Comparative Analysis of Integration Indices and Object-Based Approach Using Sentinel-2 Data for Effective Monitoring of Aquaculture Fish Cages in Nasipit Port, Agusan Del Norte

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Comparative Analysis of Integration Indices and Object-Based Approach Using Sentinel-2 Data for Effective Monitoring of Aquaculture Fish Cages in Nasipit Port, Agusan Del Norte

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Abstract*: Fish cages in Nasipit Port, Agusan del Norte, have experienced a decline in recent years, indicating a shift in aquaculture activity. To accurately detect and monitor these structures, a method using Segmentation and Combined Index generation with Sentinel 2 satellite data is proposed. A comparative assessment between integrated indices and object-based image analysis (OBIA) from 2019 to 2023 was conducted. Integrated Indices achieved higher accuracy with an average of 95.55% and a Kappa coefficient of 0.94734, it also demonstrated the Producer's and User's Accuracy of 97.42% and 94.46% for identifying fish cages. Over the years, fish cage areas decreased from 6.98 ha in 2019 to 3.18 ha in 2023, indicating a decline. The transition matrix revealed the probabilities of class changes, with fish cages showing retention probabilities of 42.26%, 57.63%, 55.51%, and 63.78% from 2019 to 2023, while the remaining percentage was attributed to the water class.*

Keywords: Fish cages; Monitoring; Integration Indices; OBIA; Change Detection.

1. INTRODUCTION

Aquaculture involves cultivating aquatic organisms and plants in saltwater and freshwater environments. Also referred to as fish farming, it offers a diverse array of high-quality, nutrient-rich, and valuable food resources [1]. Fish farming, a predominant facet of aquaculture, entails the purposeful breeding of fish in freshwater or seawater settings to yield nourishing food sources. Its popularity arises from its capacity to generate cost-effective protein options, effectively catering to the growing demand for sustenance [2]. In tandem with terrestrial agriculture, aquaculture effectively addresses the global need for protein-rich nutrition while concurrently mitigating pressures on stressed marine ecosystems. Anchored by thorough methodologies like fish farming, aquaculture emerges as a cornerstone of responsible resource management, encompassing the transformative potential to nourish societies while upholding the intricate equilibrium of our aquatic environments [3].

Fish cages have become an essential instrument in aquaculture, strategically countering the challenges of overfishing and the change of indigenous fish reserves. By providing strictly controlled environments, these structures offer an unparalleled opportunity to cultivate aquatic organisms optimally. This deliberate approach promotes robust growth and reinforces the imperative of sustainable aquaculture practices. As empirical sources indicate, by exemplifying precision in growth management, prudent resource allocation, and adeptness in accommodating diverse aquatic ecosystems, fish cages have garnered widespread recognition as an indispensable solution for advancing responsible and impactful aquaculture [4].

Sentinel-2 satellites are equipped with advanced multispectral sensors that capture data in various spectral bands, allowing for the detailed analysis of land cover, vegetation health, urban development, and other environmental parameters. The strategic integration of Sentinel-2 imagery, with its impressive spatial resolution of up to 10 meters, has proven to be paramount, particularly in the dynamic context of aquaculture monitoring. Sentinel-2 imagery is used for different types of applications for specific purposes. This cutting-edge technology profoundly advances our ability to observe and manage aquatic environments. By offering high-resolution, multispectral imagery, Sentinel-2 revolutionizes the precision with which the researchers monitor various facets of aquaculture, thereby addressing key challenges and contributing to the sustainable growth of this vital industry [5].

In the contemporary era of remote sensing, indices, and band combinations, exemplified by the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), have become indispensable tools for extracting valuable insights from satellite imagery. Nowadays, these techniques, complemented by the 10m spatial resolution bands like B2, B3, B4, and B8, play a crucial role in unraveling the complexities of Earth's landscapes and environmental dynamics. Spectral indices, such as NDVI, leverage specific bands to quantify critical surface characteristics, notably vegetation health, while NDWI is tailored for water content assessment [6]. Object-Based Image Analysis (OBIA) represents a transformative shift in remote sensing and image interpretation. Unlike traditional methods focusing on individual pixels, OBIA operates by grouping pixels into meaningful and contextually relevant objects [7]. A sophisticated segmentation process aggregates similar pixels to form coherent entities, and subsequent analysis considers their spectral, geometric, and spatial characteristics. This methodological departure from pixels to objects enhances the interpretability and accuracy of satellite or aerial imagery [8].

The monitoring approach in this study harnesses the capabilities of exclusive GIS software, emphasizing its essential role in generating Object-Based Image Analysis (OBIA) segmentation and deriving essential indices and band combinations through tools like the Raster Calculator. Integrating GIS and RS functionalities, providing a comprehensive platform for spatial analysis and raster processing. This strategic utilization ensures a streamlined workflow, enabling the extraction of valuable information from satellite imagery and facilitating precise monitoring of aquaculture fish cages in Nasipit Port [9]. Applications for change detection can benefit from the data from earth observation satellites, which include Sentinel. Change-detection applications measure features such as distribution, setting, and development or declination [10].

2. STUDY AREA

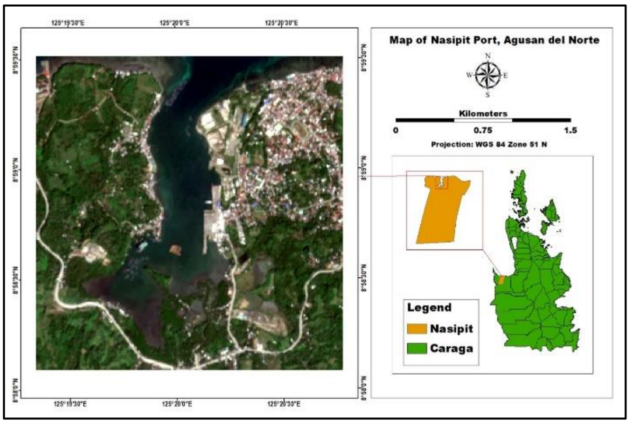

Figure 1. Location of the study area

Nasipit, located in Agusan del Norte, Caraga, Philippines, is a vibrant municipality with a population of 44,822 residents as of the 2020 census. Positioned strategically at approximately 8° 59′ 18″ North latitude and 125° 20′ 28″ East longitude [Fig. 2]. Nasipit covers an expansive 14,440-hectare area. Recognized as the major seaport by the Philippine Ports Authority (PPA), the Port of Nasipit plays a crucial role in regional trade (Nasipit, Agusan Del Norte Profiel - PhilAtlas). The area around the port is notable for a significant presence of aquaculture fish cages, highlighting its economic and aquatic significance.

3. MATERIALS AND METHODS

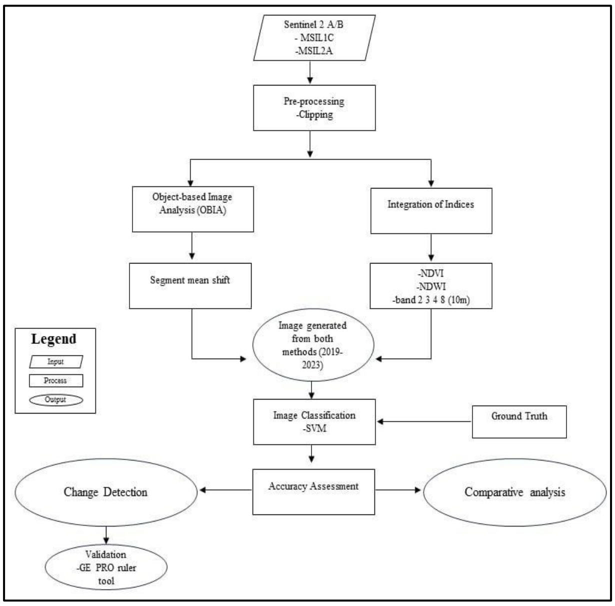

Fig. 2. Methodological Flowchart of the Study

3.1 Data Acquisition

The study utilized satellite images from sources like Sentinel-2 provided by platforms such as Copernicus Browser or the European Space Agency (ESA). These images, obtained from 2019 to 2023, belonged to S2MSIL1C and S2MSI2A product categories, offering top-of-atmosphere and atmospherically corrected bottom-of-atmosphere reflectance data, respectively.

Table 1. Datasets used in the Study.

Year	Date	Satellite Image	Product Type	Source
2019	07 - Jan	Sentinel 2A	S2MSI2A	ESA
2020	22-Dec	Sentinel 2B	S2MSIL1C	ESA
2021	12-Dec	Sentinel 2A	S2MSI2A	ESA
2022	07 - Dec	Sentinel 2A	S2MSI2A	ESA
2023	04 – Aug	Sentinel 2B	S2MSIL1C	ESA

3.2 Image Pre-processing

The foundational step in handling image datasets, exemplified by Sentinel-2 Images, involves pre-processing. This critical procedure aims to enhance the effective display and recording of data for subsequent visual interpretation, effectively converting raw data into a format conducive to extracting meaningful information. Pre-processing is imperative before further manipulating and analyzing the image data to extract specific insights. This process becomes particularly crucial given that Sentinel-2 images are already processed depending on the product type. ArcMap is being used as the tool choice for clipping the area scope of all images within Nasipit Port. This involves land masking and employing band composites or layer stacking all bands at a 10-meter spatial resolution to ensure precision and clarity in subsequent analyses of aquaculture fish cages.

3.3 Combining Bands and Indices

Band indices play an essential role in analyzing remote sensing data, particularly in the context of Sentinel-2 imagery. These indices are derived from specific spectral bands and are instrumental in extracting valuable information about the Earth's surface desire. This study combines the Normal Difference Vegetation Index (NDVI), Normal Difference Vegetation Water Index (NDWI), and corresponding 10m spatial resolution bands, such as bands 2, 3, 4, and 8, through band composite.

Table 2 shows the following sentinel-2 multispectral bands.

Table 2. Sentinel-2 MSI band

MSI Band	Descriptor	S-2A Central Wavelength (nm)	S-2B Central Wavelength (nm)	Resolution (m)
Band 1	Coastal Aerosol	442.7	442.3	60
Band 2	Blue	492.4	492.1	10
Band 3	Green	559.8	559.0	10
Band 4	Red	664.6	665.0	10
Band 5	Red Edge 1	704.1	703.8	20
Band 6	Red Edge 2	740.5	739.1	20
Band 7	Red Edge 3	782.8	779.7	20
Band 8	NIR	832.8	833.0	10
Band 8a	Narrow NIR	864.7	864.0	20
Band 9	Water Vapour	945.1	943.2	60
Band 10	SWIR Cirrus	1373.5	1376.9	60
Band 11	SWIR 1	1613.7	1610.4	20
Band 12	SWIR 2	2202.4	2185.7	20

3.4 NDVI and NDWI

The study employed NDVI and NDWI, which are widely recognized vegetation and water indices derived from satellite imagery, respectively. The Normalized Difference Vegetation Index (NDVI) stands as a widely utilized vegetation index derived from satellite imagery, assessing vegetation's presence and health based on distinct reflective properties across various light bands [11]. Within the scope of this study, NDVI plays a crucial role in evaluating vegetation health within the Nasipit Port area and in facilitating the precise distinction of fish cages. Given that fish cages lack typical vegetation characteristics, the application of NDVI proves instrumental in accurately identifying and differentiating these aquatic structures, enhancing the image.

The Normalized Difference Water Index (NDWI) is a widely employed water index derived from satellite imagery, gauging the presence and characteristics of water bodies based on their unique reflective properties across specific light bands [12]. In the context of this study, NDWI holds significance in assessing water content and dynamics within the Nasipit Port area and contributing to the accurate identification and differentiation of fish cages. As fish cages exhibit distinct features from natural water bodies, the utilization of NDWI proves indispensable in precisely delineating these aquatic structures, thereby augmenting the overall precision and effectiveness of the monitoring process.

The following is the Normal Difference Vegetation Index (NDVI) formula.

$$\text{NDVI}=\frac{NIR-RED}{NIR+RED} \qquad \textbf{[Eq. 1]}$$

Where:
NIR = Band 8 reflectance values
RED = Band 4 reflectance values

The following is the Normal Difference Water Index (NDWI) formula.

$$\text{NDWI}=\frac{GREEN-NIR}{GREEN+NIR} \qquad \textbf{[Eq. 2]}$$

Where:
NIR = Band 8 reflectance values
GREEN = Band 3 reflectance values

Hence, the layer stacking arrangement includes NDVI as band 1, NDWI as band 2, Band 2 as band 3, Band 3 as band 4, Band 4 as band 5, and Band 8 as band 6.

3.5 Segmentation

One of the critical challenges in information extraction using Sentinel-2 is segmentation, a crucial step in Object-Based Image Analysis (OBIA). Segmentation involves dividing an image into homogeneous and coherent objects, enhancing landscape representation with precision. This process groups pixels into meaningful objects, considering spatial relationships and contextual information. For this study, only three bands of 10 m spatial resolution, specifically band 2 as band 1, band 4 as band 2, and 8 as band 3, are utilized since segmentation requires only three bands. ArcMap software employs the mean-shift algorithm for segmentation, with tailored parameters, including spectral detail 20, spatial detail 20, and minimum segment size in pixels 10, to distinguish fish cages effectively.

3.6 Image Classification

There are two types of Image Classifications: Supervised and Unsupervised Classifications. This study employs a Supervised Classification approach, specifically the Support Vector Machine Classification (SVM), using ENVI 5.3 software to generate an aquaculture map of fish cages in the Nasipit port area from 2019 to 2023. SVM offers distinct advantages, including high classification accuracy and the capability to handle multi-class classification. This study has (seven classes: Water, Built-up, Fish Cage, Barren, Cropland, Forest, and other floating objects like Ships), optimal separation of classes even in complex scenarios, and robustness in handling noisy data.

3.7 Accuracy Assessment

The accuracy assessment for aquaculture fish cage mapping in this study is essential, as it directly impacts the reliability and precision of the resulting maps. Through this thorough process, researchers can critically evaluate the quality of the fish cage maps, identifying and rectifying any potential inaccuracies or misclassifications. This quality control procedure bolsters the overall trustworthiness of the study's findings and instills confidence in the accuracy of the aquaculture fish cage information. Accurate mapping of aquaculture fish cages is indispensable for making well-informed decisions in aquaculture management and environmental planning. The accuracy assessment enables researchers to validate the fish cage maps by comparing them with ground truth data or other reference datasets, ensuring coherence and strengthening their reliability.

3.8 Comparative Analysis of Accuracy Assessment

In the Comparative Analysis of Accuracy Assessment, researchers accurately evaluate the precision of monitoring aquaculture fish cages in the vicinity of Nasipit Port. This involves a detailed comparison of outcomes between the Integral Band Indices and Object-Based Image Analysis (OBIA) methods. The researchers aim to discern the most effective approach for detecting changes in fish cages, ensuring the tools employed provide reliable information. This comparative assessment contributes to the study's overall credibility and strengthens the accuracy of aquaculture fish cage information.

3.9 Change Detection

The researchers will specifically conduct the change detection for fish cages within the Nasipit Port area using the method that demonstrates the highest accuracy. Focusing intervals: 2019-2020, 2020-2021, 2021-2022, and 2022-2023, this targeted approach aims to identify and utilize the method, whether Integral Band Indices or Object-Based Image Analysis (OBIA), that consistently exhibits the highest accuracy in assessing changes in fish cage dynamics. The systematic analysis will provide crucial insights into the evolving aquaculture landscape over the specified time intervals, emphasizing the precision of the chosen method in detecting changes with the utmost accuracy.

3.10 Validation

Validation was performed using Google Earth Pro, using its high-resolution imagery to accurately measure the area of each fish cage. This process involved utilizing the toolbar buttons in Google Earth Pro to compute the precise area of individual fish cages. By employing high-resolution imagery and precise measurement tools within Google Earth Pro, the validation process ensured an accurate and reliable assessment of the fish cage areas. This step enhances the credibility of the study's findings by confirming the accuracy of the detected fish cage boundaries and dimensions [13].

4. RESULTS

4.1 Image Delineation

The delineation of images was processed in ArcGIS software using two methods: the Integration of indices as an image (a) and Object-based Image Analysis as an image (b).

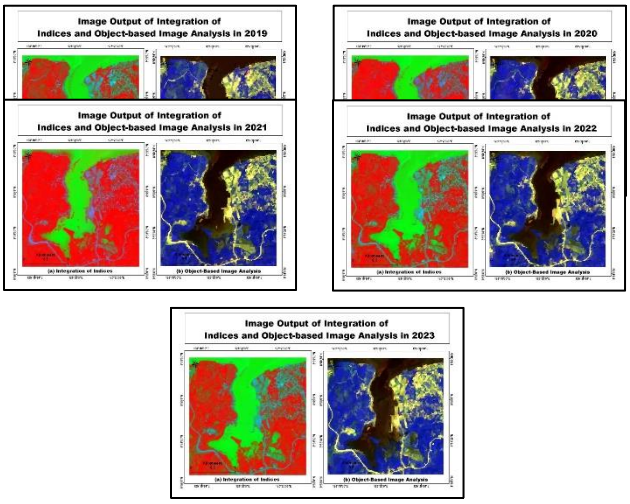

Fig. 3. Integration Indices and Object-based Image Analysis (OBIA)

4.2 Land Cover Maps

The Land Use and Land Cover (LULC) maps were processed using ENVI Classic software, employing Support Vector Machine Classification.

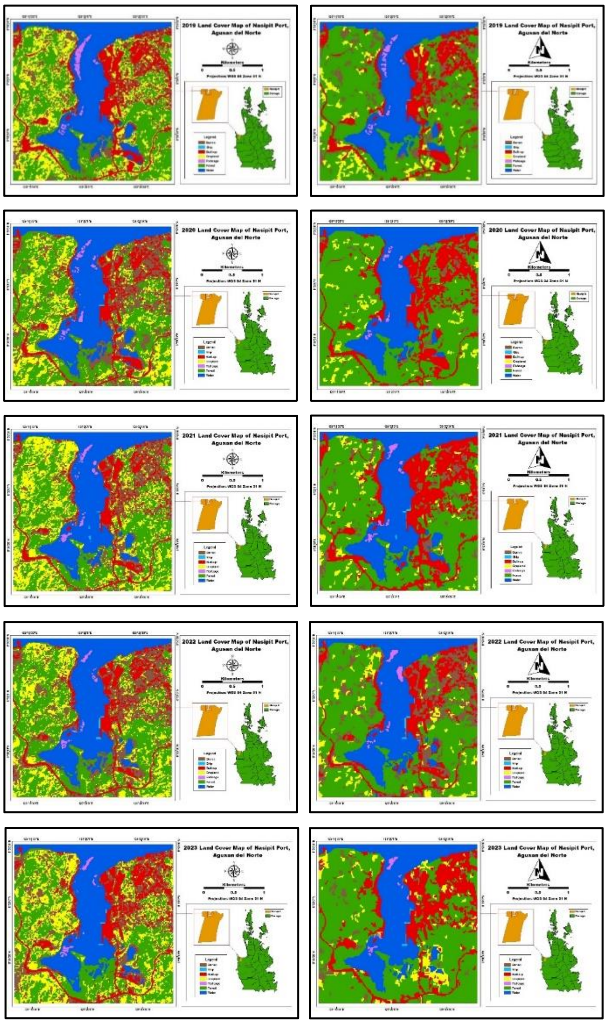

Figure 4. LULC Maps of Nasipit Port, Agusan del Norte (Integrated Indices and OBIA)

4.3 Overall Accuracy

Table 3. Summary of Overall Accuracy of Integrated Indices and OBIA

Year	Overall Accuracy of Integrated Indices	Kappa Coefficient of Integrated Indices	Overall Accuracy of OBIA	Kappa Coefficient of OBIA
2019	95.3437 %	0.9445	91.9981 %	0.8981
2020	95.2555 %	0.9440	89.2380 %	0.8498
2021	94.8247 %	0.9385	90.9969 %	0.8835
2022	94.1127 %	0.9309	90.1790 %	0.8722
2023	98.2127 %	0.9788	90.0267 %	0.8697
Average	**95.55%**	**0.94734**	**90.49%**	**0.87466**

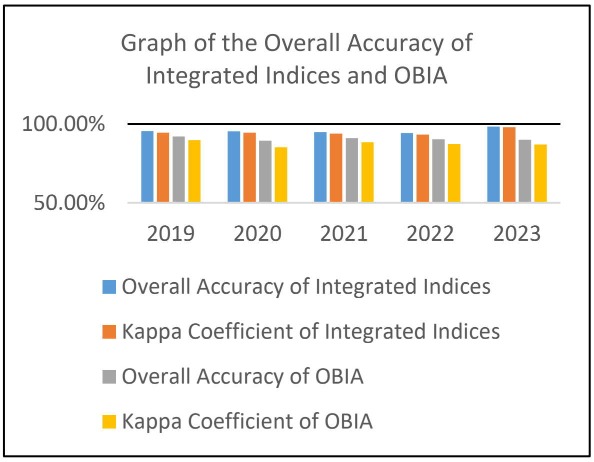

Fig. 5. Summary of Overall Accuracy of Integrated Indices and OBIA

4.4 Change Detection

Since the Integrated Indices has shown a higher accuracy compared to the OBIA, the researchers will now proceed to the change detection using the Integrated Indices. Change Detection Analysis was conducted using ArcMap software to analyze alterations in fish cages between each year. The changes of the fish cages in each year were identified by employing the Field Calculator within the attribute table. Additionally, the area of these changes was determined by calculating the geometry.

Table 4. Total Fish cages per Year

Year	Area (ha)
2019	6.98
2020	4.96
2021	4.37
2022	3.60
2023	3.18

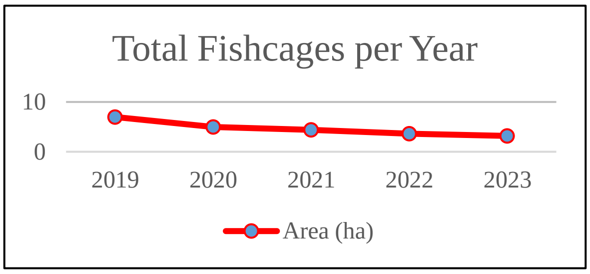

Fig. 6. Total Fish cages per Year

Table 5. Area Change during (2019-2020)

Change (2019-2020)	Area Change (ha)
Barren-Fish cage	0.00
Fish cage-Barren	0.03
Fish cage-Built-up	0.04
Fish cage-Fish cage	2.95
Fish cage-Forest	0.04
Fish cage-Water	3.92
Water-Fish cage	2.01

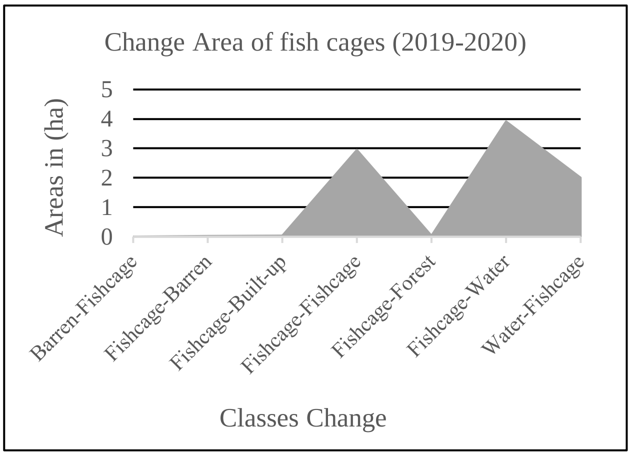

Fig. 7. Area Change during (2019-2020)

Table 6. Area Change during (2020-2021)

Change	Area Change (ha)
Barren-Fish cage	0.02
Built-up-Fish cage	0.00
Fish cage-Fish cage	2.83
Fish cage-Forest	0.00
Fish cage-Water	2.13
Water-Fish cage	2.17

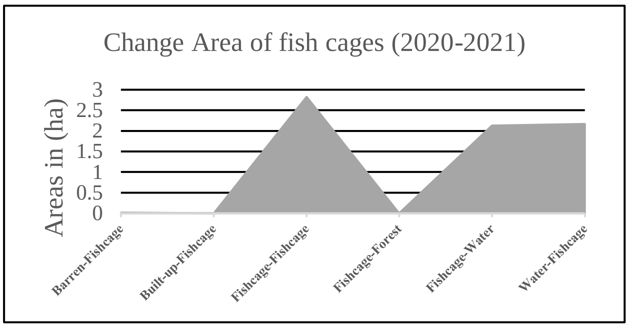

Fig. 8. Area Change during (2020-2021)

Table 7. Area Change during (2021-2022)

Change	Area Change (ha)
Barren-Fish cage	0.01
Built-up-Fish cage	0.02
Fish cage-Fish cage	2.80
Fish cage-Water	2.22
Water-Fish cage	0.77

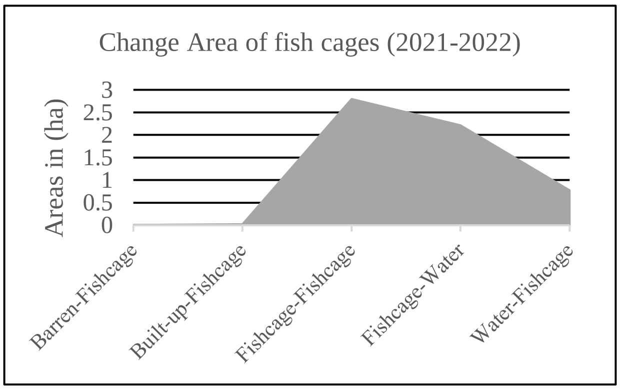

Fig. 9. Area Change during (2021-2022)

Table 8. Area Change during (2022-2023)

Change	Area Change (ha)
Fish cage-Fish cage	2.29
Fish cage-Water	1.31
Water-Fish cage	1.31

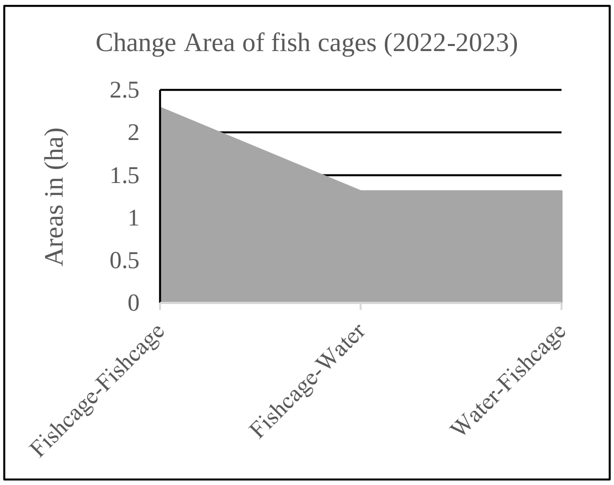

Fig. 10. Area Change during (2022-2023)

Table. 9. Percentage of change for each class between years

Classes	(2019-2020)	(2020-2021)	(2021-2022)	(2022-2023)
Barren	6.79%	-4.50%	4.79%	-3.25%
Ship	0.02%	0.03%	0.04%	-0.06%
Built-Up	-2.88%	-1.21%	0.62%	2.67%
Cropland	-3.12%	4.73%	-4.75%	4.11%
Fish cage	-0.29%	-0.09%	-0.11%	-0.06%
Forest	-0.86%	2.04%	-0.76%	-3.70%
Water	0.33%	-1.01%	0.18%	0.28%

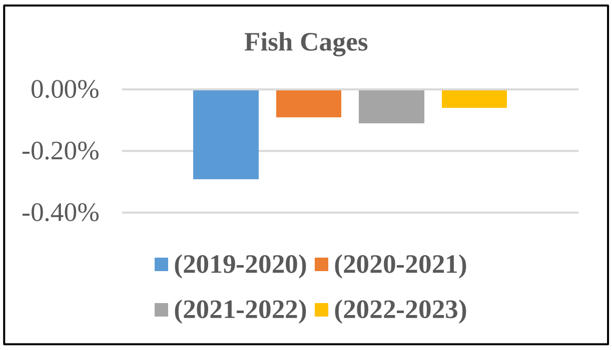

Fig. 11. Percentage of change for each class between years

In table 9 and Figure 11 shows the percentage of change each class between a 1-year interval. Negative percentage indicates the declination of the class, while the positive percentage indicates the increase of that certain class. The fish cage class can be seen slowly declining on the table while the other classes have an increase and decrease patterns. In the year 2019-2020 has the greatest declination with -0.29% followed by 2020-2021 with -0.09%, 2021-2022 with -0.11%, and 2022-2023 with -0.06%. The reason for this was because of the COVID-19, Typhoon Odette, a Municipal Ordinance, and the continuation of the said ordinance from 2019 to 2023, respectively that occurred in the port that made a huge impact in the declination of the fish cages.

4.5 Transition Matrix

Transition Matrix will be used in determining the class's probability to change into a different class or to stay as it is when compared with a different year. This method is useful in terms of change detection. The diagonal line indicates the percentage of a class to remain as it is, while the other values indicate the percentage that the specific class will have a chance to change into another class.

Table 10. Transition Matrix for (2019-2020)

	BARREN	BOAT	BUILT-UP	CROPLAND	FISH CAGE	FOREST	WATER	SUM
BARREN	0.59	0	0.10	0.19	0	0.1	0.03	1
BOAT	0	0.7	0	0	0	0	0.3	1

	BARREN	BOAT	BUILT-UP	CROPLAND	FISH CAGE	FOREST	WATER	SUM
BUILT-UP	0.33	0	0.59	0.04	0	0.01	0.03	1
CROPLAND	0.27	0	0.02	0.39	0	0.32	0	1
FISH CAGE	0	0	0.01	0	0.42	0.01	0.56	1
FOREST	0.11	0	0	0.16	0	0.72	0.01	1
WATER	0.02	0	0.01	0	0.01	0	0.95	1

Table 11. Transition Matrix for (2020-2021)

	BARREN	BOAT	BUILT-UP	CROPLAND	FISH CAGE	FOREST	WATER	SUM
BARREN	0.46	0	0.11	0.21	0.	0.21	0.01	1
BOAT	0	0	0.06	0	0	0	0.94	1
BUILT-UP	0.37	0	0.57	0.03	0	0.01	0.01	1
CROPLAND	0.12	0	0.02	0.56	0	0.30	0	1
FISH CAGE	0	0	0	0	0.58	0	0.42	1
FOREST	0.03	0	0	0.23	0	0.74	0	1
WATER	0.04	0	0.01	0	0.01	0.02	0.92	1

Table 12. Transition Matrix for (2021-2022)

	BARREN	BOAT	BUILT-UP	CROPLAND	FISH CAGE	FOREST	WATER	SUM
BARREN	0.74	0	0.13	0.09	0	0.02	0.02	1
BOAT	0	0.16	0	0	0	0	0.84	1
BUILT-UP	0.21	0	0.77	0	0	0	0.02	1
CROPLAND	0.21	0	0	0.54	0	0.24	0	1
FISH CAGE	0	0	0	0	0.56	0	0.44	1
FOREST	0.1	0	0	0.1	0	0.8	0	1
WATER	0.01	0	0	0	0.01	0.01	0.97	1

Table 13. Transition Matrix for (2022-2023)

	BARREN	BOAT	BUILT-UP	CROPLAND	FISH CAGE	FOREST	WATER	SUM
BARREN	0.62	0	0.15	0.15	0	0.07	0.01	1
BOAT	0	0.28	0.02	0	0	0	0.69	1
BUILT-UP	0.07	0	0.90	0	0	0	0.02	1
CROPLAND	0.13	0	0	0.69	0	0.17	0	1
FISH CAGE	0	0	0	0	0.64	0	0.36	1
FOREST	0.07	0	0	0.18	0	0.73	0	1
WATER	0.01	0	0	0	0.01	0.01	0.97	1

4.6 Validation

Validation was conducted in Google Earth Pro using its ruler toolbar to approximate the dimensions and area of fish cages, leveraging its higher resolution imagery.

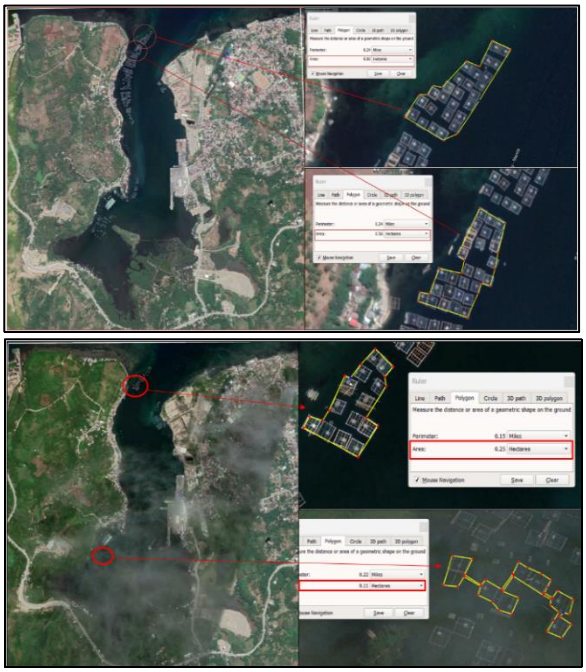

Fig. 12. Validation of data in the year 2019 and 2023

Table 15. Validation for Fish cage areas

Year	LULC Fish cage area (ha)	Google Earth Fish cage area (ha)	Difference	Percentage of the Difference
2019	6.98	6.44	-0.54	-8.39%
2020	3.18	2.74	-0.44	-16.06%

5. CONCLUSION

5.1 Conclusion

The integration of indices and Object-Based Image Analysis (OBIA) has provided valuable insights into the dynamics of fish cages in Nasipit Port, serving as an input for image classification using the SVM classifier. Indices such as NDVI, NDWI, and the corresponding 10m spatial resolution bands have proven advantageous for image classification. Notably, the combination 261 band, which includes NDWI as band 2, NIR as band 6, and NDVI as band 1, effectively distinguishes fish cages due to the presence of three NIR bands. In OBIA segmentation, the study successfully highlighted changes in fish cage distribution, although Sentinel-2 was unsuitable for OBIA due to its inability to recognize true color images, leading researchers to generate a new layer stock employing bands 2, 4, and 8.

Land cover maps for Nasipit Port, Agusan del Norte, from 2019 to 2023, were generated using Integration Indices and OBIA. The Integration Indices method achieved an overall average accuracy of 95.55% and a Kappa coefficient of 0.94734, while OBIA had an overall average accuracy of 90.49% and a Kappa coefficient of 0.87466. Specifically, for the fish cages class, Integration Indices showed a Producer's Accuracy of 97.42% and a User's Accuracy of 94.46%, outperforming OBIA's Producer's Accuracy of 84.57% and User's Accuracy of 87.48%. Consequently, Integration Indices are the preferred input for change detection due to their higher accuracy.

The change detection analysis using Integration Indices data revealed a decline in the total fish cage area from 2019 to 2023. The areas recorded were 6.98 ha, 4.96 ha, 4.37 ha, 3.60 ha, and 3.18 ha, respectively. This decline can be attributed to several factors: the market downturn during COVID-19 in 2020, Typhoon Odette in 2021, and a municipal ordinance in 2022 and 2023 mandating the relocation of fish cages to a new mariculture park in Brgy. Ata-atahon. The fish cages' continuous reduction is supported by tables and figures showing year-over-year area changes and consistently negative percentages in the fish cages class.

Validation of the fish cage data was performed by manually computing the areas for 2019 and 2023, which were 6.44 ha and 2.74 ha, respectively. The LULC analysis showed areas of 6.98 ha and 3.18 ha, with some discrepancies due to pixel misclassification from water to fish cages. The study's findings underscore the significant decline in fish cages over the years and highlight the effectiveness of Integration Indices for accurate change detection in this context.

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