A Project Report

on

Remote sensing Garbage patches in the Indian Ocean using Sentinel-2

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Under The Supervision of

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CANDIDATE'S DECLARATION

I/We hereby certify that the work which is being presented in the project, entitled **"Remote sensing Garbage patches in the Indian Ocean using Sentinel-2"** in partial fulfillment of the requirements for the award of the B. Tech.(Computer Science and Engineering) submitted in the School of Computing Science and Engineering of Galgotias University, Greater Noida, is an original work carried out during the period of January, 2024 to April, 2024, under the supervision of Dr. Alok Katiyar, Department of Computer Science and Engineering, of School of Computing Science and Engineering , Galgotias University, Greater Noida.

The matter presented in the project has not been submitted by me/us for the award of any other degree of this or any other places.

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This is to certify that the above statement made by the candidates is correct to the best of my knowledge.

15/4/2024

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CERTIFICATE

This is to certify that Project Report entitled "**Remote sensing Garbage patches in the Indian Ocean using Sentinel-2**" which is submitted by Ansh Shankar (20SCSE1180088), Dhruv Varshney (20SCSE1180139) in partial fulfillment of the requirement for the award of degree B. Tech. in Department of Computer Science and Engineering of School of Computing Science and Engineering Department of Computer Science and Engineering Galgotias University, Greater Noida, India is a record of the candidate own work carried out by him/them under my supervision. The matter embodied in this thesis is original and has not been submitted for the award of any other degree

22/4/2024

Signature of Examiner(s) **Signature of Supervisor(s)**

Signature of Program Chair **Signature of Dean**

Date: 22 April,2024

Place: Greater Noida

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ABSTRACT

Garbage patches in the world's oceans are a growing environmental concern, with the Indian Ocean experiencing its share of marine debris accumulation. This research employs remote sensing techniques with Sentinel-2 satellite data to identify and monitor garbage patches in the Indian Ocean. Sentinel-2's Multi Spectral Imagery (MSI) provides valuable ocean colour information, enabling the detection and characterization of these pollution hotspots. This study presents a comprehensive analysis of the application of Sentinel-2 data for the remote sensing of Indian Ocean garbage patches, focusing on the acquisition, preprocessing, and analysis of MSI imagery. By leveraging the unique capabilities of Sentinel-2, we gain insights into the spatial and temporal dynamics of garbage accumulation in the Indian Ocean, contributing to our understanding of this critical environmental issue. The results demonstrate the utility of Sentinel-2 in monitoring and managing marine debris in the Indian Ocean, offering valuable information for policymakers and environmental agencies working towards effective mitigation strategies.

Keywords: Remote Sensing, Satellite Image, Indian Ocean, Sentinel-2, Garbage patches Plastics, NDVI, FDI, PI

List of Tables

S.No.	Caption	Page No.
1	*Comparison of Different Index*	29
2	*Time Series Analysis*	31

List of Figures

S.No.	Title	Page No.
1	*Flowchart*	14
2	*Raw Satellite Image*	19
3	*Mapping of Plastic Patches*	27
4	*Comparison of A) raw NDVI Image and B) plastic detected patch of Figure 2*	27
5	*Comparison of A) raw Plastic Index Image and B) plastic detected patch of Figure 2*	28
6	*Comparison of A) raw FDI Image and B) plastic detected patch using FDI of Figure 2*	28
7	*Detection of Plastic Accumulation from April 2020 to September 2023*	31

Table of Contents

Title		Page No.
Abstract		I
Contents		II
Chapter 1	Introduction	9
Chapter 2	Literature Survey	11
Chapter 3	Model Design	14
Chapter 4	Data Acquision	15
Chapter 5	Data Preprocessing	18
Chapter 6	Methodology	21
Chapter 7	Results and Discussion	27
Chapter 8	Conclusion and Future Scope	33
	Reference	35

CHAPTER-1

Introduction

The Earth's oceans, enveloping more than 70% of the planet's surface, stand as indispensable components of our global ecosystem, fostering a rich tapestry of marine life [1]. Nevertheless, a pressing environmental menace has emerged in recent decades, threatening these expansive bodies of water—the proliferation of garbage patches. These patches, zones within the oceans where marine debris accumulates, pose significant risks to aquatic ecosystems, wildlife, and human activities like fisheries and navigation [2]. The Indian Ocean, spanning vast distances, is not exempt from this escalating crisis.

The mounting accumulation of marine debris in the Indian Ocean has garnered attention due to its detrimental ecological and socio-economic repercussions. Plastic waste, abandoned fishing gear, and various forms of pollution infiltrate this immense expanse, generating focal points of environmental degradation. The repercussions of these garbage patches extend far beyond their immediate locations.

The ecological fallout of garbage accumulation in the Indian Ocean is profound [2]. Marine life, ranging from minuscule plankton to majestic mammals, contends with the ingestion or entanglement in plastic and other debris. The toxins released during the decomposition of plastics infiltrate the food web, potentially endangering species up the chain, including humans reliant on the ocean's resources for sustenance. Moreover, the altered habitat conditions within garbage patches can disturb the delicate equilibrium of marine ecosystems.

Economic ramifications of marine debris are equally substantial. Fisheries, pivotal for the livelihoods and sustenance of coastal communities in the Indian Ocean region, encounter heightened challenges due to debris interference with fishing gear and the possible contamination of catches. Coastal tourism, another vital economic driver, faces setbacks as pristine beaches and waters succumb to accumulating waste.

Addressing this environmental challenge effectively necessitates monitoring and comprehending the dynamics of garbage patches. Remote sensing technologies, particularly satellite-based methods, have emerged as potent tools for studying marine debris across the globe. In this domain, the Sentinel-2 satellite, equipped with Multi

Spectral Imagery (MSI), emerges as a standout resource. MSI furnishes crucial ocean color information, enabling the detection and characterization of pollution hotspots, making it an ideal candidate for investigating garbage patches in the Indian Ocean.

This paper constitutes a thorough exploration of the application of Sentinel-2 satellite data for remote sensing of garbage patches in the Indian Ocean. Our study encompasses the entire process, from data acquisition and preprocessing to the analysis of MSI imagery. Leveraging the distinctive capabilities of Sentinel-2, our aim is to illuminate the spatial and temporal dynamics of garbage accumulation in this critical region. Our research contributes to a deeper understanding of the environmental challenges posed by marine debris in the Indian Ocean.

Moreover, the insights garnered from this study bear significant implications for policymakers and environmental agencies involved in formulating and implementing effective mitigation strategies. The results underscore the utility of Sentinel-2 as a crucial tool for monitoring and managing marine debris, ultimately contributing to the preservation of the Indian Ocean's delicate ecosystems and safeguarding the livelihoods of coastal communities. In an era where environmental sustainability is paramount, the knowledge derived from this research proves invaluable in our collective endeavor to protect the future of our oceans.

CHAPTER-2
Literature Survey

The expansive realms of the Great Pacific are overshadowed by the presence of one of the largest accumulations of floating plastic debris globally. A pioneering study by Young-Je Park et al. delves deeply into the detection of plastic litter within the Great Pacific Garbage Patch (GPGP), employing high-resolution satellite imagery as a key tool [3]. This research marks a significant stride in understanding and addressing the pervasive issue of plastic pollution in our oceans. The study not only focuses on the identification of plastic debris but also utilizes spectral differences and anomalies in satellite imagery to pinpoint suspected plastic litter. It accentuates the potential of spectral-based approaches, particularly in clear sky and calm sea conditions, shedding light on the challenges associated with detecting plastics in rough sea conditions. Importantly, this research serves as a pivotal reference for the broader application of remote sensing techniques to identify plastics in garbage patches worldwide.

Simultaneously, the Plastic Gyre of the Indian Ocean has been steadily expanding since its discovery in 2010, presenting another critical environmental concern. P. Seifert et al.'s comprehensive study undertakes a nuanced analysis of cirrus clouds over the tropical Indian Ocean, elucidating their formation, properties, and potential interactions with atmospheric processes [4]. Drawing on data from the Indian Ocean Experiment (INDOEX) and satellite observations, the research investigates the complex factors influencing cirrus clouds in tropical regions. This understanding of atmospheric processes emerges as a crucial aspect for effectively interpreting satellite imagery, particularly in the context of remote sensing applications in the Indian Ocean.

In tandem, Maelle et al.'s study provides empirical evidence of macro-litter, particularly plastic debris, in the rarely explored southwestern Indian Ocean [5]. Conducted during the austral summer of 2019-2020, this observation identifies a concerning accumulation of litter in the southern Indian Ocean, hinting at the presence of a garbage patch in this region. The study underscores the imperative need for further research and on-site monitoring to comprehensively grasp the extent and impact of plastic pollution in the Indian Ocean. By shining a light on the seldom-explored areas, this research contributes significantly to the holistic understanding of the distribution of plastic debris in the oceans.

Furthermore, Mirjam et al.'s study delves into the dynamics of buoyant marine plastic debris in the southern Indian Ocean, providing insights into the unique oceanic and atmospheric dynamics of the region and investigating the transport mechanisms influencing plastic accumulation [6]. This understanding of plastic debris dynamics proves crucial for our ongoing research in remote sensing of garbage patches in the Indian Ocean. The study not only adds to the growing body of knowledge but also emphasizes the interconnectedness of various environmental factors influencing the fate of marine plastic debris.

Adding to the technological dimension, Chris Greenly et al.'s study demonstrates the practical application of satellite imaging technology to observe and track ocean plastics, with a specific focus on the GPGP [7]. By emphasizing factors such as ground sampling distance (GSD) and radiometric resolution in satellite payloads, the study underscores their significance for effective plastic monitoring—a crucial aspect of our ongoing research in remote sensing techniques. This research represents a convergence of technological innovation and environmental monitoring, providing essential insights into the nuances of employing satellite technology for tracking and analyzing ocean plastics.

The environmental consequences of ocean garbage patches are explored comprehensively in Kabir Malhotra's study, which not only delves into the harm inflicted on marine life but also addresses the disruption of natural processes and the broader implications for climate change [8]. The study goes beyond the immediate concerns of plastic pollution and discusses monitoring methods, including remote sensing, as well as innovative cleanup solutions. By presenting a multifaceted approach to addressing global garbage patch issues, this research underscores the urgent need for holistic strategies to mitigate the environmental impact of plastic debris.

Adding another layer to the discourse, Huang Yin et al.'s study emphasizes the critical need to monitor and mitigate marine plastic pollution using remote sensing technology [9]. By discussing the limitations of in-situ observations and advocating for global-scale, high-resolution continuous monitoring, the research aligns seamlessly with our study's focus on remote sensing. This study resonates with the broader imperative of addressing marine plastic pollution on a global scale and underscores the significance of continuous monitoring for effective mitigation.

Exploring the technical challenges, Chuanmin Hu's study delves into the complexities and conditions for remote sensing of marine debris, specifically using spectral data [10]. By addressing issues of sensitivity, discrimination, and spectral analysis in the context of detecting different types of marine debris, the study offers invaluable technical insights. This technical understanding proves instrumental for our ongoing research, providing a foundation for navigating the intricacies of remote sensing in the context of marine debris detection.

Shifting focus to the Indian Ocean, Charitha et al.'s study contributes by discussing the sources and impacts of plastic debris in the Indian Ocean (IO) [11]. The research not only highlights the existing challenges, including entanglement and ingestion, but also explores the economic consequences of plastic pollution. Additionally, the study sheds light on emerging policies and initiatives in Indian Ocean rim countries to address plastic pollution, providing a comprehensive overview of the efforts being made at the regional level.

In conclusion, the collective body of research presented in these studies paints a vivid and intricate picture of the challenges posed by ocean garbage patches, with a specific focus on the Great Pacific and Indian Oceans. These studies, each contributing a unique perspective, span a spectrum from technological applications to atmospheric processes and socio-economic impacts. As the global community grapples with the escalating crisis of marine plastic pollution, this comprehensive understanding becomes the cornerstone for effective strategies, policies, and technological innovations to safeguard the health of our oceans and the delicate balance of marine ecosystems. The knowledge derived from these studies serves as a guiding beacon in our quest for sustainable and responsible stewardship of the oceans for generations to come.

CHAPTER-3
Model Design

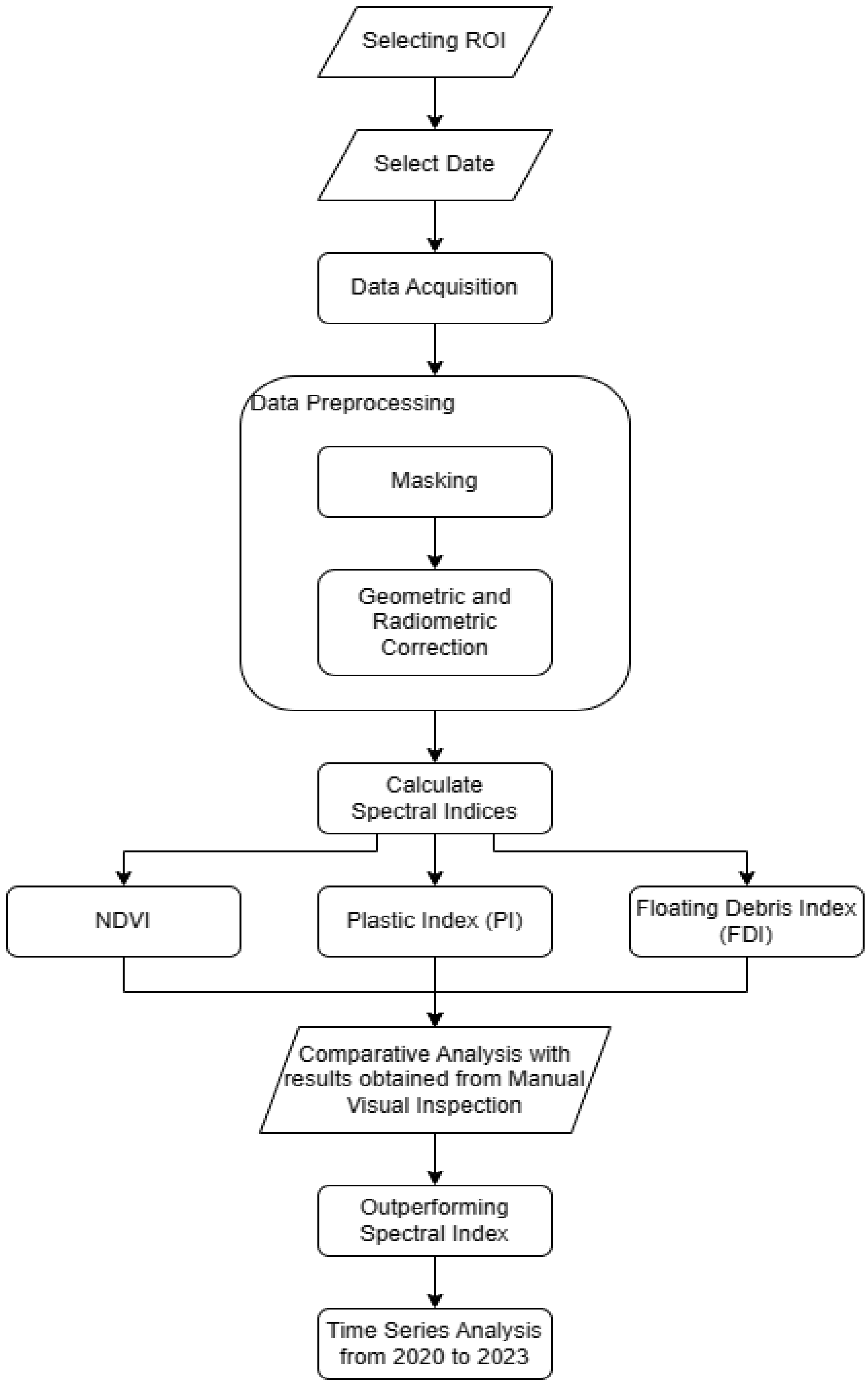


Figure 1: Flowchart

CHAPTER-4
Data Acquisition

After establishing the foundation of our study on remote sensing of garbage patches in the Indian Ocean using Sentinel-2 imagery, our attention turned to the crucial aspect of data acquisition and preprocessing. Recognizing the significance of acquiring accurate and up-to-date information, we meticulously implemented a systematic workflow facilitated by the powerful capabilities of Google Earth Engine—an instrumental platform for real-time access and processing of satellite imagery.

The initial steps of our data acquisition workflow were meticulously crafted to ensure precision and relevance:

A. Study Area:

The study area encompassed a region within a 3 km radius, defined by coordinates approximately ranging from latitude 14° 33’ to 14°35’ N and longitude 80°11’ to 80°12’ E. The selection of this specific point for investigation was influenced by the works of Charitha [12] and Murugan et al. [13], both of whom conducted research focusing on the Indian Ocean region within the Bay of Bengal. Additionally, the proximity of the Penna River near Nellore further contributed to the relevance of this chosen study location [14]. This geographical scope ensures alignment with previous research efforts while also allowing for a more nuanced exploration of the specified area.

As per the findings outlined in the study [14], between 1.18 tons and 3.14 tons of marine debris were discharged into the sea by the Penna River in 2011. This significant volume of debris served as a focal point for our research, prompting a heightened interest in studying this particular area.

Moreover, Murugan et al. [13] discovered that in the Penna River, at a depth of 16.0 meters, the concentration of microplastics was 36,474 particles.km^{-2}, while at a depth of 31.0 meters, the concentration increased to 109,244 particles.km^{-2}. Their findings also revealed variations in microplastic abundance in sediment samples, with higher particle densities offshore of the Penna River compared to nearshore areas. This additional information further underscores the complexity of the microplastic distribution in the study area, providing valuable context for the research focus.

B. **Selection of Date and Region of Interest (ROI):**

We initiated our process by strategically choosing a specific date of interest, a decision pivotal for capturing temporal variations in the locations of garbage patches. Simultaneously, we defined our Region of Interest (ROI) by meticulously outlining polygons on the interactive map interface provided by Google Earth Engine. This ROI was strategically designed to encompass the Indian Ocean region where garbage patches are known to manifest. The selection of this specific point was influenced by Charitha's research [12], which centered around the Indian Ocean region of the Bay of Bengal.

C. Preprocessing:

We retrieved Satellite's Sentinel-2 data from the Google Earth Engine's extensive archive. This data included multispectral imagery with several spectral bands, which are essential for characterizing environmental features, such as garbage patches.

We began by selecting a specific date of interest, allowing us to focus on temporal variations in garbage patch locations. Additionally, we defined the Region of Interest (ROI) by drawing polygons on the map interface provided by the Google Earth Engine. This ROI encompassed the Indian Ocean area where garbage patches are known to occur

Our workflow focused on acquiring the most recent cloud-free image within the selected date range. Real-time data access capabilities offered by Google Earth Engine were instrumental in obtaining the latest available data for monitoring dynamic changes in garbage patches.

I. Geometric and Radiometric Correction:

Images were corrected for geometric distortions and radiometric inconsistencies to ensure accurate and meaningful data for our research.

II. *Band Resampling:*

To facilitate uniform analysis, we resampled all spectral bands to the same resolution, specifically a grid of 40x40 pixels. This step was crucial for creating consistent and comparable datasets.

III. *Cloud Masking:*

To ensure the quality of the acquired imagery, we applied a cloud and cirrus masking function to remove images with significant cloud cover. This step is crucial to minimize interference from atmospheric conditions and maintain the reliability of our analysis.

IV. *Image Metadata:*

In the data acquisition process, we extracted relevant metadata from the acquired image. This metadata included the acquisition date, cloud cover percentage, and the area of the ROI. These details were critical for contextualizing the imagery and understanding the conditions under which the data was collected.

The implementation of this meticulous data acquisition workflow was foundational to the success of our study. By integrating cutting-edge technology and leveraging the capabilities of Google Earth Engine, we secured a robust dataset that serves as the backbone for our remote sensing analysis of garbage patches in the Indian Ocean. As we move forward in our research endeavours, this meticulous approach to data acquisition positions us to derive nuanced insights and contribute meaningfully to the broader understanding of marine environmental challenges.

CHAPTER-5
Data Preprocessing

As we transition from data acquisition to the analytical phase of our study on remote sensing of garbage patches in the Indian Ocean using Sentinel-2 imagery, an indispensable component of our methodology involves the meticulous preprocessing of the acquired satellite imagery. These preprocessing steps are pivotal in refining and enhancing the utility, accuracy, and consistency of the data, ensuring that our subsequent analyses yield meaningful insights into the dynamics of garbage patches in this critical region.

A. Geometric and Radiometric Correction:

One of the initial preprocessing steps involved the correction of geometric distortions and radiometric inconsistencies present in the raw satellite images. Geometric correction is vital for accurately aligning the spatial features of the imagery with the Earth's surface, mitigating distortions that may arise during the data acquisition process. Concurrently, radiometric correction ensures the normalization of pixel values across the image, addressing variations in brightness and contrast. By rectifying these distortions and inconsistencies, we aimed to establish a reliable foundation for subsequent analyses.

B. Band Resampling:

To facilitate a uniform and comprehensive analysis, we implemented band resampling, ensuring that all spectral bands were adjusted to the same resolution. Specifically, we resampled the data to a grid of 40x40 pixels, a deliberate choice to maintain consistency and comparability across different bands. This step is crucial for creating datasets that can be seamlessly integrated, allowing for a holistic examination of the Indian Ocean's environmental features, with a particular focus on garbage patches. The resampling process is depicted in Figure 1, showcasing the transformation from raw satellite imagery to a standardized grid, enhancing the quality and interpretability of our data.

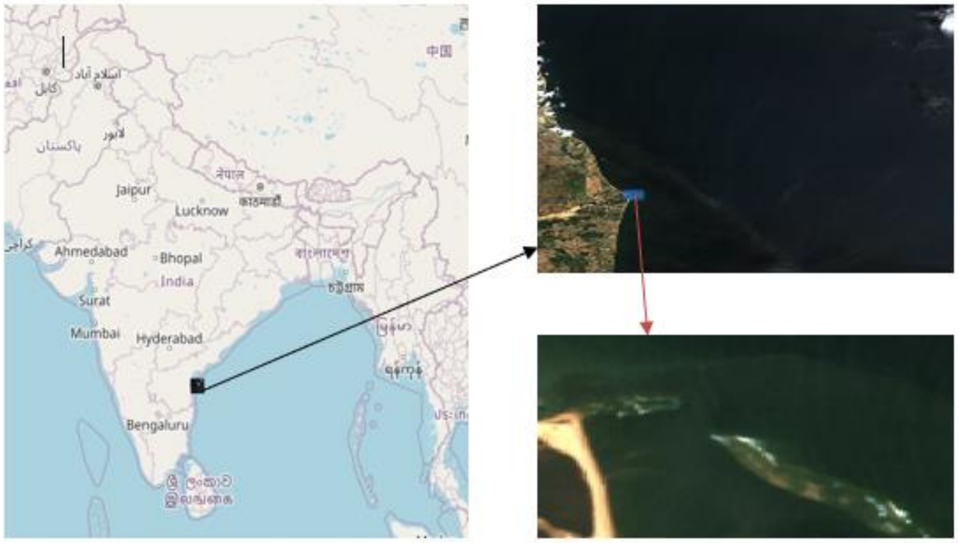


Figure 2: Example-1 of a Raw Satellite Image

C. Image Metadata

Extracting relevant metadata from the acquired satellite imagery was an integral part of our preprocessing workflow. This included essential details such as the acquisition date, cloud cover percentage, and the specific area covered by the Region of Interest (ROI). Understanding the context in which the data was collected is crucial for accurate interpretation and contextualization of the findings. For instance, knowledge of cloud cover percentages enables us to filter out images significantly impacted by atmospheric conditions, ensuring the reliability of subsequent analyses. Figure 1 provides an example of a raw satellite image from our data acquisition workflow, illustrating the Indian Ocean region's specific characteristics.

This combination of efficient data acquisition, real-time access, and robust preprocessing lays a solid foundation for our subsequent analysis of plastic detection in the Indian Ocean. The refined imagery resulting from these preprocessing steps is now poised for in-depth examination, allowing us to discern patterns, trends, and variations in garbage patch dynamics with a heightened level of accuracy and reliability.

Moving forward, the preprocessed satellite imagery will undergo sophisticated analysis, leveraging advanced algorithms and spectral techniques to identify and characterize plastic debris in the Indian Ocean. The insights derived from this comprehensive approach will not only contribute to the understanding of the spatial and temporal dynamics of garbage patches but also serve as a valuable resource for environmental policymakers, researchers, and stakeholders invested in mitigating the impact of marine plastic pollution. By marrying cutting-edge technology with meticulous preprocessing, our study stands at the forefront of efforts to address the urgent environmental challenges posed by plastic debris in one of the world's most critical oceanic regions.

CHAPTER-6
Methodology

Our comprehensive methodology for detecting and monitoring garbage patches in the vast expanse of the Indian Ocean is anchored in the sophisticated analysis of satellite imagery, specifically leveraging the capabilities of Sentinel-2 data. Recognizing the urgent need to address the escalating issue of marine plastic pollution, our approach combines innovative spectral indices with established remote sensing techniques to gain detailed insights into the presence and characteristics of garbage patches.

Our methodology for detecting and monitoring garbage patches in the Indian Ocean is rooted in the analysis of satellite imagery, specifically Sentinel-2 data. To gain insights into the presence and characteristics of these patches, we harnessed several spectral indices that are well-established in remote sensing and environmental monitoring. These indices include the Normalized Difference Vegetation Index (NDVI), Plastic Index (PI), and Floating Debris Index (FDI).

A. *Through Visual Inspection:*

Through visual inspection, I employed the EE map feature to estimate the extent of plastic debris. Utilizing vector data models represented by lines, I plotted the patches of plastics in the offshore area. This method yielded a total area of 0.1365 km^2 covered by plastics.

Subsequently, I leveraged this visual inspection-based calculation as a benchmark for comparison while calculating various indices. These indices were used in comparison to assess their effectiveness in delineating and quantifying the extent of plastic debris in the studied area.

B. *Normalized Difference Vegetation Index (NDVI):*

The Normalized Difference Vegetation Index (NDVI) stands as a cornerstone in our methodology, drawing upon its well-established application in quantifying the presence of live vegetation in an area. Calculated using the near-infrared (NIR) and red (RED) spectral bands of the Sentinel-2 imagery, the NDVI formula produces values ranging from -1 to 1. Higher NDVI values traditionally indicate a greater abundance of healthy vegetation, but we repurposed this index for our study. In our context, we deployed the NDVI to identify areas exhibiting deviations from the expected NDVI values for typical vegetation, providing a potential indication of the presence of garbage patches.

This adaptation of the NDVI is integral to our ability to detect subtle variations in the environmental landscape, enabling us to pinpoint regions where the spectral characteristics deviate from the norm. By incorporating this widely recognized index into our methodology, we enhance the robustness of our analysis, allowing us to identify potential areas of concern in the Indian Ocean where garbage patches may be lurking beneath the surface.

$$\text{NDVI} = \frac{(R_{rs,NIR} - R_{rs,RED})}{R_{rs,NIR} + R_{rs,RED}}$$

C. *Plastic Index (PI):*

The Plastic Index (PI) is a bespoke addition to our methodology, crafted to specifically address the need for detecting and quantifying the presence of plastic materials in the ocean. Developed for our research and derived from multiple spectral bands of Sentinel-2 imagery, the PI formula serves as a targeted tool for identifying areas with a higher concentration of plastics. A higher PI value within a given region is indicative of a greater presence of plastic materials.

This index is pivotal in our study, offering a nuanced approach to detecting plastics amidst the vastness of the Indian Ocean. By combining spectral information from different bands, the PI provides a more focused and tailored analysis specifically attuned to the unique spectral characteristics of plastic materials. This innovative addition empowers us to discern subtle variations in the ocean's composition, facilitating the identification and monitoring of garbage patches with a heightened level of precision.

$$\text{Plastic Index} = \frac{R_{rs,NIR}}{R_{rs,NIR} + R_{rs,RED}}$$

D. *Floating Debris Index (FDI):*

The Floating Debris Index (FDI) stands as another custom index meticulously tailored to the specific objectives of our research. Computed from the NIR, SWIR, and red-edge bands of the Sentinel-2 data, the FDI is designed to highlight floating debris, a category encompassing plastics and other materials commonly found in garbage patches. The FDI formula encapsulates a sophisticated calculation process.

The derivation of 〖R'〗 involves intricate computations utilizing the spectral information from different bands, including the red-edge band. This complexity is necessary to account for the diverse characteristics of floating debris, allowing the FDI to provide a more nuanced understanding of the likelihood of debris accumulation in a given area.

Higher FDI values signify an increased probability of floating debris presence, making this index a valuable component of our methodology. By focusing on the specific spectral signatures associated with floating debris, the FDI contributes to the precision of our garbage patch detection efforts. This custom index serves as a powerful tool for identifying regions where floating debris is likely to accumulate, further enriching our understanding of the distribution and dynamics of garbage patches in the Indian Ocean.

$$\text{FDI} = R_{rs,NIR} - R'_{rs,NIR}$$

$$R'_{rs,NIR} = R_{rs,RE2} + \left(R_{rs,SWIR1} - R_{rs,RE2}\right) X \left(\frac{\lambda_{NIR} - \lambda_{RED}}{\lambda_{SWIR1} - \lambda_{RED}}\right) X\ 10$$

E. *Time Series Analysis:*

We conducted a comprehensive Time Series Analysis employing the Floating Debris Index (FDI) within the previously defined 3-kilometer radius region, characterized by coordinates ranging approximately between latitude 13° to 19° N and longitude 80° to 85° E. The selection of this area was motivated by its relevance to the research presented by Charitha [12] and Murugan [13], both of whom focused on the Indian Ocean region, specifically the Bay of Bengal, with proximity to the Penna River near Nellore.

The Floating Debris Index (FDI) was selected for its superior accuracy compared to alternative models, ensuring a robust and reliable analysis. The time frame for our investigation spanned from April 2020 to September 2023, allowing us to capture a substantial period and observe any temporal patterns in the presence of floating debris.

Our findings not only shed light on the evolving trend of plastics within the specified area but also contribute valuable insights into the broader environmental dynamics and impact of floating debris over time. As we delve deeper into the intricacies of this issue, we aim to provide a nuanced understanding of the factors influencing the presence and distribution of debris in this region, ultimately contributing to the ongoing discourse on marine environmental conservation.

In essence, our methodology integrates cutting-edge spectral indices, each serving a distinct purpose in enhancing our ability to detect and monitor garbage patches in the vast and complex environment of the Indian Ocean. By combining the traditional utility of the NDVI with the targeted capabilities of the PI and FDI, our approach leverages the strengths of each index to provide a comprehensive and nuanced understanding of the presence and characteristics of garbage patches. As we move forward with our analysis, these indices will prove instrumental in unraveling the intricate tapestry of marine plastic pollution, contributing vital information for the development of effective mitigation strategies and environmental conservation efforts.

Plastic Detection Workflow

The plastic detection workflow embedded in our study represents a meticulous and innovative approach, leveraging a combination of spectral indices and advanced algorithms to discern, label, and quantify the presence of plastics in the vast expanse of the Indian Ocean. This section delineates the detailed steps undertaken in our plastic detection workflow, from index calculation to the quantification and visualization of plastic materials.

Index Calculation

The foundation of our plastic detection workflow lies in the calculation of key spectral indices for each pixel within the Sentinel-2 imagery. Leveraging the preprocessed and resampled data ensures a consistent and accurate basis for our subsequent analysis. The four primary indices harnessed in our study include the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Plastic Index (PI), and Floating Debris Index (FDI).

For each pixel, the calculation involves intricate spectral computations based on the appropriate bands, capturing the nuanced characteristics of the Indian Ocean's composition. The NDVI, NDWI, PI, and FDI values for each pixel serve as crucial indicators, providing insights into the presence and characteristics of potential plastic materials. This initial stage sets the stage for a granular and comprehensive analysis of the Sentinel-2 imagery, allowing us to discern subtle variations indicative of plastic debris.

Labeling and Plastic Detection

The subsequent step in our workflow involves the implementation of a sophisticated labeling algorithm. This algorithm is designed to categorize each pixel into distinct classes, including "water," "seaweed," "timber," "plastic," or "foam." The classification is driven by predefined NDVI thresholds and intricate relationships between the computed indices.

The differentiation between classes, particularly the identification of pixels indicative of plastic materials, is a critical aspect of our study. Pixels with specific combinations of NDVI values and index values characteristic of plastics are accurately labeled as "plastic." This stage is a pivotal point in the workflow, as it allows for the precise identification and isolation of areas potentially impacted by plastic debris within the expansive Indian Ocean.

The labeling algorithm is carefully calibrated to ensure accuracy and reliability in classifying pixels, minimizing the risk of misinterpretation. By incorporating predefined thresholds and nuanced relationships between spectral indices, we enhance the specificity of our plastic detection, reducing the likelihood of false positives and false negatives. This step is a testament to the meticulous design of our methodology, ensuring that the subsequent analysis is grounded in precise and meaningful data.

Quantification and Visualization

Following the accurate labeling of pixels indicative of plastic materials, the next stage involves quantifying the extent of plastics within our defined Region of Interest (ROI). This quantification is achieved by determining the percentage of pixels labeled as "plastic" relative to the total number of pixels in the ROI.

This quantitative approach provides a robust measure of the density of plastic materials in the Indian Ocean within the designated study area. The percentage calculation allows for a comparative assessment of plastic distribution across different regions within the ROI, highlighting areas with heightened concentrations of plastic debris. The quantification process is essential for establishing a baseline understanding of the magnitude of the plastic pollution problem in the Indian Ocean, contributing valuable data for environmental monitoring and policymaking.

In tandem with quantification, the workflow incorporates a visualization component, allowing for the representation of plastic distribution patterns in a spatial context. Visualization aids in the interpretation of the data, offering a comprehensive view of the spatial distribution of plastic materials within the Indian Ocean. This visual representation enhances the communicative power of our findings, making them accessible to a broader audience, including policymakers, researchers, and the general public.

The quantification and visualization stages collectively contribute to the holistic understanding of plastic pollution in the Indian Ocean. By marrying quantitative data with spatial representation, our methodology transcends mere detection and delves into the broader context of plastic distribution dynamics. This comprehensive approach positions our study at the forefront of efforts to tackle marine plastic pollution, providing actionable insights for targeted interventions and long-term environmental conservation strategies.

CHAPTER-7
Results

Visualization of Plastic Patches:
The results obtained from visual inspection is as follows:

The evaluation results underscored the superiority of the Floating Debris Index (FDI) in detecting plastic debris, surpassing both the Plastic Index and the Normalized Difference Vegetation Index (NDVI) in accuracy. Through a comprehensive comparative analysis, it became evident that the FDI offered a more precise identification of plastic debris in the provided Figure 1 compared to the alternative indices.

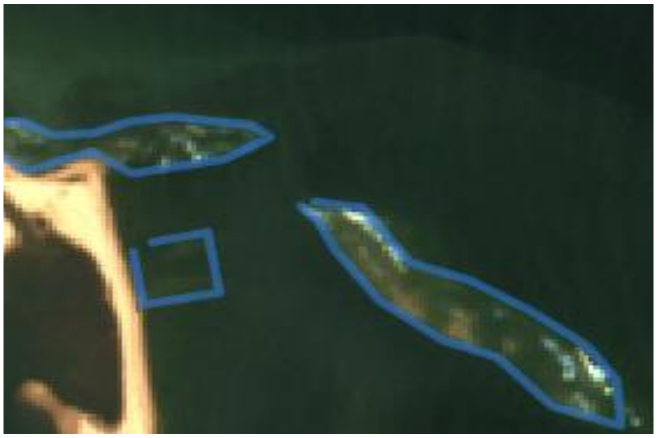


Figure 3: Mapping of plastic Patches

Figure 4 elucidates the contrast between the raw NDVI image and the plastic-detected patch from Figure 1. A visual inspection distinctly showcases the heightened accuracy of the FDI in pinpointing plastic debris, underscoring its superior performance in contrast to the NDVI.

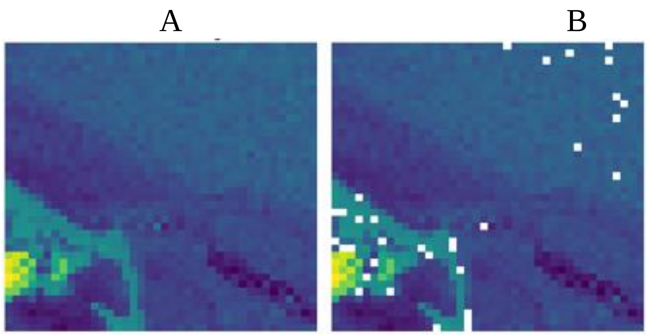


Figure 4: Comparison of A) raw NDVI Image and B) plastic detected patch of Figure 2

Figure 4 illustrates the comparison between the raw NDVI image and the plastic-detected patch from Figure 2. The visual analysis clearly depicts the enhanced accuracy of the FDI in identifying plastic debris, showcasing its superior performance in contrast to the NDVI.

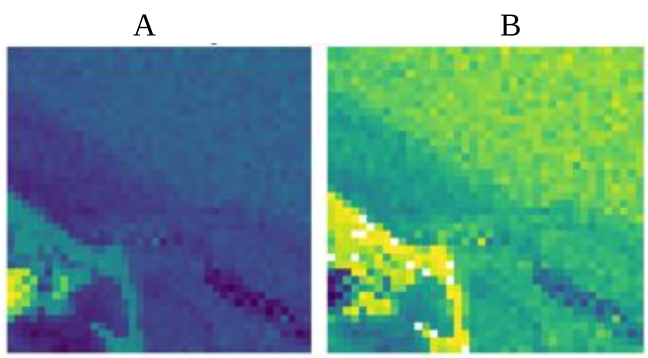


Figure 5: Comparison of A)raw Plastic Index Image and B)plastic detected patch of Figure 2

Likewise, Figure 5 provides a comparative assessment between the raw Plastic Index Image and the plastic-detected patch from Figure 2. The outcomes reinforce the notion that the FDI outperformed the Plastic Index in effectively identifying plastic debris.

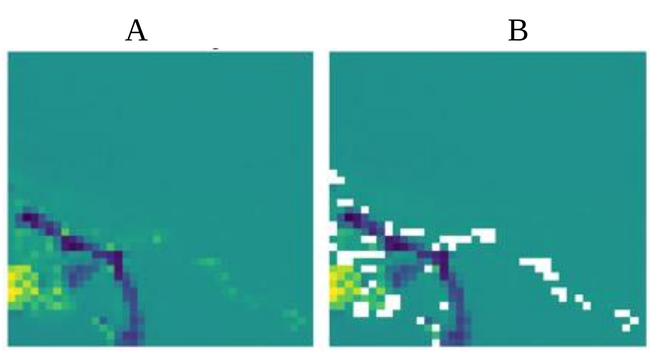


Figure 6: Comparison of A)raw FDI Image and B) plastic detected patch using FDI of Figure 2

Figure 6 further bolsters these findings, presenting a comparison between the raw FDI Image and the plastic-detected patch from Figure 2. The visual depiction solidifies the superior accuracy of the FDI in discerning plastic debris, highlighting its efficacy as an index for environmental monitoring.

The evaluation outcomes unequivocally emphasize the pivotal role of the FDI in accurately detecting plastic debris, surpassing traditional indices such as the Plastic Index and the NDVI. This superiority was consistently demonstrated across various comparative analyses, validating the FDI's efficacy in environmental monitoring applications.

Furthermore, the visual evidence provided by Figures 4, 5, and 6 underscores the enhanced precision of the FDI in identifying plastic debris when compared to alternative indices. This precision is crucial in environmental assessments where accurate detection of plastic pollution is imperative for informed decision-making and effective mitigation strategies.

The findings of this evaluation have significant implications for environmental monitoring and management efforts. By leveraging the FDI as a robust tool for plastic debris detection, stakeholders can obtain more accurate and reliable data for assessing the extent of plastic pollution and implementing targeted interventions.

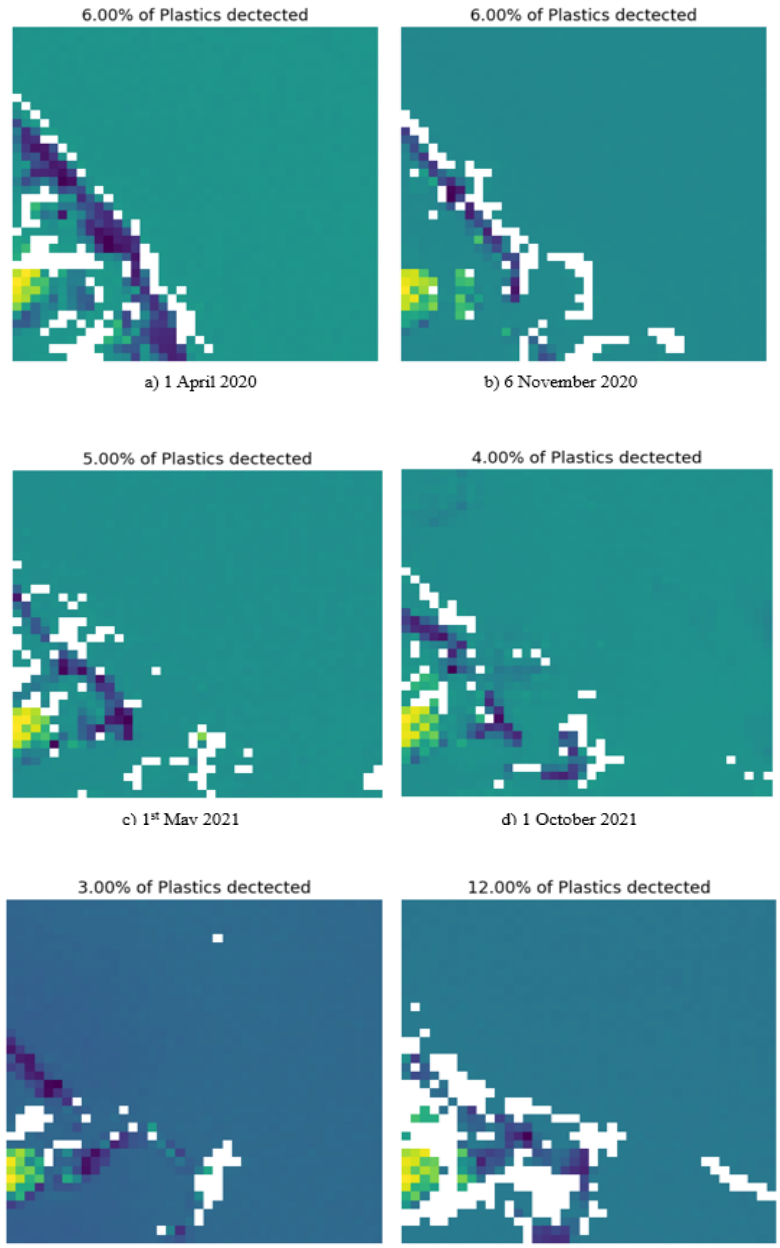
Moreover, the demonstrated superiority of the FDI highlights the importance of continually exploring and refining remote sensing techniques for environmental applications. As plastic pollution continues to pose a significant threat to ecosystems worldwide, innovative approaches like the FDI offer valuable insights and solutions for mitigating its adverse impacts.

Table 1: Comparison of Different Index

Indices/Method	**Total Area of ROI (km^2)**	**Total Area of Plastic Detected (km^2)**	**Percentage**
Through Visual Confirmation	3.259	0.1365	4%
Plastic Index (PI)	3.259	0.032	1%
Floating Debris Index (FDI)	3.259	0.13	4%
NDVI	3.259	0.065	2%

The table presents a comparative analysis of different indices/methods used for detecting plastic debris within a Region of Interest (ROI). The ROI covers a total area of 3.259 square kilometers. The "Total Area of Plastic Detected" column indicates the extent of plastic debris identified by each respective index, measured in square kilometers. The results show that visual confirmation, which serves as a reference point, identified 0.1365 square kilometers of plastic debris, constituting approximately 4% of the total ROI. Among the automated indices, the Floating Debris Index (FDI) performed the best, detecting 0.13 square kilometers of plastic debris, equivalent to 4% of the total ROI. This indicates that FDI had the highest level of accuracy in identifying plastic debris compared to the other indices. The Plastic Index (PI) identified 0.032 square kilometers (1% of the

ROI), and the NDVI identified 0.065 square kilometers (2% of the ROI). The results suggest that FDI outperforms both PI and NDVI in terms of precision and accuracy in detecting plastic debris within the specified region.



a) 1 April 2020
b) 6 November 2020
c) 1st May 2021
d) 1 October 2021
e) 1st April 2022
f) 21 September 2022

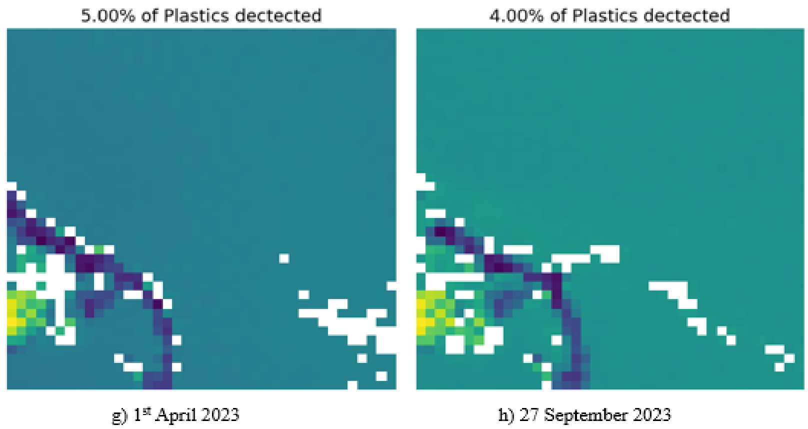


Figure 7: Detection of Plastic Accumulation from April 2020 to September 2023

The Time Series Analysis conducted with the Floating Debris Index (FDI) over the specified period revealed dynamic patterns in the presence of plastic debris within the study area. The following table presents the measured areas of plastics in square kilometers on various dates:

Table 2: Time Series Analysis

Date	**Area of Plastics (in km^2)**
1 April 2020	0.1955
6 November 2020	0.196
1st May 2021	0.163
1 October 2021	0.13
1st April 2022	0.098
21 September 2022	0.39
1st April 2023	0.163
27 September 2023	0.13

The results depict fluctuations in the extent of plastic debris over time, providing valuable insights into the temporal variations and trends in the accumulation of debris within the study area. The data serves as a foundation for understanding the impact of time on the distribution and concentration of plastic debris in the marine environment.

The recorded data reveals dynamic fluctuations in the area of plastic debris over a series of dates, providing insights into the temporal variations of plastic pollution within the studied region. On April 1, 2020, the initial measurement reported a detection of 0.1955 square kilometers of plastic debris. Subsequently, on November 6, 2020, a slight increase was observed, with the area expanding marginally to 0.196 square kilometers. The following data point on May 1, 2021, marked a decrease in the detected plastic area, registering at 0.163 square kilometers. This trend continued on October 1, 2021, with a further reduction to 0.13 square kilometers.

As of April 1, 2022, a notable decrease was recorded, with the detected plastic area diminishing to 0.098 square kilometers. However, the situation underwent a significant change by September 21, 2022, where a substantial increase was observed, reaching 0.39 square kilometers. Moving forward to April 1, 2023, the plastic area decreased once again to 0.163 square kilometers, maintaining a level consistent with the earlier detection on September 27, 2023, which also reported an area of 0.13 square kilometers.

These temporal fluctuations in the detected area of plastic debris may be influenced by a myriad of factors, including environmental conditions, anthropogenic activities, and the efficacy of local waste management practices. Analyzing these patterns can contribute to a better understanding of the dynamics of plastic pollution and inform strategies for its mitigation and control within the specified region.

CHAPTER-8
Conclusion and Future works

In conclusion, our research establishes the efficacy of Sentinel-2 satellite data and spectral indices, specifically the Floating Debris Index (FDI), Plastic Index (PI), and Normalized Difference Vegetation Index (NDVI), in accurately detecting and mapping garbage patches in the Indian Ocean. The comparative analysis demonstrates the superior accuracy of the FDI in identifying plastic debris, surpassing both the PI and NDVI. Our findings emphasize the importance of integrating multiple indices for a more nuanced understanding of marine debris dynamics. This research contributes valuable insights to policymakers and environmental agencies, offering a reliable approach for near real-time monitoring and strategic management of plastic pollution in the Indian Ocean, ultimately aiding in the preservation of marine ecosystems and the well-being of coastal communities.

This study builds upon related research focused on different oceanic regions, providing specific insights tailored to the challenges and conditions of the Indian Ocean. By leveraging remote sensing technologies, our approach not only enhances environmental stewardship but also aligns with global efforts toward sustainability. Moving forward, the integration of diverse spectral indices will be critical for advancing our understanding of marine pollution dynamics and implementing effective mitigation strategies on a broader scale.

Our research also lays the foundation for further exploration and development in the field of plastic pollution monitoring. Several avenues for future work are worth exploring:

A. Expanding to Other Ocean Gyres:
   While our current study focused on the Indian Ocean, our methodology can be extended to other ocean gyres worldwide. Each oceanic gyre presents its unique set of challenges and pollution characteristics. Future research efforts can adapt our approach to monitor and understand plastic pollution in these diverse marine environments.

B. Time Series Analysis:

The temporal data collected during our research provides a valuable dataset for time series analysis. Further investigation can explore the long-term trends in plastic pollution, revealing seasonal patterns, interannual variations, and the impact of environmental factors. Time series analysis can offer insights into the evolution of garbage patches over time.

C. Machine Learning Integration:

The integration of machine learning techniques can enhance the accuracy of plastic detection. By training algorithms to recognize plastic features from Sentinel-2 imagery, automated detection and classification can be achieved, reducing the need for manual validation.

D. Multi-Sensor Data Fusion:

Our research relied on Sentinel-2 imagery; however, the fusion of data from multiple satellite sensors can provide a more comprehensive view of the marine environment. Combining optical data with synthetic aperture radar (SAR) and other remote sensing technologies can improve the detection of plastics, especially in cloudy or adverse weather conditions.

E. Policy and Conservation Implications:

Understanding the dynamics of plastic pollution is essential for developing effective policies and conservation strategies. Future work should bridge the gap between research and policy, informing decision-makers on the most critical areas for intervention and cleanup efforts.

F. Building a Framework for Future Research:

While our study represents a significant stride, it lays the foundation for further exploration and development in the field of plastic pollution monitoring. Several avenues for future research emerge, each holding the promise of expanding our understanding and refining methodologies.

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