K.[2]; Rabbaniha M.[3]; Moradi G.[1]

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Abstract

This study aimed to identify the potential fishing zone (PFZ) for shrimp in Bushehr province waters, located in the south of Iran using remote sensing data. The Sea surface temperature (SST) and chlorophyll-a (Chl-a) data were extracted from the +ETM Landsat 7 sensor and MODIS Aqua (EOS PM) satellite images from the summer of 2002 to the summer of 2017. The land-based physicochemical parameters were recorded using a CTD (Conductivity, Temperature, Depth) device in 27 stations in the geographical positions from E 50˚ 44΄ and N 28˚ 59΄ to E 51˚ 40΄ and N 27˚ 33΄, in June and July 2017. The shrimp catch per unit effort (CPUE) was calculated from the results of Shrimp stock assessment projects performed in Bushehr province waters by Iran Shrimp Research Center. The highest values of SST-Chl-CPUE fuzzy overlay were obtained at stations 24, 22, 4, 16, 21, 19, 27, 26, 25 and 10. The highest amount of shrimp CPUE was recorded in the areas where the SST was lower and the chlorophyll-a was higher. The results showed a strong and positive relationship between the amounts of long-term shrimp CPUE and fuzzy overlay of SST-Chl-a in the studied area ($p<0.05$). Based on the results, the potential zones for shrimp capture in Bushehr province waters were Nakhiloo, Mond River, Ra's-e-Khan, Motaf, Heleyleh, and Rostami, which located in the southern and northern parts of the studied area. Results of the validation study showed that 63% of the captured shrimp by commercial vessels were in the introduced PFZ.

Keywords: Potential fishing zone, Shrimp, Fuzzy overlay, Remote sensing, Persian Gulf

1-Shrimp Research Center, (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Bushehr, Iran
2-Department Sistemasy Recursos Naturales, ETSI Montes, Forestalesy Medio Natural, Universidad Politécnica de Madrid, Madrid, Spain
3-Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran
*Corresponding author's Email: kh.aeinjamshid@areeo.ac.ir

Introduction

The Persian Gulf is an important habitat of several species for penaeid shrimp. Although 16 species of shrimp have been identified in the Persian Gulf and the Sea of Oman, the exploitation is carried out on five species. The most economically important species is the green tiger shrimp (*Penaeus semisulcatus*), which is found in most habitats of the Persian Gulf and Oman Sea, but its highest distribution and catch is in the coastal waters of Bushehr province. The banana shrimp (*Fenneropenaeus merguiensis*), which ranks second commercially, is mostly caught in the waters of Hormozgan province. Other species such as the Indian white shrimp (*Fenneropenaeus indicus*), the Kruma shrimp (*Penaeus japonicus*), and the giant tiger prawn (*Penaeus monodon*) are not economically exploited due to their limited habitat and low abundance (Niamaimandi *et al.,* 2018).

The average catch of shrimp in Iranian waters of the Persian Gulf and the Oman Sea was 10,025 tons from 2016 to 2021. During this period, the average annual export of Iranian shrimp, including both marine captured and farmed shrimp, was 27,751 tons, with a total value of $137 million (Iran Fisheries Organization, 2021). Many traditional and industrial fishing vessels capture shrimp stocks in the Persian Gulf., The Bottom trawl net is the only method for shrimp capture, which is a destructive and non-selective device. The most critical issues related to the fisheries management of shrimp stocks are the identification and zoning of their habitats and the assessment of their stocks (Niamaimandi *et al.,* 2007).

Sea surface temperature and chlorophyll-a are the two main environmental data, also known as critical indices for finding suitable habitats and fishing grounds for aquatics (Hela and Laevastu, 1961). Phytoplanktons are the main source of primary production in marine ecosystems. Environmentally nutrient-rich zones potentially attract phytoplankton, and hence the chlorophyll concentration in these marine hotspots is higher than in other areas (Chassot *et al*., 2010). Due to more food in these areas and suitable ecological conditions, planktons aggregate more, and hence, the hunter aquatics aggregate more (Mansor *et al.*, 2001).

Over the past decade, researchers have conducted various studies to identify the potential fishing zone using satellite data (Sajinkumar *et al*., 2008; Pandey *et al*., 2011). Predicting the potential fishing zone (PFZ) has become an important aspect for fishermen. Many researchers have studied satellite-based PFZ forecasts, which integrate ocean color monitor (OCM) derived chlorophyll concentration and advanced very high-resolution radiometer (AVHRR) derived sea surface temperatures (SST) (Solanki *et al*., 2005). Comparisons of mean CPUE in PFZ and mean CPUE in other areas from different habitats revealed that the environmental situation of the water column is a key factor contributing to the fisheries resource in PFZ.

The current traditional sampling for environmental parameters is a time-conserving, point-based, expensive method (Justice *et al.*, 2002). Satellite data estimate ecological parameters of the habitat and ecosystems, which influence marine resources at high temporal and spatial scales. These data can help increase fishing efforts' efficiency by identifying areas of enhanced biological production sites at oceanic fronts where the zooplankton and fish populations are known to be accumulated for feeding (Zhou *et al.*, 2016).

To lower the cost and the fishing operations, there is a need to accurately predict and detect economically fishable fish aggregations in space and time (Victor, 2012). The validation of PFZ helps in fish schools and productive fishing areas that can minimize the fuel consumption and time expended in commercial fisheries.

The distribution and presence of the shrimp population are related to the conditions of the living environment. In the present work, we aimed to determine the potential shrimp fishing zones in the northern part of the Persian Gulf in Bushehr province waters using satellite data of chlorophyll-a and sea surface temperature and integrating these data with shrimp catch (CPUE) data.

Materials and methods

Study Area

The studied area included 27 stations from the Bushehr city area to the Motaf area in Bushehr province waters, in geographical position from E 50˚ 44´ and N 28˚ 59´ to E 51˚ 40´ and N 27˚ 33´, in June and July 2017 and June 2018 (Fig. 1 and Table 1). To calibrate the satellite data, the ground-based physicochemical data of the water column were recorded using a CTD device, in the studied area, from 29th June to 2nd July 2017.

Determination of Shrimp CPUE and Local physicochemical data

To calculate the shrimp CPUE, two research cruises were conducted in June and July of 2017. Sampling was implemented using a traditional ship (bottom trawler with 24 m length and 360 horsepower engine). Before and after sampling with bottom trawl net, geographical position, depth, time, and direction were recorded at each station. A speed of 3 knots was maintained during sampling. Sub-samples were randomly collected from the total catch (5 Kg) to record the biometric characteristics of shrimps, including total number, weight, and length based on Roper *et al*. (1984) and Dore and Frimodt (1987). The CPUE was calculated based on equation No. 1 (Sparre and Venema, 1998):

$$CPUE = \frac{Cw}{t}$$

Where C_w is the weight of shrimp catch (kg) and t is the shrimp fishing time (hour). The OCEAN SEVEN 316 CTD device used for recording the physicochemical parameters included Temperature (°C), Salinity (ppt), Conductivity (ms/cm), Sigma-T (g/cm^3), Dissolved oxygen, pH, and Chlorophyll-a.

Satellite data processing

Images from the ETM+ sensor (Path 163, Row 40 and 41) of the Landsat 7 satellite were used to extract the intended data at the Persian Gulf region. Also, the images of the MODIS Aqua (EOS PM) sensor were used for calibration of the global algorithm of sea surface temperature (TSS) and chlorophyll (Chl-a), which has a daily periodicity, to be able to use the potentials of both satellites in the present work.

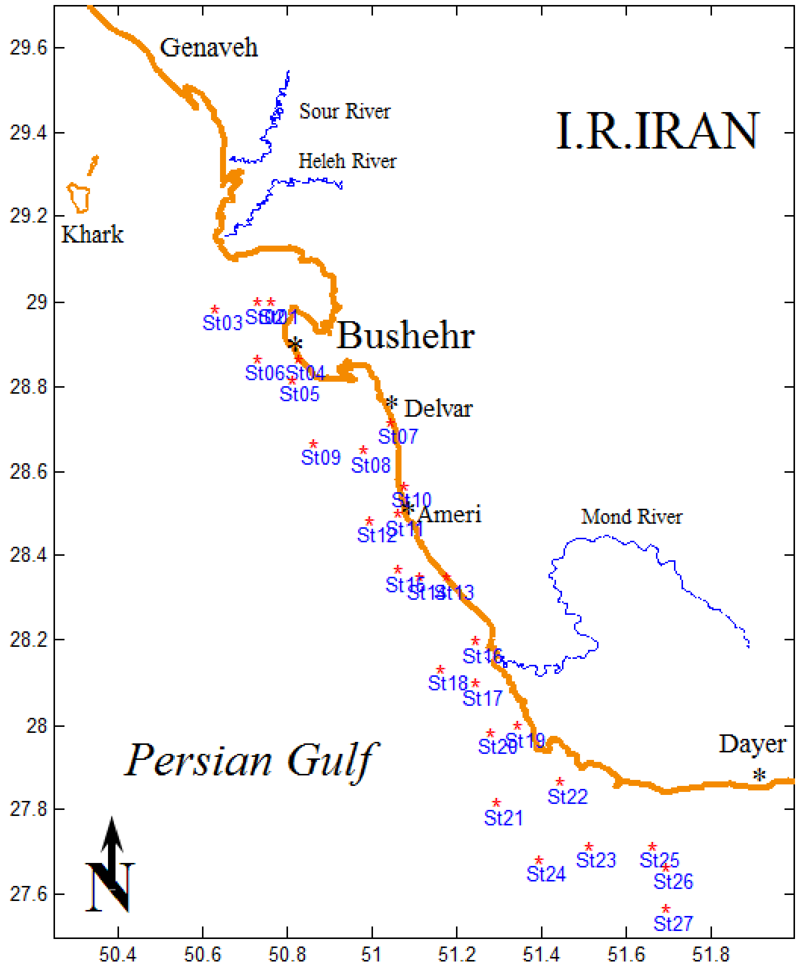

Figure 1: Map of the studied stations (St01-St27) in Bushehr province waters, 2002-2018.

MODIS sensor data were used from https://ladsweb.modaps.eosdis.nasa.go, and Landsat 7 satellite data were obtained from EarthExplorer at: https://earthexplorer.usgs.gov/

The SST data was extracted from their thermal bands by processing and interpreting these images. The lighting temperature of the satellite images was processed, and a linear relationship between the calculated temperature and the lighting temperature was extracted using SPSS software. Seawater surface temperature was used as a dependent variable for the linear fitting. (Bands 31 and 32). The temperature of MODIS thermal band 31, temperature differences of bands 31 and 32, and satellite angle were used as independent variables. Finally, by performing linear equation statistical analysis, SST was calculated from MODIS thermal bands (Bands 31 and 32). The temperature difference between bands 31 and 32 was used for atmospheric correction.

Table 1: The geographical position of the studied stations (St01-St27) in Bushehr province waters, from 2002 to 2018.

Station	Depth (m)	Latitude		Longitude	
		degree	minute	degree	minute
St01	8.56	28	59	50	44
St02	15.75	28	59	50	42
St03	29.82	28	58	50	36
St04	8.51	28	51	50	48
St05	19.66	28	48	50	47
St06	30.46	28	51	50	42
St07	4.93	28	42	51	1
St08	15.18	28	38	50	57
St09	27.03	28	39	50	50
St10	8.67	28	33	51	3
St11	16.23	28	29	51	2
St12	27.29	28	28	50	58
St13	10.05	28	20	51	9
St14	20.12	28	20	51	5
St15	27.7	28	21	51	2
St16	10.93	28	11	51	13
St17	15.92	28	5	51	13
St18	24.36	28	7	51	8
St19	7.53	27	59	51	19
St20	19.85	27	58	51	15
St21	24.7	27	48	51	16
St22	8.61	27	51	51	25
St23	19.29	27	42	51	29
St24	27.54	27	40	51	22
St25	8.6	27	42	51	38
St26	11.74	27	39	51	40
St27	22.29	27	33	51	40

To correct the data, the calculated data from satellite images were compared with the ground data of surface temperature and chlorophyll-a recorded by CTD at studied stations using statistical analysis. Finally, using the Global Algorithm, considering the algorithm with the highest coefficient of determination and its components as independent factors and field data as a dependent factor, the coefficients of the algorithm for Bushehr province waters were calibrated. To test the accuracy of the proposed algorithm, the data were recalculated using 2017 satellite images.

Sea Surface Temperature (SST) data processing

SST is estimated from the brightness temperature of cloud-free pixels. In order to extract and calibrate the data, the following equations were used:

1- Radiant temperature calculation

SST was calculated based on the following equation (Iron, 2012):

$$L = \left(\frac{\mathrm{LMax} - \mathrm{LMin}}{\mathrm{DNMax} - \mathrm{DNMin}}\right)(\mathrm{DN} - \mathrm{DNMin}) + \mathrm{LMin}$$

where L is spectral radiation and DN is the digital number of pixels, which is a number between 1 to 255. LMin is the minimum spectral radiation and LMax is the maximum radiation. DNMin is the minimum calibration value of each image and DNMax is the maximum calibration value of each image. LMax=12.65 and LMin=3.20.

2- Kelvin temperature calculation

Kelvin temperature calculation was calculated based on the equation no. 3

$$T = \left(\frac{\mathrm{K2}}{\ln\left(\frac{K1}{L}\right)}\right) + 1$$

Where K2 and K1 are the coefficients that are calculated by the satellite sensor's effective wavelength.

K1=607.76 and K2=1260.56 (Iron, 2012).

The model used to calculate the SST was the MCSST, which is more accurate due to the zenith angles of the satellite and atmospheric correction. The MCSST was calculated based on the following equation (Walton *et al.*, 1998):

$$\mathrm{MODIS\_SST} = C1 + \frac{\mathrm{C2} \times \mathrm{T31}}{\mathrm{C3} \times \mathrm{T3132}} + (\mathrm{C4} \times (\sec(\Theta) - 1) \times \mathrm{T3132})$$

Where T31 is the brightness temperature of band 31, T3132 is the brightness temperature difference between 31 and 32 bands and Θ is the zenith angle of the satellite. The satellite zenith was extracted from the initial data of the satellite image and its value was calculated for all image pixels. Two sets of coefficients are usually used to calculate the coefficients of the MCSST model. These coefficients are the coefficients of the ECMWF global model and the coefficients obtained from the different radiosondes. The coefficients of the MCSST equation have been calculated in two cases where the difference between the brightness temperatures in bands 31 and 32 is greater than 0.7 and less than or equal to 0.7 (Table 2).

Table 2: Coefficients of the MODIS_SST global algorithm.

	T31-32 <= 0.7	T31-32> 0.7
C1	1.22855	1.692521
C2	0.95766	0.9558419
C3	0.11822	0.0873574
C4	1.77463	1.199584

Where C1 to C4 are the coefficients of the MODIS_SST global algorithm.

Based on the results of field data collecting, the global sea surface temperature (SST) algorithm was modified for Persian Gulf waters as follows:

$$\mathrm{SST} = -2{,}818\mathrm{T11} + 27{,}495\mathrm{d} - 0{,}012\sec(\Theta) + 726{,}398$$

Where T31 is the brightness temperature of band 31, d is the temperature difference of 31 and 32 bands, and Θ is the zenith angle of the satellite. To test the calibrated algorithm, calculations, and were carried out on 2nd July 2017.

Chlorophyll-a (Chl) data processing

Surface chlorophyll was calculated based on the following equation (Rodríguez *et al*., 2014):

$$\mathrm{Chl-a} = 0{,}0979\mathrm{Exp}\left(\frac{2{,}5926\mathrm{B2}}{B1}\right)$$

Where B1 and B2 are band numbers. The algorithm of OC2 and OC3 (Table 3) was used to determine seawater chlorophyll using a MODIS (Moderate Resolution Imaging Spectroradiometer) sensor.

Table 3: OC2 and OC3 Band ratio coefficients of MODIS chlorophyll algorithms.

OC3	OC2
Chl_a (µg/L) = 10^(a+a1R+a2R^2+a3R^3+a4R^4)	Chl_a (µg/L)= 10^(a+a1R+a2R^2+a3R^2+a4)
R=log[(max(Rrs443,Rrs488))/Rrs551)	R=log(Rrs488,Rrs488))/Rrs551)
a=[0.283,-2.753,1.457,0.659,-1.403]	a=[0.319,-2.336,0.879,-0.135,-0.071]

Where R is the value obtained by calculating the band ratio of specific remote sensing reflectance values, a is a set of coefficients used in the algorithm calculations, Rrs443, Rrs488, and Rrs551 are specific remote sensing reflectance values measured at different wavelengths.

Optimized model for determination of the Potential Fishing Zone (PFZ)

Fuzzy overlay analysis is based on set theory, which permits entities to be partial members of different, overlapping attribute classes. This model is used to identify the areas which satisfy a particular ecological condition (Baidya *et al.*, 2014).

The seawater surface temperature and chlorophyll-a data, extracted from Landsat 7 satellite images, were atmospheric and radiometric using the commands of Atmospheric and Radiometric correction in ENVI software. Then, the proposed algorithms were formulated using the Raster calculator command.

The inverse Planck's constant, radiometric correction, and MODIS_SST were calculated using MATLAB software. Using the MODIS_Swach_Type_L1B sub-program and by changing and identifying the variables, the matrix file of sea surface temperature and chlorophyll is generated. By importing these matrix files into ArcGis software, SST and chlorophyll-a concentrations for desired points will be obtained.

After applying the algorithms and extracting the data, the RMSE (Root Mean Square Error) of the data was calculated. The RMSE shows the difference between the calculated values from the statistical model or calibrated algorithm and the filed data. The lower the difference between these data, the greater their consistency.

SST and chlorophyll-a data overlap were performed using ArcGIS 10.2 software in the Spatial Analysis section, → Fuzzy Overlay, → using the MSSmall method. For the fuzzy data process, the data were changed from discrete to continuous data.

In order to determine the potential fishing zone (PFZ) of shrimp, after normalization of data, the fuzzy overlay of sea surface temperature, chlorophyll-a, and shrimp CPUE was calculated, the map of the studied parameters and their overlay map was drawn using ArcGIS 10.2 software. Finally, by reviewing the maps and analyzing data the potential shrimp fishing zones in different years, and the whole period of study were introduced (Zhou *et al.*, 2016) (Fig. 2).

To validate of the proposed model and the introduced potential fishing area (PFZ), the SST and chlorophyll-a data were extracted from +ETM Landsat 7 satellite images in June 2018, before starting the shrimp open season in Bushehr province marine waters. The potential fishing zones were re-determined. Data processing and statistical analysis have been done using

SPSS, 21 software. Pearson's correlation and ANOVA tests were used to determine the relationship between shrimp CPUE and physicochemical parameters.

Results

Table 4 summarize the results of algorithm calibration for ground-based and satellite-based data of SST in the study area. The calibrated temperatures ranged from 30.91 to 31.35°C, while the uncalibrated temperatures ranged from 30.73 to 31.23°C.

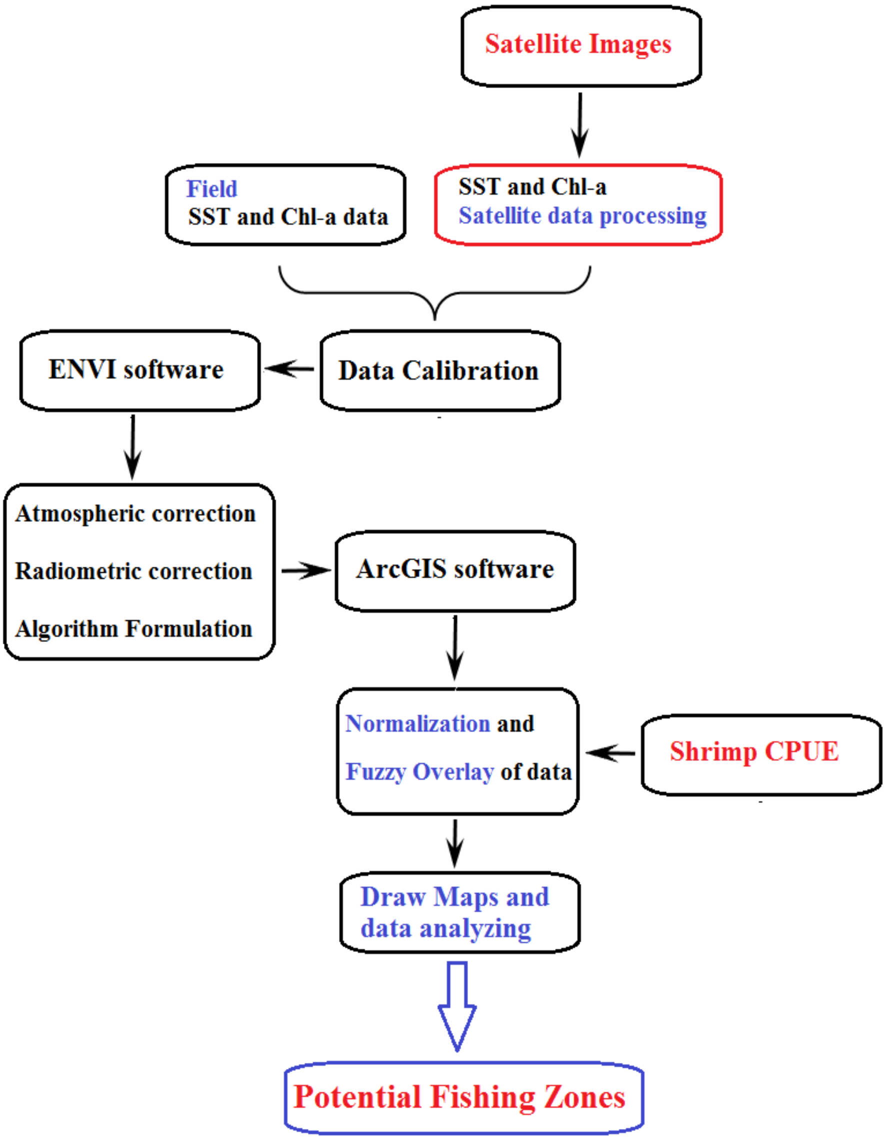

Figure 2: The pattern of satellite image processing, environmental data, data integration, and introduction of Potential Fishing Zones (optimized pattern of Zhou, 2016).

Table 4: The results of the algorithm calibration of ground-based water temperature and satellite-based SST for the Persian Gulf, on 2nd July 2017.

Station number	Calibrated temperature	Uncalibrated temperature	Temperature recorded with CTD[1]	RMSE[2]
1	31.35	31.23	31.57	0.35
2	30.91	30.73	31.06	
3	31.01	30.85	30.28	

1 Conductivity, Temperature, Depth
2 Root Mean Square Error

The temperature recorded with the CTD device ranged from 30.28 to 31.57°C. The RMSE (Root Mean Square Error) measures the difference between the calibrated and recorded data, with lower values indicating better accuracy of the proposed algorithms. The results demonstrate the accuracy of the algorithms in calculating the studied parameters and their effectiveness in improving the accuracy of satellite data.

The calibrated chlorophyll-a concentrations ranged from 0.30 to 0.31 mg/m³, while the non-calibrated chlorophyll-a concentrations ranged from 0.51 to 0.67 mg/m³. The chlorophyll-a concentrations recorded with the CTD device ranged from 0.13 to 0.23 mg/m³. The low value of RMSE for chlorophyll-a data indicated a good accuracy of the proposed algorithm (Table 5).

Table 5: The results of the algorithm calibration of ground-based surface chlorophyll-a and satellite-based chlorophyll-a for the Persian Gulf, on 2nd July 2017.

Station number	Calibrated Chlorophyll	Noncalibrated Chlorophyll	Chlorophyll registered with CTD	RMSE
1	0.30	0.67	0.16	0.13
2	0.30	0.56	0.23	
3	0.30	0.67	0.20	
4	0.31	0.51	0.13	
5	0.30	0.66	0.15	

Table 6 and Figures 3 to 6 present the average values of the studied parameters in the Bushehr province waters from 2002 to 2017. The average value of SST was 29.77°C, while the average value of Chl-a was 0.88 µg/L. The average value of SST-Chl fuzzy overlay was 0.64 and the average value of shrimp CPUE was 10,169 g. The correlation coefficients between SST, Chlorophyll-a, and Shrimp CPUE values were -0.34 and 0.03, respectively. While the physicochemical parameters showed a weak relationship with Shrimp CPUE, the correlation between SST-Chl fuzzy overlay and Shrimp CPUE was significantly negative (r= -0.84). Furthermore, the ANOVA results indicated that the SST-Chl fuzzy overlay had a strong and significant relationship with Shrimp CPUE (p-value<0.05). The results of validation data collecting and testing of the introduced potential fishing area (PFZ) in Bushehr province waters from the summer of 2002 to the summer of 2018 are presented in Figure 7.

Table 6: The average of studied parameters in the Bushehr Province waters, from 2002 to 2017.

Parameter	SST (°C)	Chl- a (μg/ L)	SST-Chl fuzzy overlay	CPUE (g)
Average	29.77	0.88	0.64	10169
Min	20.51	0.31	0.08	20
Max	32.99	2.25	1.00	533184

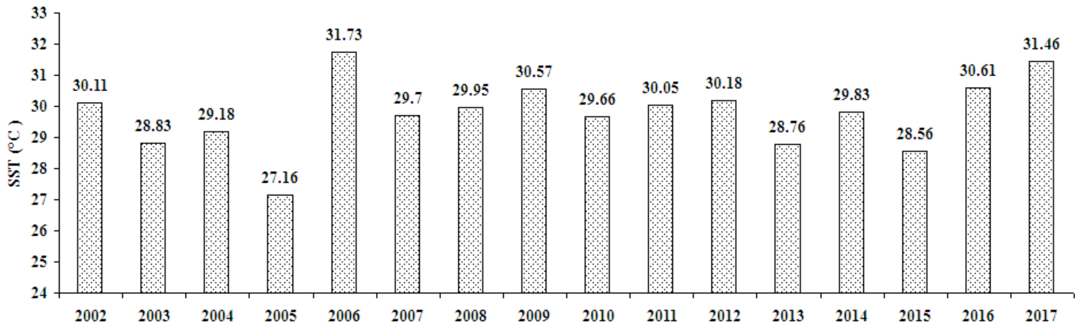

Figure 3: The average satellite-based SST in the studied stations in Bushehr province waters, from 2002 to 2017.

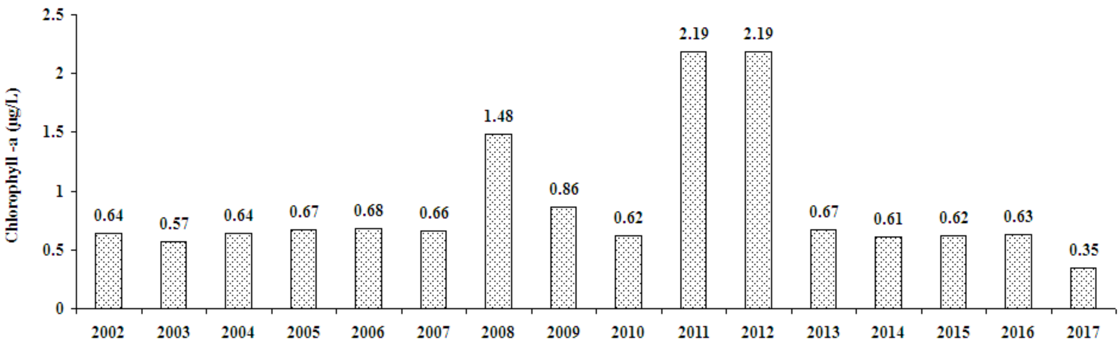

Figure 4: The average satellite-based Chlorophyll-a in the studied stations in Bushehr province waters, from 2002 to 2017.

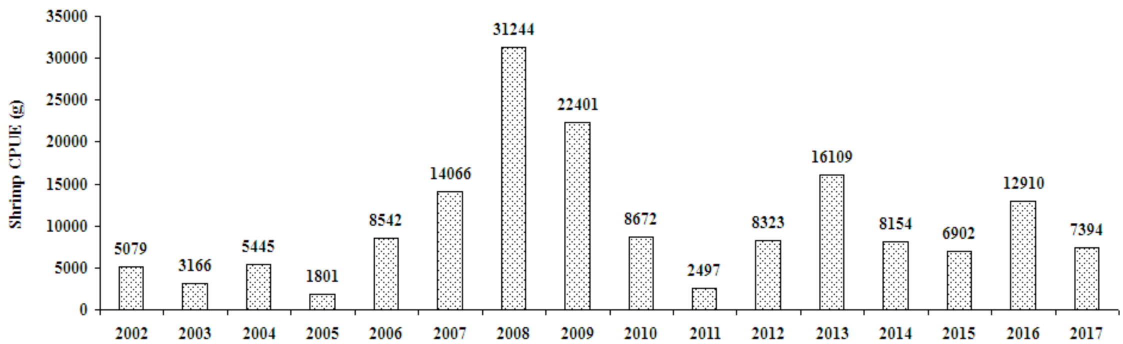

Figure 5: The average shrimp CPUE in the studied stations in the waters of Bushehr province, from 2002 to 2017.

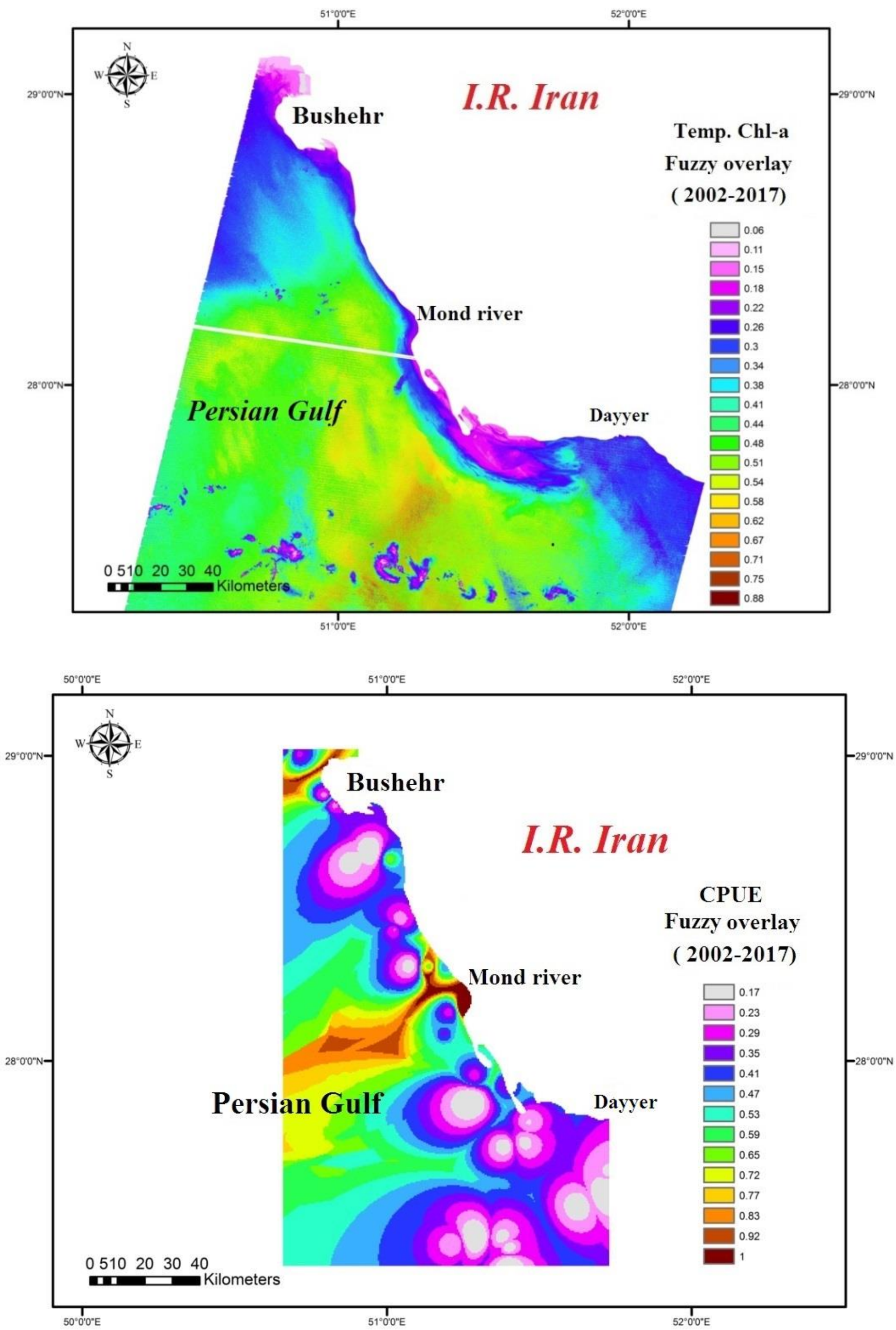

Figure 6: SST-Chl fuzzy overlay and CPUE distribution in the waters of Bushehr province, from summer 2002 to summer 2017.

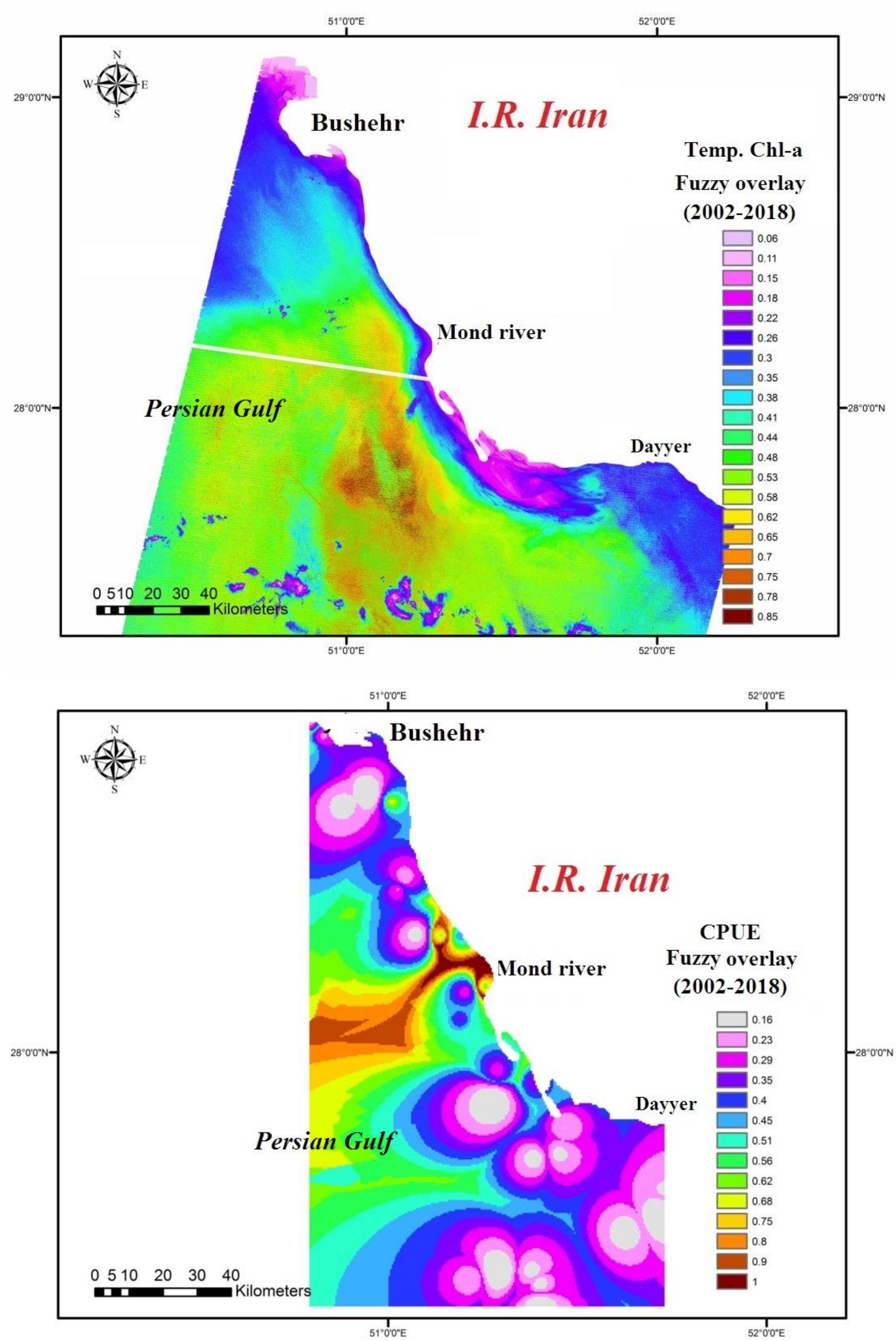

Figure 7: SST-Chl fuzzy overlay and CPUE distribution in the waters of Bushehr province, from the summer of 2002 to the summer of 2018.

Discussion

The average SST in the studied area was 29.77 °C from 2002 to 2017. The minimum of SST was 20.51°C at Station 7 in July 2005, and its maximum value was 32.99°C at station 27 in July 2017. The average of Chlorophyll-a in the studied area was 0.88 µg/L from 2002 to 2017. The minimum of Chlorophyll-a was 0.31 µg/L at most of the studied stations in July 2017, and its maximum value was 2.25 µg/ L at station 7 in July 2011 and station 12 in 2012. The average shrimp catch per unit effort (CPUE) in the studied area was 10,169 g/h from 2002 to 2017. The highest amount of shrimp CPUE was 533,184 g/h at station 24 in 2008, and the lowest amount of it was 20 g/h at station 27 in 2008. The averages of SST-Chl overlay values in the studied area from 2002 to 2017 were 0.64 (Table 6). The lowest value of SST-Chl overlay was 0.08 at station 4 in 2002 and at station 18 in 2013, and its highest value was 1.00.

The negative correlation between the SST-Chl overlay and shrimp CPUE suggests that the CPUE values in the studied stations increase with decreasing SST-Chl fuzzy overlay values. The fuzzy overlay values close to 1 indicates a low value of the studied parameter, while the values close to zero indicates a high value of the studied parameter. Therefore, a lower SST-Chl overlay value indicates areas with higher SST and richer Chlorophyll values, while a higher SST-Chl overlay indicates areas with lower SST and poorer Chlorophyll values. In general, the results suggest that there is a negative correlation between CPUE and SST/Chlorophyll-a in the studied area, with the CPUE value increasing as SST and Chlorophyll-a decrease. These findings are consistent with previous studies in the Persian Gulf, which have shown that the CPUE value increases with a decrease in water temperature and an increase in Chlorophyll-a.

The areas with the highest values of the SST-Chl-CPUE fuzzy overlay were located in stations 24, 22, 4, 16, 21, 19, 27, 26, 25 and 10, respectively. Interestingly, the highest CPUE values were observed in areas with lower SST and higher Chlorophyll-a concentrations, specifically in areas with an SST-Chl fuzzy overlay value between 0 to 0.4 (Fig. 6). The results of the shrimp CPUE calculation revealed that 60% of the shrimp catch were in stations 23, 24, 17, 18, 21, 26, 27, 4, and 10, which are located in the southern and northern parts of the studied area areas, indicating that these areas were the potential fishing zones for shrimp in the Bushehr province waters. The optimal water temperature range for shrimp growth is between 28 to 32°C (Kumlu *et al.,* 2000). Therefore, areas with water temperature closer to this range are expected to have a higher abundance of shrimp. Interestingly, despite the higher chlorophyll-a concentration in coastal areas, the study found that shrimps were more abundant in areas where the water temperature was closer to their optimum range, as depicted in Figure 6.

To validate the results obtained in this study, data on SST and Chlorophyll-a were extracted from +ETM Landsat 7 satellite images in June 2018, prior to the start of the shrimp open season in Bushehr province marine waters. The potential fishing zones were re-evaluated based on this validation data. The average SST-Chl fuzzy overlay value in the studied area in 2018 was 0.50, according to the validation data. The lowest SST-Chl fuzzy overlay value was 0.07 at station 22, while the highest value was 0.90 at stations 1 and 27. During the shrimp open season in July 2018, the average shrimp catch per unit effort (CPUE) in the studied areas in Bushehr province waters was 7,823 g/h. The highest amount of shrimp CPUE was recorded at station 19, with a value of 27,260 g/h, while the lowest amount was 260 g/h at station 1. The highest values of SST-Chl fuzzy overlay were in stations 22, 10, 11, 25, 19, 20, 17, and 14 in the studied areas, in June 2018 (Fig. 7). Results of the validation study showed that 63% of captured shrimp by Bushehr province fishermen caught in the introduced PFZ and 37% of shrimps captured in non-PFZ, in the shrimp open season of 2018. The linear regression analysis conducted between the SST-Chl fuzzy overlay and shrimp CPUE in the studied stations in 2018 showed a strong and significant positive correlation between these parameters, with a correlation coefficient of 0.75. This result confirms the validity of the suggested model proposed in this study. Chen *et al*. (2012) studied the distribution of shrimp in the East China Sea and found that water temperature, salinity, and Chlorophyll-a concentration were the main factors affecting shrimp distribution. They also found that the optimal water temperature range for shrimp growth was between 18 to 30°C. Wang *et al*. (2014) investigated the relationship between environmental factors and shrimp CPUE in the Yangtze River Estuary, China. They found that water temperature, salinity, and Chlorophyll-a concentration were the main factors affecting shrimp distribution, with the optimal water temperature range for shrimp growth being between 20 to 28°C. Chen *et al*. (2016) conducted a study in the Bohai Sea, China, and found that the distribution of shrimp was closely related to water temperature, salinity, and Chlorophyll-a concentration. They also found that the ideal water temperature range for shrimp growth was between 20 to 30°C. Kumar *et al*. (2018) found a negative correlation between SST and shrimp CPUE in the Gulf of Mannar, India, with the CPUE value increasing as SST decreased. They also found a positive correlation between Chlorophyll-a concentration and shrimp CPUE, with the CPUE value increasing as Chlorophyll-a concentration increased. In the current study, the identified potential fishing zones for shrimp in the Bushehr province were found to be associated with higher levels of Chlorophyll-a concentration and lower levels of sea surface temperature (SST).

Kamei *et al.* (2014) reported that the mean CPUE of experimental fishing in PFZ and the non-PFZ area was 30.7 kg/h and 18.7 kg/h respectively. The mean CPUE calculated from feedback data of fishermen in PFZ was 18.31 kg/h, whereas the mean CPUE in the non-PFZ area was only 5.23 kg/h. The dissolved oxygen level was 0.45 ppm more in PFZ compared to non-PFZ. The recorded chlorophyll data was 0.02–0.03 μg/l. Sanjeev *et al*. (2011) conducted a study along the Uttara Kannada coast of Karnataka and found a mean CPUE difference of 17.70 kg between PFZ and non-PFZ areas, with a difference of 58 kg in catch. The cost-benefit analysis for satellite fishery forecasts showed an increase in benefit for bottom trawling and gillnet fishing. Maity *et al*. (2013) investigated the benefit of satellite-derived PFZ advisories in the coastal stretch of West Bengal, India. They found that the PFZ advisories provided by the Indian National Centre for Ocean Information Services (INCOIS) were effective in reducing search time for fish schools and increasing the mean catch per unit effort (CPUE) in the notified area, which was almost two times higher than the CPUE in the non-notified area. Kamei *et al.* (2014) compared the mean CPUE of experimental fishing in PFZ and non-PFZ areas and found that the mean CPUE in the PFZ area was higher than that in the non-PFZ area. They also found that the dissolved oxygen level was higher in the PFZ area, with a difference of 0.45 ppm compared to the non-PFZ area.

In conclusion, the global algorithm of sea surface temperature and chlorophyll-a was calibrated for Bushehr province marine waters. There was a strong and positive significant relationship between long-term shrimp CPUE with inverse value of SST-Chl fuzzy overlay in Bushehr province waters in the Persian Gulf, from 2002 to 2018. Based on the results of this study, the shrimp Potential Fishing Zones can be determined using the fuzzy overlay of SST-Chl satellite data. The highest amount of shrimp catch was recorded in the areas where the value of SST-Chl fuzzy overlay was between zero to 0.4. Based on the results, the shrimp Potential Fishing Zones in Bushehr province waters were; Nakhiloo, Mond River, Ra's-e-Khan, Motaf, Heleyleh and Rostami areas which located in the southern and northern part of the studied area areas. By integrating SST and Chlorophyll-a satellite data and providing distribution maps of their fuzzy overlay data, fishermen can be guided to shrimp hunting grounds. Using these satellite-derived PFZ advisories can result in various benefits, such as reducing the time and effort needed to search for shrimp, minimizing fish bycatch, and can contribute to reducing the harmful effects of shrimp trawling on the seabed and marine environment. These advantages can lead to lower fishing costs, decreased fuel consumption, and ultimately improve the socio-economic conditions of fishermen. Additionally, it can be effectively used as a management tool to support sustainable fishing practices and protect marine ecosystems.

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