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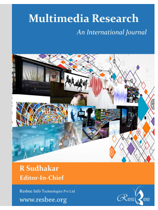

Mapping Potential Fishing Zones Using Remote Sensing Data and GIS: A Case Study of Moroccan Waters

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Abstract: Fishing, if sustainably managed, plays a crucial role in providing jobs and feeding the world. However, the exploitation of potential fishery resources is still underutilized in the fishing industry. Fish catch in the Potential Fishing Zones (PFZs) is 3 to 4 times higher when compared to non-PFZ areas. Remote Sensing (RS) provides reliable data on oceanographic conditions and supports marine environmental monitoring and assessment. This research aims to highlight the efficiency of remotely sensed data and advanced satellite image processing techniques to determine PFZs using Geographic Information Systems (GIS). The study focuses on the distribution of chlorophyll-A (Chl-A), sea-surface temperature (SST), and Particulate Organic Carbon (POC) concentrations, using MODIS (Moderate Resolution Imaging Spectro radiometer) satellite imagery with are solution of 4km. The methodology was implemented in Moroccan waters as a case study from January to December 2021. The results indicate that the suspected PFZs are between September and December 2021, mostly found in the region of Dakhla Oued Eddahab in the south of Morocco. The results were compared to the fishing catches given by the Ministry of Agriculture, Maritime Fisheries, Rural Development, and Waters and Forests of Morocco (published on 12/09/2022).

Keywords: Remote Sensing; Potential Fishing Zones; MODIS; Satellite Image Processing; Chl-A; SST; POC

Nomenclature

Abbreviations	Descriptions
RS	Remote Sensing
PFZs	Potential Fishing Zones
MODIS	Moderate Resolution Imaging Spectro radiometer
SIP	Satellite Image Processing
GIS	Geographic Information Systems
Chl-A	Chlorophyll-A
SST	Sea-Surface Temperature
POC	Particulate Organic Carbon
GDAL	Geospatial Data Abstraction Library
TIFF	Tagged Image File Format
HDR	High Dynamic Range
OBPG	Ocean Biology Processing Group
AVHRR	Advanced Very High- Resolution Radiometer
IRS P4	Indian Remote Sensing
OCM	Ocean Color Monitor
DMSP	Defense Meteorological Satellite Program
OLS	Operating Lines System
HDF	Hierarchical Data Format
QGIS	Quantum GIS
SMI	Standard Mapping Image
AIC	Akaike's Information Criterion

1. Introduction

Improving the management of the fishing industry is essential to increase local fish production, promote exports, contribute to national food security, and strengthen the national economy. The demand for

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fishery products globally continues to increase, and there is a need for sustainable, cost-effective, and modern techniques to exploit marine resources. Identifying PFZs would be of great value to the fishing community, as it would improve overall fishing effectiveness.

Fishing zones are still determined based on fishermen's experiences. However, the spatial distribution and fish community structure are continuously changing and vulnerable to various dynamic factors, such as the environment, climate change, and global change. This complexity makes it difficult for fishermen to determine the optimal fishing zones using traditional experimental-based techniques. Thus, it is necessary to find better solutions that fully exploit the richness of the ocean by identifying the best potential fishing zones [1].

The existence of fish can be predicted through different physical and biological indicators of marine ecosystems. CHL-A, SST, and POC are the most important oceanographic parameters and are commonly used to predict potential fishing zones [2]. CHL-A is the universal oceanographic parameter that significantly determines ocean productivity and is a suitable index of phytoplankton biomass [3], which is related to fish production. SST is an index of the ocean's physical environment and considerably influences the physiology of living organisms, especially affecting phytoplankton growth [4]. POC is defined as all combustible, non-carbonate carbon, and its dynamics in the ocean are central to the marine carbon cycle. POC is the link between the sea surface, the deep ocean, and sediments. The rate at which POC is degraded in the deep ocean can impact atmospheric CO2 concentration and thus affect the existence of zooplankton. The characteristics of CHL-A, SST, and POC are very important for studying physical and biological conditions that affect the existence of fish [5]. Therefore, integrating CHL-A concentration with SST and POC is likely to have great potential in exploring fishery resources and fish grouping, and thus identifying Potential Fishing Zones (PFZs) [6].

Remote sensing can provide reliable global ocean coverage of CHL-A, SST, and POC at relatively high spatial and temporal resolutions. This allows for a more effective analysis of the spatial and temporal distribution that can be measured from space [7]. RS enables the monitoring of changes in marine ecosystems globally [8] because it offers a means by which physical and biological variability can be synoptically viewed and systematically quantified across the entire region [9]. The use of satellite images is an effective and efficient alternative to the costly, time-consuming, and limited-coverage ship board sampling method.

The MODIS sensor aboard the NASA Earth Observing System satellites Terra (launched in December 1999) and Aqua (launched in April 2002) was designed for various parameter measurements. Its products are used to study global change and are being used by scientists from a variety of disciplines, including oceanography, biology, and atmospheric science. MODIS can monitor the entire Earth's surface every one to two days. As a result, the MODIS-derived CHL-A, SST, and POC provide a good opportunity for the scientific community to promote research over the ocean [10].

The objective of this research is to demonstrate the efficiency of remote sensing data and advanced satellite image processing techniques in identifying PFZs. Specifically, this research aims to:

1. Analyze the distribution of Chl-A, SST, and POC concentrations using MODIS satellite imagery with a resolution of 4km.

2. Determine the PFZs based on the analysis of Chl-A, SST, and POC data.

3. Implement the methodology in Moroccan waters as a case study to demonstrate its effectiveness and feasibility.

4. Compare the identified PFZs with fishing catch data provided by the Ministry of Agriculture, Maritime Fisheries, Rural Development, and Waters and Forests of Morocco.

5. Assess the potential of using remote sensing data and satellite image processing techniques to improve the sustainability of the fishing industry in Morocco.

Although several studies have been conducted to identify PFZs using remote sensing data and satellite imagery in different parts of the world, there is still a lack of research in identifying PFZs in certain marine regions. While some studies have evaluated the effects of environmental variations on the abundance of specific fish species, they did not specifically focus on identifying PFZs. Additionally, most studies used only one or two parameters to identify potential fishing zones, while this study aims to analyze the distribution of three parameters (Chl-A, SST, and POC) to improve the accuracy of PFZ identification.

Furthermore, there is a gap in the literature on the assessment of the potential of using remote sensing data and advanced satellite image processing techniques to improve the sustainability of the fishing industry. Therefore, this study will contribute to filling the research gap by demonstrating the effectiveness of using remote sensing data and advanced satellite image processing techniques in identifying PFZs and improving the sustainability of the fishing industry in various marine regions.

The remainder of this paper is organized as follows: Section 2 introduces existing strategies for estimating potential fishing zones and highlights our contribution. In Section 3, explain research methodology. Experiment is presented in Section 4, and the results are discussed and evaluated in Section 5. Section 6 outlines the challenges and limitations of this research, and finally, conclusion is given in Section 7.

2. Related Works

Several approaches have been developed to determine PFZs using various satellite data sources. For example, the sea-surface temperature can be obtained from satellite sensors such as the AVHRR or through MODIS, while Chl-A and POC concentrations can be obtained from the IRS P4 OCM data and MODIS. Previous research by [11] provided a global evaluation of POC flux parameterizations and their implications for atmospheric pCO2.

The author [12] employed aqua-MODIS satellite data to evaluate potential fishing zones in Aceh Besar waters from January to December 2019. The authors processed the satellite images, extracted information from each image, and overlaid Chl-A and SST data to generate maps of potential fishing zones.

In a previous study, [13] remotely sensed data were used to monitor the management of marine fisheries in Egypt (south Mediterranean Sea region). The authors developed a new model and applied it to the Sardinellaaurita fisheries to determine optimal fishing zones, and then detected the potential fishing zones for other local fish species. The parameters used in the approach are Chl-A and SST. The ranges of SST and Chl-A were obtained from MODIS aqua as well as Sentinel-3 satellites during the period from 2018 to 2020 [13]. The authors [13] evaluated the effects of oceanographic conditions on the potential fishing zones for Pacific saury in the western North Pacific. First, they constructed species habitat models using both fishing locations of Pacific saury from DMSP/OLS and satellite-based oceanographic data. A second method was used to identify the bright areas as actual fishing zones from OLS images, collected during the highest fishing season of Pacific saury in the North Pacific. Model selection is the third step, in which statistical metrics, including the significance of model terms, visualize the scale distributions of the Pacific saury habitat. The predicted potential fishing reduction in the Akaike's Information Criterion (AIC) was used. Finally, the selected model was then used for zones that showed spatial correspondence with the fishing locations. They also used [13] the NOAA-AVHRR-derived SST and IRS-P4 OCM chlorophyll data from October 2000 to February 2001 to validate the fishery forecast in PFZs. The results of data analysis showed that approximately 68-80 % of observations in PFZs were found to be positive during experimental fishing.

In previous research, S. aurita populations were studied by [17] in El-Arish, South eastern Mediterranean water based on monthly data collected between January 2008 and December 2009. Additionally, [19] evaluated the effects of environmental variations on the abundance of S. aurita in Moroccan waters using additive models based on satellite data between 2009 and 2016. They found that environmental parameters such as SST, Chl-A, and upwelling index were able to explain the differences in monthly landings for S. aurita. The high abundance of S. aurita was observed in autumn due to the favorable environmental conditions in the south of Morocco, which influenced the migration of this species from Mauritanian to Moroccan waters.

2.1 Review

Table 1 below summarizes the key findings and approaches of the related works discussed above. The table provides a comparison of the different parameters used in each study, as well as the satellite data sources and techniques employed. This comparison highlights the strengths and weaknesses of each approach and allows for a better understanding of the state-of-the-art in the field of potential fishing zone mapping using satellite data. This information is essential for identifying gaps in existing research and developing a more effective approach to determining potential fishing zones in the study area.

Table 1: *Comparison of Related Works in Potential Fishing Zone Mapping*

Study	Satellite Data /Parameters	Methodology	Advantages	Disadvantages
Ali *et al.*, [13]	MODIS Aqua and Sentinel-3 (Chl-A and SST)	New model development and application	• Able to determine optimal fishing zones and potential fishing zones for multiple fish Species.	• Limited to Egypt's south Mediterranean Sea region.
Muhammad *et al.*, [12]	Aqua-MODIS (Chl-A and SST)	Image processing and	• Able to determine potential fishing zones.	• Limited to Aceh Besar waters.

		mapping		
Baali *et al.*, [19]	Satellite data (SST, Chl-A, and up welling index)	Additive models	• Used additive models to evaluate the effects of environmental variation on S.aurita Abundance.	• Limited to Moroccan waters.
Rintaka *et al.*, [11]	AVHRR and MODIS (SST,Chl-A and POC)	Statistical model	• Used multiple satellite data sources (AVHRR, MODIS, IRSP4OCM). • Validated using experimental fishing.	• Limited to Moroccan waters.
Syah *et al.*, [14]	DMSP/OLS and satellite-based oceanographic data	Habitat models and statistical analysis	• Correspondence with actual fishing locations. • Used statistical metrics to select the habitat model.	• Limited to Pacific saury.

3. Research Methodology

In this section, we present the steps used for potential fishing zone mapping. Before starting the experiment, we need to collect several data, apply various processing techniques, extract data from the satellite images, identify the appropriate range for each parameter, and finally map the PFZ. Remotely sensed data are now allowing researchers to monitor the entire oceans, for a better understanding of the marine ecosystem.

In this paper, we implemented a methodology (Figure 1) composed of four steps: 1) Data Collection, 2) Data Processing, 3) Data Range Identification, and 4) Potential Fishing Zones Mapping [20].

Fig. 1. *Research Methodology*

3.1 Data Collection

Potential fishing zone mapping using remotely sensed data requires various parameters. In this study, we distinguished three kinds of data: 1) Chl-A, 2) SST, and 3) POC. All of these data can be extracted from different satellites such as Terra and Aqua. Each satellite presents different products, and these products differ in their sizes, spatial resolution, and spectral range.

1. **Chl-A:** Phytoplankton is the base of the fish food chain, from which Chl-A is produced to reflect the ocean and water color, allowing life in the open ocean to flourish. Zooplankton eats phytoplankton, and small bait fish eat zooplankton and phytoplankton. Moreover, bigger fish like tuna and marlin chase down these small baitfish. Hence, the higher the concentration of Chl-A is the greater the quantity of fish is likely to be in the ocean [13].
2. **SST:** Sea temperature determines the ideal habitat for most fish to survive. SST is an important geophysical parameter. In the past, SST was only measured using traditional methods such as ships and buoys, which had limited coverage. Remote sensing technology has improved our ability to measure SST by allowing global coverage [21].
3. **POC:** POC is defined as all combustible, non-carbonate carbon that can be collected on a filter. POC is the major pathway by which organic carbon produced by phytoplankton is exported from the surface to the deep ocean and eventually to sediments and is the key component of the biological production of fish [22].

3.2 Data Processing

After collecting all the satellite images, several processing techniques must be applied before potential fishing zone mapping can occur. This process involves various techniques to extract the necessary data from the images [20].

1) Data Conversion: The first step in data processing is to convert the collected images to the format required by the destination data system. As the images are in HDF format, they are converted to TIFF format using QGIS or the GDAL library.

2) Data Cleaning: Once the images are in a readable format, it must be verified that they are suitable for potential fishing zone mapping. Cloud cover, technical problems with the satellite, or distribution services can all cause data gaps in the images, which must be excluded from consideration.

3) Data Clipping: The satellite images must now be clipped to match the format of the study area. However, many difficulties can be faced while performing this operation, the main problem is the image volume, the more the image has a higher resolution, the more it is big and the more it is difficult to be processed, and few tools and platforms support processing large images. Therefore, it is important to carefully consider image size and available processing tools when conducting this step. One well-known and widely used free library for satellite image processing is the GDAL library.

3.3 Data Range Identification

The objective of this step is to determine the preferred values of Chl-A, SST, and POC concentration for fish. To accomplish this, we need to analyze the satellite images using different techniques to define appropriate data ranges for Chl-A, SST, and POC for fish abundance in the sea.

The first step in this process is to extract the data from all the collected satellite images and save it in CSV files. Since the images have the same size matching study area, the CSV files will have the same number of lines and columns. To extract the data values from the satellite images, we must read each image pixel "one-by-one" and then record it in to the CSV file in the right cell.

For each parameter, we must analyze the data variation in each of the CSV files representing the satellite images. For each file, we must first identify the minimum, maximum, and average values. Then, we take the lowest value of all 12 minimum values and the highest value of all 12 maximum values. These two values will represent the general range of the parameter in that time.

The general range must now be divided into five ranges (classes), indicating the confidence of fish existence in the sea (Premium, Good, Medium, Low, and Bad). This is done by studying the data values of all the CSV files.

Once obtained five ranges, the same operation for the remaining parameters was continued and obtained five ranges for each one. These ranges will help us identify the most suitable areas for fishing and provide an indication of the potential abundance of fish in different areas. The ranges will also be useful for predicting fish migration patterns and for identifying potential areas for future fishing activities. Overall, this step is crucial in determining the preferred values of Chl-A, SST, and POC concentration for fish in the study area, which will be used in the next step of potential fishing zone mapping.

3.4 Potential Fishing Zones Mapping

The final step of the methodology is PFZ mapping, which involves creating geo- referenced images with 5 colors representing different classes of potential fishing zones (Premium: red, Good: orange, Medium: yellow, Low: cyan, and Bad: blue). The goal is to create a visual representation of potential fishing zones in the study area, based on the analysis of the satellite images and the data range identification process. To achieve this, we need to follow these steps:

1) Data preparation and processing: The first step is to upload the satellite images and check their properties to determine whether they have a scale factor and offset. If so, we need to recalculate the values using Equation (1) to obtain the correct values for analysis.

$$new\_value=old\_value*scale\_factor+offset \quad (1)$$

2) Classification: Each zone in the study area must be classified into one of the 5 classes described above based on the PFZ score computed for the zone. The PFZ score is a value between 0 and 15, and it is computed by assigning a score to the pixel values for the three parameters (Chl-A, SST, and POC concentration) according to the 5 ranges we obtained in the previous step. Table 2 provides the classification for each PFZ score.

Table 2: *Potential fishing zones classification*

PFZ score	PFZ Category	Color
0	unclassified	None
1to 3	Bad	Blue
3to 6	Low	Cyan
6to 9	Medium	Yellow
9 to12	Good	Orange
12 to15	Premium	Red

3) Image Creation: A new geo-referenced image is created with the same shape as the study area, and the PFZ score for each pixel is used to assign a specific color to the pixel based on the potential fishing zone class. The final image shows potential fishing zones in the study area, with different colors indicating different levels of confidence in the presence of fish (Premium: red, Good: orange, Medium: yellow, Low: cyan, and Bad: blue).

4) Percentage Calculation: The final step is to calculate the percentage of each class in the mapped image and compare it to real data as a validation process. This helps to ensure that the PFZ mapping accurately represents the potential fishing zones in the study area.

Overall, the PFZ mapping step provides a visual representation of potential fishing zones in the study area, based on the analysis of satellite images and the classification of zones into different classes of confidence. This information helped fishermen to identify the best areas to fish, there by optimizing their catch and reduce the time and resources required for fishing.

4. Experiment

In this section, we will enlighten our experiment by presenting our study area, satellite-based data, and finally the implementation of the research methodology.

4.1 Study Area

The study area is located in Moroccan waters (Figure 2). Moroccan waters are considered one of the richest fishing grounds in the world, with a coastline of approximately 3,500 km covering two sea fronts (the Mediterranean Sea and the Atlantic Ocean). Fishing is a major industry in Morocco, and it has experienced tremendous growth, with the annual catch exceeding 430,000 tons in the 1980s and over 594,000 tons in the 1990s. These record catches demonstrate the maturity of the Moroccan fishing industry, which now accounts for approximately 45% of agricultural exports. Over 100,000 Moroccans are employed in the fishing industry, and it generates over 600 million dollars in foreign exchange each year.

Fig. 2. *Study Area.*

4.2 Satellite-Based Data

In this study, Chl-A, SST, and POC were derived from MODIS-Aqua measurement. Level 3 (4 km) monthly SMI data from January 2021 to December 2021 were downloaded from the ocean color website (http://oceancolor.gsfc.nasa.gov/).

4.3 Implementation

The implementation of the proposed methodology took place between January 2021 and December 2021in the study area as described earlier. The initial step involved collecting the satellite images for the three parameters of interest, namely Chl-A, SST, and POC. The HDR files for the collected images were then converted into TIFF format, which covered the entire earth as depicted in Figure 3. The next step was to identify and clean deficient images, such as those with cloud cover or other technical problems, to ensure the quality of the data. Finally, the processed images were clipped to match the study area shape as shown in Figure 4. The conversion and clipping processes were achieved using the GDAL library, which is an open-source and versatile image processing tool.

Fig. 3. *SatelliteimageinTIFFformat.*

Fig. 4. *Satelliteimageinthestudyareashape.*

After collecting and processing the satellite images for Chl-A, SST, and POC, the next step was to identify the data range for each parameter. This involved analyzing the values of all the collected satellite images to determine the preferred parameter values for fish in the study area. For each month, we identified the minimum and maximum values of all three parameters, as shown in Table 3. We then obtained the global data range for each parameter, which is presented in Table 4.

Table 3: *Data range identification for each parameter between January 2021 and December 2021.*

	Chl-A (mgm^{-3})	**SST (°C)**	**POC ($mg\ m^{-3}$)**
January	[0.1-54.1]	[14.4-22.4]	[35.8- 850]
February	[0.2-16.3]	[15.2- 20.9]	[63.4-996]
March	[0.1-35.8]	[15.3-30.7]	[42.8- 999]
April	[0.1-14.1]	[15.9 -27.9]	[36.4 - 994]
May	[0.08- 90.2]	[16.1 -28.2]	[33.8- 997]
June	[0.07-95.3]	[15.9 -29.6]	[32.2- 1000]
July	[0.07-74.8]	[15.3 -29.4]	[28.6- 998]
August	[0.07- 88.1]	[17.1 -27.6]	[25.8- 999]
September	[0.07-80.8]	[18.1 -27.1]	[28.6- 997]
October	[0.08-58.6]	[17.3 -25.5]	[29.4-999]
November	[0.1-54.1]	[16.2 -24.3]	[38.2-998]
December	[0.1-21.8]	[14.2 -22.4]	[42.6-999]

Table 4: *Global data range for each parameter.*

	MIN	MAX	AVG
Chl-A(mgm-3)	0,07	95,30	1,04
SST(°C)	14,23	30,66	20,08
POC(mgm-3)	25,80	1000	138,16

Based on the results presented above, we concluded data ranges of the three parameters, as follows:

1. Chl-A: [0.07-95.30] (mgm^{-3})
2. SST: [14.23 30.66] (°C)
3. POC: [25.801000] ($mg\ m^{-3}$)

Now, we must divide each range into five ranges, linked to the five classes described above. After analyzing the data of the three parameters for all images, we obtained the ranges presented in Table 5 below:

Table 5: *Data range division according to PFZ classes.*

	Chl-A (mgm^{-3})	SST (°C)	POC ($mg\ m^{-3}$)
Premium	[2 -95.30]	[24 -30.66]	[400 -1000]
Good	[0.65 -2]	[22 -24]	[200 -400]
Medium	[0.25 -0.65]	[20.5 -22]	[80-200]
Low	[0.15 -0.25]	[18.5-20.5]	[50 -80]
Bad	[0.07 -0.15]	[14 -18.5]	[25 -50]

In the final step of our study, we developed a Python script to generate a mapped geo-referenced PFZ image for a specific month. The script uploads three satellite images, one for each parameter, and for each pixel, we calculated a PFZ score based on the value of each parameter. We then classified the PFZ score into one of the five classes and colored it based on its class. This allowed us to create visual representations of PFZs for each month and parameter, providing valuable insights into the spatial and temporal patterns of PFZs in the study area.

5. Results & Evaluation

The potential fishing zones were estimated based on satellite-derived data for SST, Chl-A, and POC concentrations along the Moroccan waters. These factors have a significant impact on the identification of PFZs. Monthly PFZs were generated from January to December 2021, and the results are presented in Table 6 and Figures 6 to 17.

Table 6: *Potential fishing zone classification.*

	Premium	Good	Medium	Low	Bad
January	18	6611	12422	10610	332
February	0	5666	12756	11514	57
March	0	5625	12545	11761	61
April	13	4414	11028	13114	1424
May	24	4703	9108	15826	331
June	35	3793	8658	14907	2605
July	46	1921	6422	11696	9906
August	26	3689	9827	14989	1227
September	894	6444	11049	11501	105
October	1025	6321	11780	10836	31
November	426	8723	12108	8690	46
December	256	8386	12610	8703	38

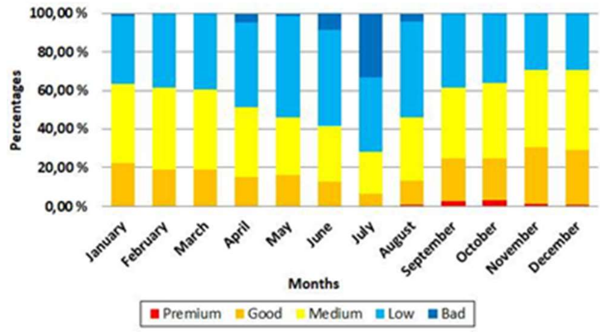

Fig. 5. *Potential fishing zone classes Distribution.*

The results indicate that the months with the highest abundance of fish were from September to December 2021, as the majority of SST values recorded from the satellite data were between 24°C and 27°C. Additionally, Chl-A values ranged between 5 and 30 mg m^{-3}, while POC values were between 500 and 800 mg m^{-3}. On the other hand, the most unsuitable month for fish abundance was observed in July 2021, as the values of Chl-A and POC were very low (Chl-A less than 2 mg m^{-3} and POC less than 200 mg m^{-3}), while SST values ranged between 17°C and 20°C. To assess the accuracy of these results, we compared them with the actual fishing catches in Moroccan waters reported by the Ministry of Agriculture, Maritime Fisheries, Rural Development, and Waters and Forests of Morocco during the same period (January-December 2021). Table 7 below presents the monthly fishing catches in Moroccan waters during 2021.

Table 7: *Monthly fishing caches in the study area during 2021.*

	Fish catch(ton)	**rank**
January	56 439	12
February	64263	10
March	92 436	7
April	89255	8
May	63 526	11
June	108 666	5
July	64 565	9
August	99321	6
September	148 871	3
October	152 987	2
November	157 015	1
December	138 187	4

The comparison of the estimated fish abundance with the actual fishing catches in Moroccan waters revealed that the months of September to December 2021 had the highest fish catch, consistent with the results of the experiment. To further evaluate the findings, the fishing catches were compared by region in the study area. Table 8 shows the real fishing catches in tons by region during 2021. The results indicated that the region of Dakhla-Oued Ed-Dahab had the highest fish catch rate (572,225 tons) and consistently performed better than other regions across all months, as confirmed by the mapped PFZ images in Figures 6 to 17. These observations provide additional validation of the estimated results from the experiment.

Table 8: *Real fishing caches by regions in the study area.*

Region	**Fish catch(ton)**
Dakhla-OuedEd-Dahab	572 225
Laâyoune-SakiaElHamra	369 328
Guelmim-OuedNoun	171 567
Marrakech-Safi	77574
Souss-Massa	36 223
Casablanca-Settat	41356
Tanger-Tétouan-AlHoceima	26305
Rabat-Salé-Kénitra	12407
L'Oriental	5 269

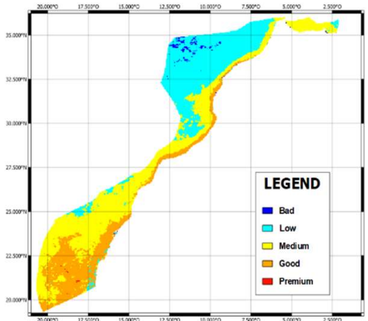

Fig. 6. *Estimation of PFZ in January*

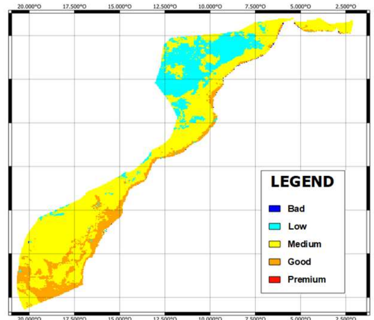

Fig. 7: *Estimation of PFZ in February*

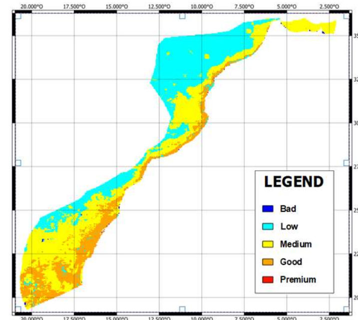

Fig. 8: *Estimation of PFZ in March*

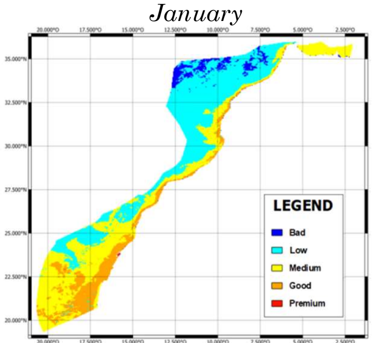

Fig. 9: *Estimation of PFZ in April*

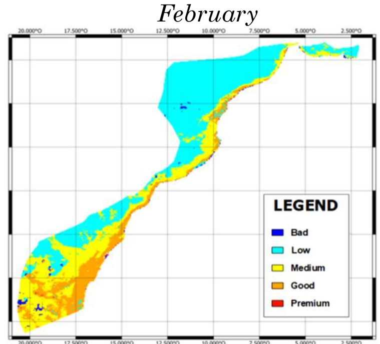

Fig. 10: *Estimation of PFZ in May*

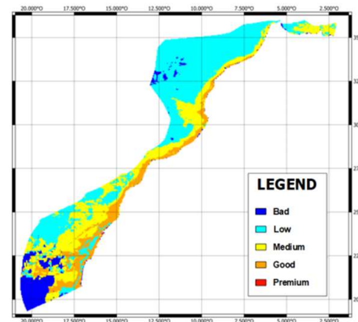

Fig. 11: *Estimation of PFZ in June*

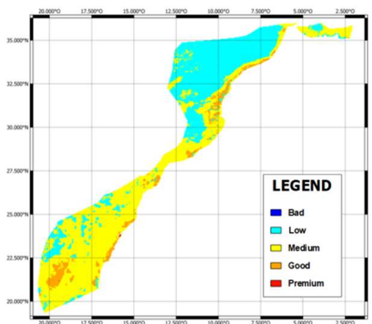

Fig. 12. *Estimation of PFZ in July*

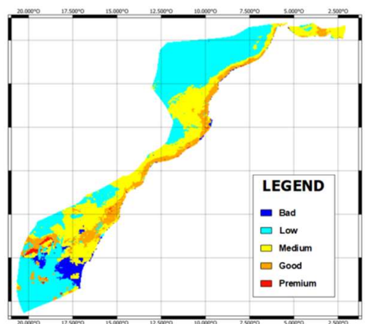

Fig. 13. *Estimation of PFZ in August*

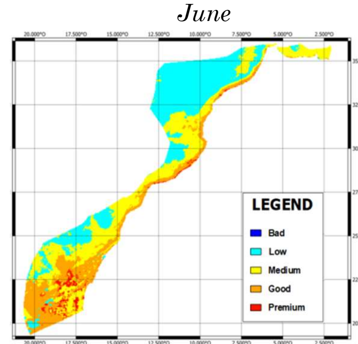

Fig. 14. *Estimation of PFZ in September*

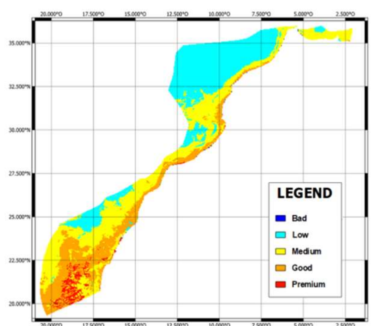

Fig. 15. *Estimation of PFZ in October*

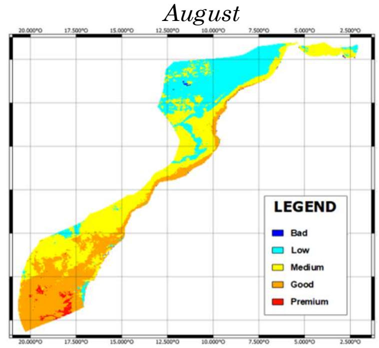

Fig. 16. *Estimation of PFZ in November*

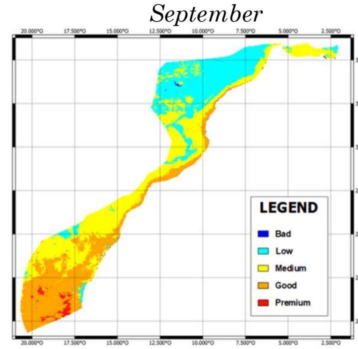

Fig. 17. *Estimation of PFZ in December*

6. Challenges and Limitations

Potential fishing zone mapping using remote sensing data and advanced satellite image processing techniques have become increasingly valuable tools for fisheries management and conservation efforts. The use of satellite data provides a cost-effective and efficient way to determine the optimal locations for fishing activities. However, there are still challenges and limitations that need to be addressed. The accuracy and reliability of satellite data can be affected by weather conditions and other environmental factors, which can lead to errors in determining potential fishing zones. Furthermore, the lack of comprehensive ground-truth data can limit the validation of satellite-derived potential fishing zones. It is also important to consider the limitations of satellite sensors and the need for continuous improvements in satellite technology to provide more accurate and reliable data. Finally, the availability of satellite data varies depending on the region and can be limited in some areas, which can affect the applicability of potential fishing zone mapping using satellite data. These challenges and limitations need to be carefully considered to ensure the effective use of satellite data for potential fishing zone mapping.

Table 9 below summarizes the challenges and limitations discussed above, as well as their impact on potential fishing zone mapping using satellite data.

Table 9: *Advantages and limitations of the proposed methodology.*

Advantages	Limitations
A cost-effective and efficient way to identify PFZs without the need for expensive and time-consuming field surveys.	Relies solely on satellite data, which may have limitations due to cloud cover, atmospheric conditions, and sensor capabilities.
Provides a comprehensive view of the ocean's dynamics can help predict the occurrence of PFZs.	Only provides an estimation of the location and distribution of PFZs, and fishing success is still subject to other factors such as fishing gear, fish behavior, and fisherman skill.
Provide real-time information, which can help fishermen optimize their fishing efforts and increase their catch.	Other factors such as ocean currents, topography, and Prey availability may also influence the distribution of fish in potential fishing zones.
Contributes to the sustainable management of fisheries by reducing the impact of fishing on non-target species and improve the overall efficiency of fishing operations.	May face challenges in identifying small-scale fishing grounds and fish aggregations that are not detectable by satellite sensors with coarser solution.
Analysis of Chl-A, SST, and POC data can provide valuable information about the location and abundance of phytoplankton, which is the base of the marine food chain and attract fish.	The resolution of the satellite imagery used in this study is limited to 4km, which may not provide sufficient detail for the identification of smaller-scale PFZs.
Comparison of identified PFZs with fishing catch data can help validate the accuracy of the method and provide useful information for fisheries management.	May not be applicable in areas with limited or no satellite coverage, such as areas with frequent cloud cover.

7.Conclusions

Marine fisheries play a significant role in boosting the economy. To maximize profits, efficient methods and technologies must be implemented. Satellite remote sensing has demonstrated its ability to generate and classify fishing zones using products such as Chl-A, SST, and POC. This research highlights the potential of earth observations in detecting fishing zones, benefiting the fishing community by reducing search time and improving profitability and socio-economic status. The proposed model uses satellite data to produce reliable PFZ maps. A case study in Moroccan waters identified the Dakhla-Oued Ed-Dahab region as having the most abundant fishing zones from September to December 2021.

Our methodology demonstrates how remote sensing technology provides real-time data and valuable insights to the fishing community, resulting in a significant increase in fish yield and profitability.

While the potential benefits of remote sensing in identifying potential fishing zones and improving the profitability of the fishing industry have been demonstrated, there is still a need for further research in this area. Here are some potential areas for future work:

1. **Integration of additional data sources:** Despite the use of Chl-A, SST, and POC data to identify PFZs in this study, there may be other data sources that could be integrated to provide more accurate and comprehensive results. For example, ocean current data, and weather data could be incorporated to provide a more complete picture of the ocean environment.
2. **Improved accuracy:** Although the promising results of this study, there is always room for improvement in terms of accuracy. Future works could explore the use of machine learning algorithms and other advanced techniques to improve the accuracy of PFZ maps.
3. **Operational implementation:** The proposed model has the potential to improve the profitability of the fishing industry, but practical considerations must be taken into account when implementing it in an operational setting. Future works could focus on developing a user-friendly interface and integrating the model into existing fishing technologies.

4. **Extension to other regions:** While this study focused on Moroccan waters, there is potential to extend the model to other countries. Future works could investigate the feasibility of applying this approach in other regions and evaluate its effectiveness in improving the profitability of the fishing industry.

Overall, the use of remote sensing technology has demonstrated great potential in improving the profitability and sustainability of the fishing industry. Further research and development in this area could have significant benefits for both the fishing community and the wider economy.

7. Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.
Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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