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Estimation of Marine Resource Vulnerability Index for the Gulf of Mannar Coast, Tamil Nadu

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ABSTRACT

Background: The Gulf of Mannar, Tamil Nadu, is a critical marine ecosystem facing threats like overfishing and habitat degradation. This study assesses the vulnerability of marine fishery resources using a Resource Vulnerability Index (RVI), highlighting key factors driving resource depletion.

Methods: The RVI was developed using indicators such as overcapacity (excessive fleets), declining catch per unit effort (CPUE), shifting species composition and environmental degradation. Data were collected from fisheries reports and local surveys, with the index calculated for Ramanathapuram, Thoothukudi and Tirunelveli districts.

Result: Ramanathapuram exhibits the highest vulnerability among the districts in the Gulf of Mannar, driven primarily by severe overfishing and significant habitat loss. Thoothukudi follows with moderate vulnerability, facing similar challenges of overcapacity and environmental degradation. Tirunelveli, while showing comparatively lower vulnerability, still displays notable signs of resource depletion, necessitating attention to ensure sustainable fisheries management. Urgent measures are needed, including regulating fleet sizes, promoting sustainable fishing, restoring habitats and implementing policies for alternative livelihoods and resource monitoring.

Key words: Gulf of mannar, Marine resources, Sustainability, Vulnerability index.

INTRODUCTION

Marine fishery resources are essential to society as they contribute significantly to employment, income generation and nutritional security. In India, the marine fisheries sector is a critical component of the economy, particularly in coastal states like Tamil Nadu. Tamil Nadu is blessed with a 1,076 km coastline, a continental shelf area of 41,412 km^2 and an Exclusive Economic Zone (EEZ) spanning 1.9 lakh km^2. These natural resources enable the state to produce approximately 5.97 lakh tons of marine fish annually. This production supports the livelihoods of 10.48 lakh marine fishers, who rely on 5,440 mechanized fishing crafts and 44,487 traditional fishing crafts actively involved in fishing activities (Handbook of Fisheires Statistics, 2024).

India, as a whole, achieved a total fish production of 175.45 lakh metric tonnes in 2022-24, making it the second-largest producer of fish globally and the second-largest in inland fish production. The fisheries sector contributes 1% to the national GDP, highlighting its economic significance. Tamil Nadu plays a notable role in this sector, ranking fifth in total marine fish production within the country. In 2022-24, Tamil Nadu exported 1.23 lakh metric tonnes of marine products, earning a substantial foreign exchange of Rs. 6,957.67 crore. Over the last decade, the state has witnessed a consistent upward trend in marine fish production and export value, as recorded in the Fisheries Policy Note (2023-24).

Despite these benefits, the marine fisheries sector faces pressing challenges, particularly the vulnerability of fishery resources due to various anthropogenic (human-induced) activities along the coast. Activities such as overfishing, habitat destruction, pollution and climate change are major drivers of marine resource depletion. This degradation not only diminishes the direct benefits derived from fisheries-such as food supply and income-but also poses serious threats to the livelihoods of coastal fishing communities and the biodiversity of marine ecosystems. The loss of natural resources has been identified as a significant factor contributing to the livelihood vulnerability of these communities, as emphasized in recent studies by Shukla *et al.* (2023) and Prakash *et al.* (2020).

Tamil Nadu's coastal ecosystems are under increasing stress due to a combination of climate change, overfishing and habitat degradation. Recent research has applied a variety of methodological approaches to evaluate both ecological and socio-economic vulnerabilities affecting

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marine fisheries in this region. Among these coastal zones, the Gulf of Mannar (GoM) stands out as one of India's most biodiversity-rich marine environments. It hosts ecologically critical habitats including coral reefs, seagrass beds and mangrove forests, all of which support a wide range of marine life and contribute significantly to the region's fishery productivity and ecological resilience. Santhoshkumar *et al.* (2023) conducted a study on finfish bycatch diversity in trawl fisheries along the Nagapattinam coast and found that bycatch accounted for approximately 21.12% of total landings. This substantial proportion of non-target species highlights the potential threat to marine biodiversity and the ecological balance of the region. In a related effort, Lakshmi *et al.* (2024) examined the biodiversity and abundance of fish species in Ennore Creek, revealing notable spatial and temporal variations in species composition. Their findings indicated significant fluctuations in the populations of vulnerable and endangered species, underscoring the ecological sensitivity and stress facing the ecosystem. Complementing these studies, Jesintha *et al.* (2022) compiled an annotated checklist of finfish and shellfish species in Pulicat Lake, recording 89 finfish and 19 shellfish species. This detailed inventory provides a valuable baseline for ongoing biodiversity monitoring and evaluation of environmental stressors affecting the coastal marine habitats of Tamil Nadu. However, the GoM has been severely affected by resource vulnerability due to human activities. This situation calls for urgent intervention to protect and sustainably manage marine fishery resources.

To address this, the present study was undertaken to evaluate the status of resource vulnerability in the Gulf of Mannar, Tamil Nadu. By analyzing the key factors contributing to resource depletion and assessing the level of vulnerability, the study aims to provide valuable insights. It emphasizes the need for targeted measures, such as stricter regulations on fishing practices, conservation of marine habitats and sustainable resource management strategies, to ensure the long-term health and productivity of marine fishery resources in the region.

MATERIALS AND METHODS

Study area

Gulf of Mannar (GoM), Tamil Nadu has stretch of 140 km between Tuticorin and Rameswaram (Lat. 8°55′-9°15′N and Long. 78° 0′ and 79°16′ E). A part of the study area was given the status of Marine Biosphere Reserve (Saravanan, 2020). Moreover 3,00,612 fisherfolk are living on the coast of which 99,039 people are employed through the exploitation of marine fishery resources (Fisherfolk Census, 2020).

Sample size

The study included a total sample size of 450 fishermen, distributed across the three coastal districts of Ramanathapuram, Thoothukudi and Tirunelveli, based on their percentage contribution to the total fishing crafts registered along the Gulf of Mannar (GoM) coast. The sample frame was composed of active fishermen, ensuring representation of those directly involved in fishing activities. Respondents were selected using a simple random sampling procedure, which provided an unbiased and statistically valid approach to gather data from the target population.

Study period

The study was conducted over a period of three years, from 2020 to 2023, at the Fisheries College and Research Institute, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Tamil Nadu.

Sampling technique

A stratified simple random sampling method was employed to ensure a representative and balanced selection of respondents from the three districts (Ramanathapuram, Thoothukudi and Tirunelveli) based on their contribution to fishing crafts registered along the Gulf of Mannar coast.

Data collection

Primary data were collected directly from fishermen through personal interviews using pre-tested survey schedules to ensure the reliability and validity of the information. The data collected were systematically tabulated and analyzed using appropriate statistical tools to derive insights into the vulnerability of marine fishery resources in the study area.

Construction of vulnerability index

Arrangement of data

The collected data were organized into a rectangular matrix, where the rows represent the regions (Ramanathapuram, Thoothukudi and Tirunelveli) and the columns represent the selected indicators of vulnerability. This matrix structure enables a systematic analysis of the data, allowing for the comparison of indicators across regions and the computation of standardized values. By arranging the data in this format, it becomes possible to apply statistical tools and normalization techniques effectively, facilitating the development of the Resource Vulnerability Index (RVI) and drawing meaningful conclusions about the vulnerability of marine fishery resources in the Gulf of Mannar.

Normalization of indicators using functional relationship

The methodology used in the UNDP's Human Development Index (HDI) (UNDP, 2006) was adopted to standardize and normalize the indicators for this study. The normalization process ensures that all indicator values lie between 0 and 1, facilitating meaningful comparisons across diverse variables. This step is crucial for maintaining consistency in measurement and avoiding scale biases.

Additionally, identifying the functional relationship between the indicators and vulnerability is essential to assess how each variable contributes to or influences the overall vulnerability of marine fishery resources. Indicators with a positive relationship with vulnerability are normalized differently compared to those with a negative relationship,

ensuring that the standardized values accurately reflect the direction and magnitude of their influence. This systematic approach provides a robust framework for developing the Resource Vulnerability Index (RVI) and understanding the dynamics of resource vulnerability in the study area.

Normalization of variables with a direct functional relationship with vulnerability (where higher values of the indicator correspond to higher vulnerability) is carried out using the following formula:

$$X_{ij} = \frac{X_{ij} - \text{Min}(X_{ij})}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})}$$

Where,

X = Actual value of the indicator.

$\text{Min}(X_{ij})$ = Minimum value of the indicator in the dataset.

$\text{Max}(X_{ij})$ = Maximum value of the indicator in the dataset.

This formula scales the values of the variable to a range between 0 and 1. A value closer to 1 indicates higher vulnerability, while a value closer to 0 indicates lower vulnerability. Normalization ensures comparability among indicators measured on different scales, making it easier to compute the overall resource vulnerability index (RVI).

$$Y_{ij} = \frac{\text{Max}(X_{ij}) - X_{ij}}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})}$$

Vulnerability index

To construct the vulnerability index (VI), the simple average of all the normalized scores for each region is calculated using the following formula:

$$VI = \frac{\sum_j X_{ij} + \sum_j Y^{ij}}{K}$$

Where,

X_{ij} = Normalized value of the direct functional relationship indicators.

Y_{ij} = Normalized value of the indirect functional relationship indicators.

K = Total number of indicators (the sum of the direct and indirect indicators)

After calculating the vulnerability indices for each region, the regions are ranked based on their VI scores. The region with the highest vulnerability index is considered the most vulnerable and is assigned rank 1. The region with the next highest index is assigned rank 2 and so on. This ranking system allows for a clear understanding of which regions are most at risk in terms of the vulnerability of marine fishery resources.

RESULTS AND DISCUSSION

Marine fishery resources provide significant benefits to society and the environment, but they are increasingly vulnerable due to various pressures. Depletion of these resources cannot be accurately assessed solely based on declining fish landings. To gain a clearer understanding of the vulnerability, the perceptions of fishermen regarding warning signals are crucial. Thus, this study focuses on analyzing key warning signals or indicative issues that contribute to the vulnerability of marine fishery resources in the area.

Seven indicative issues were selected for this analysis:

1. Overcapacity (excessive fishing efforts relative to the resource base).
2. Decline in catch per unit effort (reducing returns from fishing activities).
3. Change in captured species composition (shifts in the types of fish caught).
4. Employment migration from fishing to non-fishing sectors (movement of fishermen away from the industry).
5. Scarcity of adult fish catch (reduction in mature fish available for harvest).
6. Diminished biomass of marine habitat (reduction in the size and health of marine ecosystems).
7. Existence of conflicts over resource sharing (disputes among fishers or between communities over fishing areas and practices).

These indicative issues were selected through a preliminary study, discussions with scientists, administrators and subject experts, along with insights from published research reports focused on the study area. The vulnerability index was calculated based on key issues to assess the overall vulnerability of marine fishery resources in the region, as presented in Table 1. Furthermore, the functional relationship between the indicative issues and vulnerability variables is detailed in Table 2.

The analysis of normalized scores for various vulnerability indicators in the three coastal regions (Thoothukudi, Tirunelveli and Ramanathapuram) and given in Table 3 which reveals significant variations in the vulnerability of marine fishery resources. Among these, the Thoothukudi region showed a low normalized score (0.77) for overcapacity, indicating that the region is less vulnerable in this aspect compared to the other two regions. However,

Table 1: Primary data was tabulated as matrix format.

Regions	Score for variable						
	MRDI 1	MRDI 2	MRDI 3	MRDI 4	MRDI 5	MRDI 6	MRDI 7
Ramanathapuram	4.06	4.46	3.59	2.85	4.01	3.88	4.4
Thoothukudi	4.34	4.58	3.95	3.28	4.15	4.02	3.84
Tirunelveli	4.42	4.09	3.76	2.85	4.09	3.67	4.27

Tirunelveli and Ramanathapuram exhibited higher normalized scores, suggesting that overcapacity is a significant vulnerability factor in these regions. This aligns with findings from Infantina *et al.* (2016), who reported a significant excess in the fishing fleet size in India and Tamil Nadu, highlighting a critical issue of overcapacity in mechanized and motorized categories.

Furthermore, the study found that the decline in catch per unit effort (CPUE) was a major vulnerability indicator, particularly in the Tirunelveli region, where the resources are highly vulnerable due to the heavy livelihood dependence on fishing. This confirms the issue of dwindling fish catches, as noted in previous studies like those of Karnad and Karanth (2016), where 69% of fishermen observed a decline in fish catch and other marine species. The decline in CPUE further emphasizes the resource depletion impacting livelihoods.

The study also observed a low normalized value (0.47) for the change in captured species composition in the Tirunelveli coastal region, indicating that other regions (Thoothukudi and Ramanathapuram) are more vulnerable in terms of species composition shifts. This aligns with the trend of declining sardine catches and the significant decrease in Indian mackerel in Kerala, as highlighted by Kumar (2018). These shifts in species composition contribute to the overall vulnerability of marine fishery resources.

Another significant finding was the high normalized scores for employment migration from fishing to non-fishing sectors in Thoothukudi and Ramanathapuram, indicating that these regions are experiencing higher vulnerability in terms of livelihood shifts. Studies by Sathiadhas and Prathap (2009) and Kanaga *et al.* (2017) also found evidence of fishermen migrating to other coastal areas for better opportunities, further exacerbating the vulnerability of the resources.

The scarcity of adult fish catch was another key indicator, with Tirunelveli showing a low value (0.57), indicating relatively less vulnerability. In contrast, Thoothukudi and Ramanathapuram were found to be more vulnerable due to high levels of juvenile fish catches, contributing to growth overfishing, as discussed by Diamond *et al.* (1999).

The normalized score for diminished biomass of marine habitat was 0 in Tirunelveli, indicating low vulnerability. However, Thoothukudi and Ramanathapuram had higher scores (1 and 0.4, respectively), signifying significant vulnerability due to the degradation of marine habitats such as corals, seagrass and mangroves. This supports findings by George and Jasmine (2015) and Polidoro *et al.* (2010), who reported the deterioration of coral reefs and the rapid reduction of mangrove areas due to human activities.

Lastly, the study found that conflicts over resource sharing were more pronounced in Tirunelveli, with a normalized score of 0.76, indicating greater vulnerability. Conflicts between Indian and Sri Lankan fishermen, as well as issues between traditional craft and mechanized fishermen in Thoothukudi, highlight the growing tensions and competition over limited fishery resources, further signaling the depletion of resources in these areas.

The study identified multiple factors contributing to the vulnerability of marine fishery resources, with overcapacity, declining catch per unit effort, species composition changes, migration of fishermen, scarcity of adult fish, habitat degradation and resource-sharing conflicts being the key indicators. The findings underscore the urgent need for sustainable management practices and policy interventions to address these vulnerabilities and ensure the long-term viability of marine fishery resources in the Gulf of Mannar region.

The calculated vulnerability indices for the three regions-Ramanathapuram, Thoothukudi and Tirunelveli-were 0.663, 0.825 and 0.401, respectively (Table 4). These results indicate that marine fishery resources are most

Table 2: Functional relationship between indicative issues and vulnerability variables.

Indicators	Functional relationship
Presence of overcapacity	↑
Declined catch per unit effort	↑
Changed captured species composition	↑
Employment migration from fishing to non-fishing	↑
Scarcity of adult fish catch	↑
Diminished biomass of marine habitat	↑
Conflicts existence for sharing the resources	↑

Table 3: Computation of normalized scores.

Regions	Normalized scores							Total sum
	MRDI 1	MRDI 2	MRDI 3	MRDI 4	MRDI 5	MRDI 6	MRDI 7	of score
Ramanathapuram	1	0.245	1	1	1	0.400	0	4.645
Thoothukudi	0.778	1	1	1	1	1	0	5.778
Tirunelveli	1	0	0.473	0	0.572	0	0.768	2.813

Table 4: Resource vulnerability index.

Regions	Vulnerability Index	Rank
Ramanathapuram	0.663	2
Thoothukudi	0.825	1
Tirunelveli	0.401	3

vulnerable in the Thoothukudi region, followed by Ramanathapuram and Tirunelveli. The high vulnerability index for Thoothukudi highlights the significant challenges facing marine resources in that area, while the lower index for Tirunelveli suggests relatively less vulnerability. This ranking underscores the need for targeted interventions and sustainable management strategies, particularly in the more vulnerable regions, to protect marine fishery resources and ensure their long-term sustainability.

CONCLUSION

The Gulf of Mannar, rich in marine biodiversity, is facing severe threats due to overfishing and habitat degradation, with the Thoothukudi coast being the most affected. The region shows high vulnerability due to overcapacity of fishing fleets, declining fish stocks, migration from fishing jobs, and resource conflicts. Degradation of coral reefs and mangroves worsens the situation, threatening both ecological balance and the livelihoods of local fishing communities. The study calls for urgent action, including regulating fleet size, conserving habitats, promoting sustainable fishing, resolving conflicts, and encouraging alternative livelihoods. These measures are essential to protect marine resources and ensure long-term sustainability for the region's fisheries and communities.

Future scope of the study

The future scope of the study could involve several key directions. First, conducting longitudinal monitoring would allow for tracking changes in marine resource vulnerability over time, helping to assess the effectiveness of implemented policies. Second, incorporating seasonal variability into the analysis would provide a more nuanced understanding of resource availability and vulnerability throughout the year. Expanding the study to include other coastal regions in India would enable a comparative analysis of marine resource vulnerability across different areas. Additionally, a deeper exploration of the socio-economic impacts of resource depletion on local communities, including factors like education, health and migration patterns, would offer a more comprehensive view of the issue. Finally, integrating technological tools such as remote sensing and GIS could enhance the monitoring and management of marine habitats, providing more accurate and real-time data for decision-making. These directions would contribute to a broader and more detailed understanding of marine resource management in India.

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Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest related to the publication of this article. Additionally, no funding or sponsorship influenced the study's design, data collection, analysis, decision to publish, or preparation of the manuscript.

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