

## Assessment of occupational hazards among small-scale motorised fishers in the southernmost coasts of India

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Fishing is widely recognised as one of the most hazardous professions worldwide. The risks faced by fishers are compounded by the unpredictable nature of the ocean, which includes powerful sea currents, varying wind speeds, high wave heights, and other climate-related factors. These conditions contribute to a heightened risk of accidents at sea, especially in the absence of safety and quality management systems onboard to draw detailed insights on these aspects through an empirical assessment. This study focuses on the prevalence and incidence of occupational hazards/accidents among small-scale motorised fishermen of southern India's coastal districts, such as Thiruvananthapuram, Kollam, and Kanyakumari. To characterise the risks and prioritise them based on observed probabilities, the analysis employed two statistical methods: Relative Importance Indices (RII) and Latent Class Analysis (LCA), using quantitative primary data. The findings revealed several critical occupational hazards encountered by the sample fishers, which were measured with the help of 32 selected indicators. The top six hazards included heat-related stress (RII: 0.83, LCA: 4.27), musculoskeletal issues (RII: 0.76, LCA: 4.18), cyclones (RII: 0.75, LCA: 4.27), heavy rain (RII: 0.73, LCA: 4.09), insomnia (RII: 0.71, LCA: 3.95), and overexertion (RII: 0.65, LCA: 4.05). These identified hazards can be categorised into three primary groups: health, ergonomic, environmental, and psychological. By examining these key occupational hazards, this research contributes valuable insights that can guide efforts to improve safety and health outcomes for small-scale motorised fishermen in India's southern coastal regions.

**[Keywords:** Latent class analysis, Occupational hazards, Small-scale motorised vessels, Southern Indian coastal region]

### Introduction

Fishing and its related activities contribute significantly to most of the coastal economies across the globe. Total fisheries and aquaculture production in 2020 reached 214 Million Tonnes (MT), where Asian countries contributed more than 70 % of the total. Global capture fisheries production in 2020 was 90.3 MT with a value of USD 141 billion<sup>1</sup>. The estimated marine fish landings along the coast of the mainland of India during 2022 were 3.49 million tonnes, showing an increase of 14.53 % compared to the landings in 2021<sup>(ref. 2)</sup>. In 2022, region-wise marine fish landing estimates indicated that the southwest region, encompassing Kerala, Karnataka, and Goa, led the nation with 1.43 million tonnes, accounting for 41 % of the total national landings. Following closely, the southeast region reported 0.99 million tonnes, constituting 28 % of the national total. Notably, there was a significant increase in landings in this region compared to the previous year, with 0.75 million tonnes recorded

(22 %) <sup>3</sup>. Tamil Nadu (ranked 1<sup>st</sup> in 2022) and Kerala (2<sup>nd</sup> in 2022) have been the two major coastal states contributing a major share of marine fish landings in India for several decades, having substantial shares of artisanal and small-scale fishers of the total fisher population<sup>4</sup>.

In 2017, the United Nations General Assembly declared 2022 as the International Year of Artisanal Fisheries and Aquaculture, creating a unique opportunity to focus world attention on the crucial role of small-scale fishers, fish farmers, and fish workers in food security, nutrition, poverty eradication, and sustainable use of natural resources. Declared by the Food and Agriculture Organization (FAO) in 2022, the International Year of Artisanal Fisheries and Aquaculture (IYAFA) highlighted the critical role the small-scale fishers play in achieving the 2023 Sustainable Development Goals (SDGs). These goals align with FAO's vision of 'Four Betters': better production, better nutrition, a better environment, and a better life for all<sup>5</sup>.

This FAO aspiration of a 'better life' is important since marine fisheries are considered one of the most hazardous occupations in the world<sup>5</sup> due to the nature of the work. FAO estimates that every year 32,000 fishers die while working in fisheries, and hundreds of thousands face accidents at sea. Most of these accidents happen on board small-scale fishing vessels, frequently resulting in disability and death among fishers. Thousands of fishers drown every year: falling overboard, being caught under capsized fishing vessels, or being pulled overboard by fishing gear are among the most common causes of drowning<sup>6</sup>. The Information Fusion Centre (IFC) of the Indian Navy reports that in the first half of 2023, it recorded a total of 522 incidents in the Indian Ocean region, a 6 % increase from 2022 over the same period (492 incidents). The leading causes of these incidents are bad weather conditions, equipment failure, and collisions<sup>7</sup>.

Climate change affects the catch of fish leading to various occupational hazards, including loss of lives. Safety at sea and working conditions on board fishing vessels are positively related and are connected with the fish resources available in the sea. With reduced fish resources and overfishing in the Exclusive Economic Zone (EEZ) areas, fishers are forced to go further deep into the sea and stay for longer periods. Thus, safety at sea relates to saving lives, protecting vessels from damage, preventing serious accidents and injuries, protecting the environment, and contributing to profitable fisheries after completing a successful voyage within a specific period. Even a well-equipped vessel can have an accident at sea due to various reasons, including extreme weather events. The artisanal and small-scale fisheries sector of developing countries (Asia and Africa) generally does not have injury prevention plans and safety or quality management systems on board, thus making them prone to more fatal and nonfatal injuries<sup>8</sup>.

The International Maritime Organization (IMO), the International Labour Organization (ILO), and the Food and Agriculture Organization (FAO) are the three specialised agencies of the United Nations and the National Institute of Occupational Safety and Health (NIOSH) of the United States that play a role in ensuring fishermen's safety at sea<sup>1,9</sup>. There have been several studies related to fishing risk and its fatality upswings. IMO, FAO, NIOSH, and ILO recommend various safety measures and precautions applicable to different types of fishing vessels to handle all the worse conditions at sea, including climate-related incidents.

Climate change effects are more common among small-scale fisheries<sup>10</sup> due to small-sized crafts and the traditional use of gears. In the southernmost coastal regions, especially Kerala and Tamil Nadu, fishermen encounter various forms of occupational hazards, including loss of lives. Numerous accidents have resulted from climate change-induced extreme weather events, while unscientific infrastructure development continues to occur daily without proper accountability. Cyclone Okhi in 2017 and Cyclone Tauktae in 2021 caused several deaths and disappearances of fishermen hailing mainly from the maritime states of Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra, and Gujarat<sup>11,12</sup>. Fishermen work for long hours (multi-day fishing) under harsh weather conditions, which increases the likelihood of accidents or injuries. With this background, understanding the occupational hazards while fishing for long hours or days and analysing the present safety culture is necessary, especially among small-scale motorised fishermen, the most affected section of the fishing community.

Market pressure, resource scarcity, overfishing, and poverty often drive risk-taking in fishing, especially in deep-sea areas. Local media reports reveal that between 2016 and 2021, 327 fishers lost their lives off the shores of Kerala state, with 145 of them from the Thiruvananthapuram district, home to 50,000 largely artisanal fishers operating on small boats. Similarly, from 2011 to 2016, at least 643 accidents involving fishing boats were recorded in Kollam, Thiruvananthapuram, and Kanyakumari districts, and 75 % of these incidents involved small, motorised boats<sup>13</sup>. In marine fishing, risks extend beyond human casualties to include the loss or damage of gear, engines, and crafts, as well as the loss of fish and fishing areas. These casualties require urgent attention, particularly in the southernmost coastal regions where the majority of fishermen depend on motorised crafts for fishing. Therefore, the present study aims to identify the most important hazards encountered by fishers while fishing at sea based on their observed probabilities. Through these objectives, the study aims to provide valuable insights into enhancing safety measures for those engaged in small-scale motorised crafts within the challenging context of Southern Indian fisheries.

## Materials and Methods

### Research design and study area

This primary study focuses on the community of small-scale motorised fishers residing in the

southernmost coastal regions of India. The study was carried out in the Thiruvananthapuram and Kollam districts of Kerala, as well as in the district of Kanyakumari of Tamil Nadu. Primary data were carefully collected from the selected coastal areas covering Pozhiyoor, Vizhinjam, and Anjengo along the Thiruvananthapuram coastline, and Thoothoor, Vallavila, Muttom, and Colachel in Kanyakumari through a multi-stage stratified random sampling method. With the help of Cochran’s sample size technique<sup>14</sup>, a comprehensive total of 253 samples were collected from these coastal areas to facilitate a thorough analysis. Primary data was collected between June and November 2023, encompassing both pre-andpost monsoon seasons. This empirical study involves the collection of data through diverse methods, including sourcing information from fishery departments, conducting interviews and group interviews, engaging in focus group discussions, retrieving recall data from senior fishers, and making on-site observations in both field and coastal areas. The geographic depiction of the primary data collection areas is shown in Figure 1.

**Data collection**

A structured interview schedule, incorporating a blend of closed and open-ended questions, was employed to collect comprehensive information from the fishermen. The collected data encompassed various socio-demographic characteristics such as sex, age, household details, and educational attainment. The questionnaire was organised into twelve sections, with the second to eighth sections focusing on occupational hazard exposure. These sections covered vessel-related hazards, health hazards, biological hazards, psycho-social hazards, ergonomic hazards, chemical hazards, and environmental hazards. The questions in these sections also delved into the fishermen’s experiences with these hazards, utilising a five-point Likert scale ranging from 1 = never experienced to 5 = always experienced. The collected data, measured on a five-point Likert scale, underwent further statistical analysis.

**Study methods**

Data collection utilised the Kobo Toolbox platform, and analysis was conducted using R-based

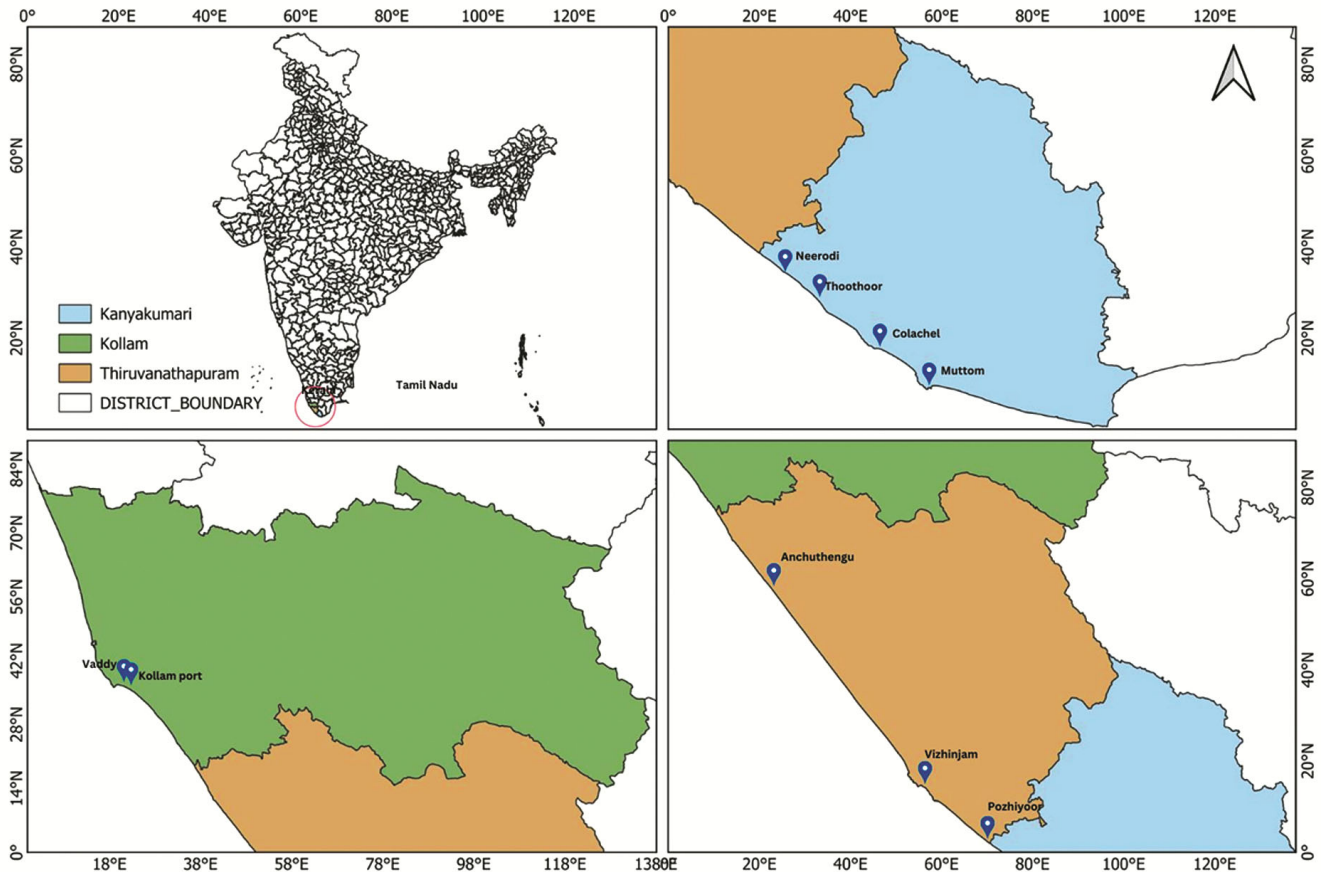


Fig. 1 — The map showing the study area

Jamovi (version 2.3.26)<sup>15-16</sup>. SR plots were employed for plotting graphs. The analysis comprised two stages. First, a Relative Importance Index (RII) was calculated to compare the impact of different occupational hazard variables across categories. Additionally, basic statistical measures of central tendency and dispersion were used to gain insights into the current state of the fishery sector. Subsequently, both RII and Latent Class Analysis (LCA) were applied to identify groups of related occupational hazards.

#### Relative Importance Index (RII)

Relative Importance Index analysis was utilised to prioritise attributes or factors (*i.e.* occupational hazards) based on their relative significance. This index is calculated by summing all responses, dividing by the total number of responses, and then dividing by the maximum Likert scale value (that ranges between 1 to 5), resulting in a weighted average of all responses. A higher value of the RII indicates a more crucial cause or impact component, as determined by the specific equation given below:

$$RII = \frac{\sum W}{AN} \quad \dots (1)$$

Where,  $W$  is the weight as assigned by each respondent on a scale of 1 to 5, with one implying the least (*i.e.* never experienced) and five the highest (*i.e.* always experienced);  $A$  is the highest weight (*i.e.*, 5 in this case), and  $N$  is the total number of respondents (*i.e.* 253 in this case).

#### Latent Class Analysis (LCA)

Latent Class Analysis (LCA) is a statistical technique that identifies unobserved subgroups (latent classes) within a population based on the observed data<sup>17</sup>. This allows us to examine different occupational hazards while accounting for the inherent heterogeneity of the fisherman population. To determine the best LCA model fit, five indices were employed: Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), adjusted BIC (aBIC), Bootstrapped Likelihood Ratio Test (BLRT), and entropy<sup>18</sup>. AIC, BIC, and aBIC are commonly used to compare alternative models, with the lowest value indicating the best fit<sup>19</sup>.

Model selection in LCA involved a stepwise approach, starting with a single-class model and progressively increasing the number of classes until optimal fit indices were reached. The AIC and BIC

were initially used to identify a range of potential models, with lower values indicating a better fit<sup>20</sup>. Given the robustness of the Bootstrapped Likelihood Ratio Test (BLRT) for model comparison<sup>18</sup>, it was employed to further refine the selection process. A significant bootstrap  $p$ -value ( $p < 0.05$ ) indicated a statistically superior fit of the current (fourth) model compared to previous ones. Additionally, an entropy value exceeding 0.998 suggested good separation of latent classes within the data<sup>18</sup>. It's important to note that BIC penalises additional model parameters more strongly than AIC. Therefore, in cases of discrepancy between AIC and other fit statistics, BIC is often prioritised for assessing model fit<sup>21</sup>.

## Results

#### A general profile of motorised fishing crafts in the study area

Table 1 includes three primary motorised fishing craft categories: single-day motorised (SD OBM) and multi-day motorised (both inboard and outboard) noted as MD OBM & MD IBM. Across all craft types, the average age range of fishers typically falls between 41 and 55 years old. Many of the fishers have primary education. Vessels are constructed mainly using fibre (FRB) materials, except for a few built from steel. The length of MD IBM, MD OBM, and SD OBM vessels spans from 10 to 20 m, boasting average overall lengths (OAL) of approximately 17.1 m, 10.9 m, and 9 m, respectively. Propulsion for these crafts is facilitated by indigenous engines, with power outputs ranging between 6 to 40 horsepower (hp) for SD OBM, 9.9 to 25 hp predominantly through Suzuki and Yamaha for MD OBM, and a higher range of 110 to 200 hp using Ashok Leyland engines for MD IBM. An estimation of the average capital expenditure for sample units of SD OBM, MD OBM, and MD IBM reveals an expenditure of Indian Rupees (INR) 0.2 – 0.4 million, 0.8 – 1 million, and 20 – 25 million, respectively. This cost includes expenses incurred on hull, engine, gear, and supplementary accessories. Notably, none of the MD IBM crafts possess freezers or onboard slurry ice-making machines. The average fishermen crew for these crafts are 2 – 4, 5 – 7, and 10 – 12 fishers, respectively. Among the sampled vessels, three-quarters predominantly utilise gillnets as their primary fishing gear, while the remaining crafts employ hook and line/troll lines and long lines. On average, a fishing unit embarks on 182, 48, and 10 fishing trips per year for single-day, five-day, and multi-day trips,

Table 1 — The basic characteristics of motorised fishing crafts in the study

Parameters (Avg/range) (N = 253)	SD-OBM	MD-OBM	MD-IBM
Fisher's age (Years)	51 – 55	41 – 45	41 – 45
Fisher's education	Primary	Primary	Primary
Fisher's experience (Years)	21 – 25	21 – 25	16 – 20
Crafts size (Feet)	32	36	65
Crew size (Number)	2 – 4	5 – 7	10 – 12
Gear use	Gillnet	Gillnet	Gillnet & hook and line
Expenditure on gear (INR)	200000	1000000	3500000
Horsepower range (hp)	9.9 – 40	9.9 – 25	110 – 280
Capital exp on vessel ( INR)	200000 – 400000	800000 – 1000000	2000000 – 2500000
Expenditure on other accessories (INR)	20000	100000	200000
Distance of fishing (nm)	5 – 10	46 – 50	200 – 900
Marine resources targeted	Oil sardine, mackerel, squids, carangids	Tuna, sheer fish, rays, sailfish, swordfish	Tuna, sharks, sheer fish, squids, sailfish
No. of trips per year	182	48	10
No. of days per trip	1	4-5	10-20
Consumption of fuel (INR)	500 – 2000	18000 – 20000	200000 – 300000
Total cost per trip (INR)	3500	50000 – 60000	400000 – 600000
Total revenue per trip (INR)	3000 – 5000	50000 – 100000	1000000 – 1200000
ICT* tools in craft	Mobile phone, handy GPS, wireless sets, echo-sounder	Mobil phone, GPS, wireless sets, AIS	Mobil phone, GPS, wireless sets, AIS, SAT phone
LSG* in craft	No LSGs	Life jackets, life buoys	Compass, life buoys

Source: Field survey, 2023. Note: ICT: Information and Communication Technologies; LSG: Life Safety Gadgets

respectively. Moreover, Table 1 shows a progression of Information and Communication Technologies (ICT) used alongside increase in craft size. While basic mobile phones and GPS devices are prevalent, larger crafts use advanced equipments like Automatic Identification Systems (AIS) and Satellite phones. However, a cause for concern is the limited safety equipment usage, with only a portion of the crafts employing life jackets and basic navigation tools. This shows that more and more awareness programmes are to be conducted among the fishers in the regions.

#### Assessment of occupational hazards faced by fishermen

Figure 2 shows the various occupational hazards faced by fishermen at sea. These hazards were identified through a combination of previous research and field observations. The seven main categorises of hazards (based on classifications used by the U.S. Department of Labor Occupational Safety and Health Administration, or OSHA) were used: vessel-related, ergonomic, personal, environmental, biological/chemical, and health<sup>22</sup>. The Relative Importance Index (RII) method was employed to assess the relative significance of these hazards. Analysis of average mean scores across occupational hazard categories (Fig. 3) reveals environmental

hazards (0.711) as the most impactful, followed by psychological (0.692) and health hazards (0.685).

#### Vessel hazards

Fishermen face a constant risk of accidents due to the nature of their work environment. Figure 4 highlights collisions with other vessels (0.59) as a significant concern. This emphasises the need for proper training in navigation, communication protocols, and adherence to maritime safety regulations. Engine errors (0.52) also pose a threat, underlining the importance of regular maintenance and having backup plans in place for equipment malfunctions.

#### Ergonomic hazards

Fishing gear itself can be a source of significant hazards. Entanglement in nets (0.69) is a major concern, potentially leading to drowning or injuries. Figure 4 reveals a high score for overexertion (0.65), indicative of the strenuous activity involved in hauling nets, lines, and heavy equipment. Similarly, getting caught by hooks (0.61) can cause serious wounds and infections. Furthermore, the high score for "Man falling onboard" (0.54) underscores the dangers associated with working on a moving vessel with slippery surfaces and limited space. This calls for

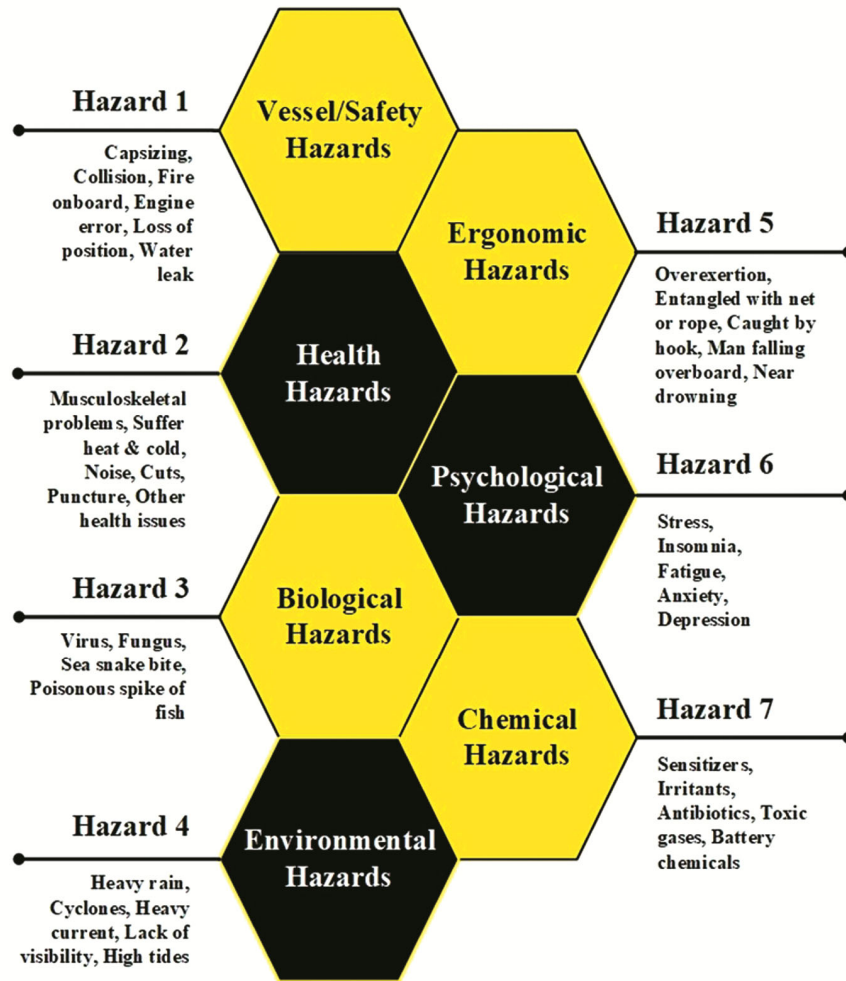


Fig. 2 — Various occupational hazards of the fisheries sector in the study areas<sup>22</sup>

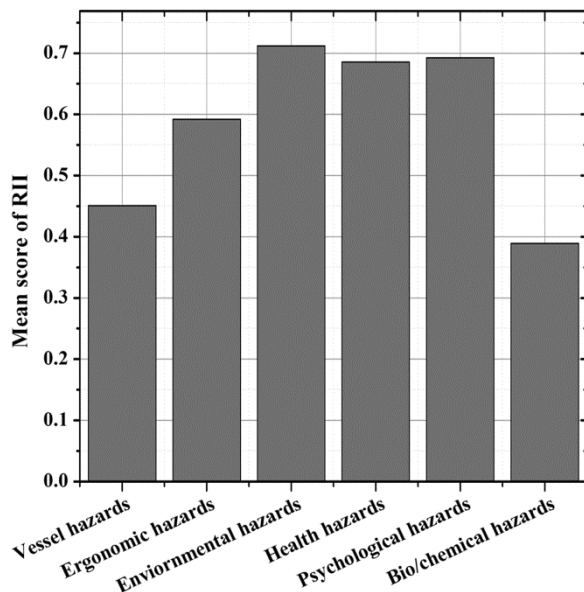


Fig. 3 — Average RII mean scores of occupational hazards for fishers in the study region

the use of appropriate safety gear like life jackets and slip-resistant footwear, along with proper deck maintenance. These findings emphasise the need for proper training in the safe handling and deployment of fishing gear, as well as the development of innovative equipments that minimise the risk of entanglement. Additionally, regular gear inspections and maintenance are crucial to prevent malfunctions or breakages.

**Environmental hazards**

The unpredictable nature of the sea poses a constant threat to fishermen. Figure 4 emphasises the dangers of heavy rain (0.74), cyclones (0.73), and strong currents (0.68). These weather events can lead to vessel-related hazards like capsizing (0.49) or loss of position (0.30), highlighting the importance of real-time weather monitoring systems, robust boat designs, and adherence to safe operating procedures during adverse conditions. Another significant environmental

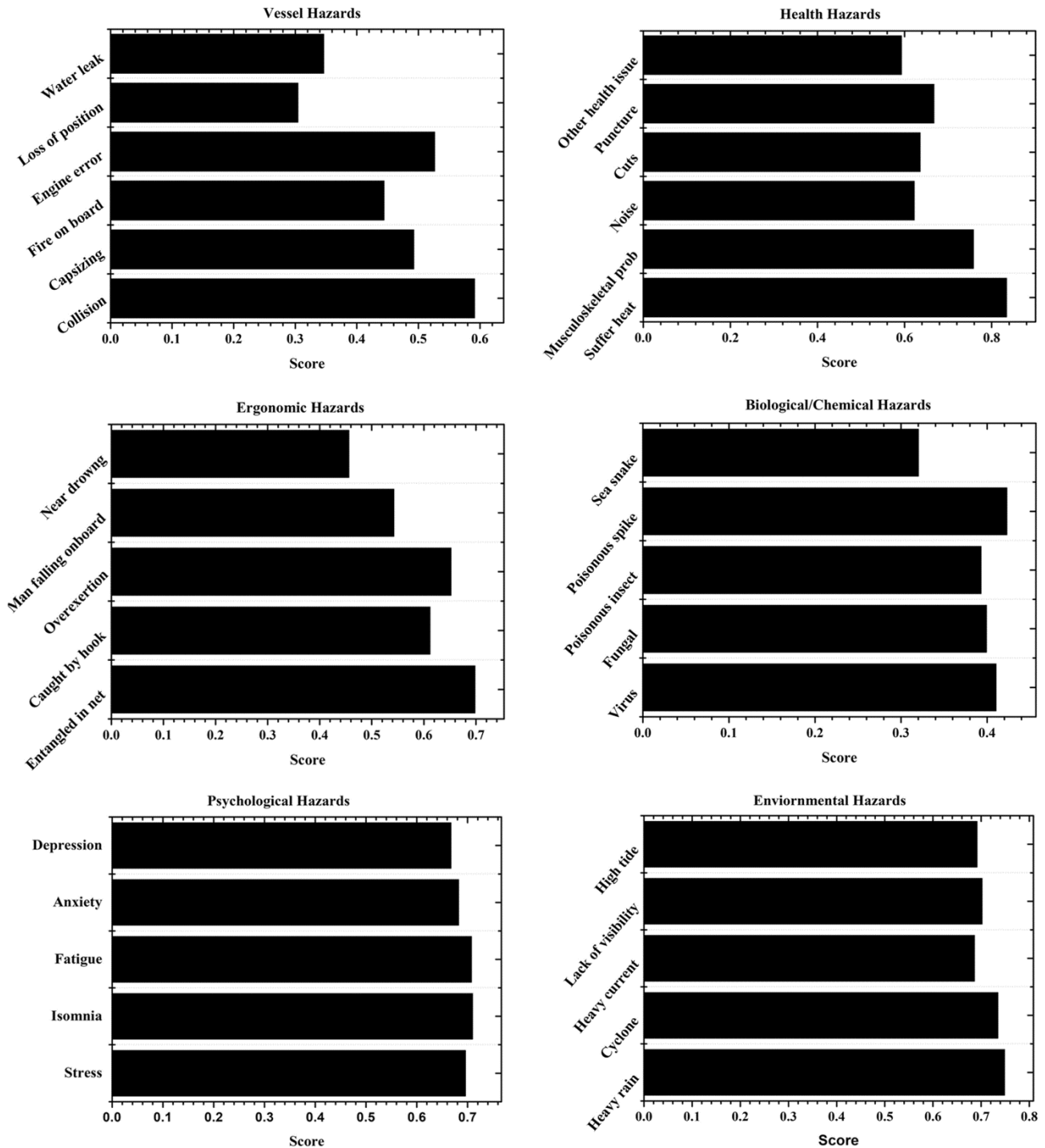


Fig. 4 — The Relative Important Index (RII) scores of various occupational hazards in fisheries sector

factor is limited visibility (0.70) caused by fog or darkness. This can increase the risk of collisions and near-miss situations. Equipping vessels with proper navigation lights, radars, and fog horns is crucial in such scenarios. Additionally, training in night navigation and emergency procedures is essential.

**Health hazards**

The physically demanding nature of fishing takes a toll on fishermen's bodies. This can lead to musculoskeletal problems (0.75), like back pain, joint injuries, and repetitive strain injuries. Furthermore, the high score for heat stress (0.83) points towards the

dangers of working long hours under the sun's harsh rays. This can lead to dehydration, heat exhaustion, or even heatstroke. Implementing work schedules that allow for breaks in shaded areas, providing adequate hydration, and encouraging the use of protective clothing are essential preventive measures.

#### *Psychological hazards*

The psychological hazards of fishing should not be overlooked. Figure 4 highlights the prevalence of stress (0.69), insomnia (0.70), anxiety (0.68), and depression (0.66) among fishermen. This can be attributed to factors like isolation at sea, long working hours, unpredictable weather conditions, and the inherent dangers of the profession.

#### *Biological/chemical hazards*

Biological and chemical hazards exhibited the lowest relative importance ratings compared to other categories within the sector, typically ranging from 3 to 4 (on a potentially larger scale). This is further supported by the specific hazards within this category. For instance, encountering poisonous fish spines received a rating of 0.423, while fungal and viral infections were rated even lower at 0.413 and 0.399, respectively (Fig. 4). These findings suggest that biological and chemical hazards play a minimal role in the overall occupational risk profile of fishermen.

#### **Latent Class Analysis (LCA)**

Latent Class Analysis (LCA) was employed to analyse the Likert-scale data, building upon previous research on applying LCA to socio-economic issues<sup>23-25</sup>. The study explored models with varying numbers of classes, ultimately comparing five potential models. The four-class model emerged as the best fit based on its favourable fit indices: low Akaike Information Criterion (AIC: 17927), Bayesian Information Criterion (BIC: 19746), and Consistent AIC (CAIC: 20261), along with a significant Bootstrapped Likelihood Ratio Test (BLRT) *p*-value and an entropy value exceeding 0.9<sup>(ref. 26)</sup>. While the two-class model had a lower BIC and CAIC than the five-class model. It wasn't a statistically superior fit due to a non-significant BLRT *p*-value (0.140). This suggests the two-class model oversimplified the data. Additionally, the four-class model balances good fit with parameter efficiency, a key consideration in LCA selection<sup>26</sup>. Table 2 presents the detailed model fit statistics for all five latent class estimations. Based on the data shown in this table, fishers can be primarily categorised into four distinct groups.

Table 2 — Absolute fit indices of the latent classes analysis

Class	AIC	CAIC	BIC	Entropy	<i>P</i> value
1	19757	-	20209	1.00	N/A
2	19510	20675	20418	0.998	0.140
3	18315	20065	19679	0.997	<.001
4	17927	<b>20261</b>	<b>19746</b>	<b>0.998</b>	<b>&lt;.001</b>
5	<b>17822</b>	20741	20097	0.997	<.001

AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion; ABIC: Adjusted Bayesian Information Criterion; BLRT: Bootstrap Likelihood Ratio Test; *p*: Bootstrap *p*-value

A graphical representation of the four-class model is shown in Figure 5. The indicators of various occupational hazards are listed on the x-axis, and the average mean value of class membership for each indicator is provided on the y-axis. Furthermore, the characteristics of the four classes based on fishermen's responses to various hazards are illustrated. Latent Class 1, 2, 3, and 4 were categorised as the 'More experienced group', 'Often experienced group', 'Less experienced group', and 'Very less experienced group'. The mean score values associated with each hazard reveal key insights. Across all classes, insomnia (3.95), overexertion (4.05), cyclones (4.27), heavy rain (4.09), and heat stress (4.27) were prevalent concerns.

Following latent class identification, a Latent Class Analysis (LCA) was conducted to examine the most prevalent occupational hazards within the fishing sector. Figure 5 presents the average hazard scores for four experience groups: More experienced, Often experienced, Less experienced, and Very less experienced. The 'More Experienced Group' (32.4 % of the population, N = 253) exhibited high exposure probabilities to a range of hazards, particularly heat stress, insomnia, fatigue, cyclones, and poor visibility. Conversely, biological and chemical hazards posed a lower risk to this group. The 'Often Experienced Group' (19.8 %) reported high probabilities for all 32 assessed hazards, indicating frequent exposure to a diverse set of occupational risks. The 'Less Experienced Group' (30.4 %) demonstrated the lowest hazard probabilities across the board, suggesting potentially shorter fishing careers or reduced exposure. The 'Very Less Experienced Group' (18.2 %) showed high probabilities for certain hazards, possibly indicating exposure to a narrower range of risks or less frequent encounters. Environmental, ergonomic, psychological, and health hazards consistently emerge as the most significant occupational risks compared to other factors. These

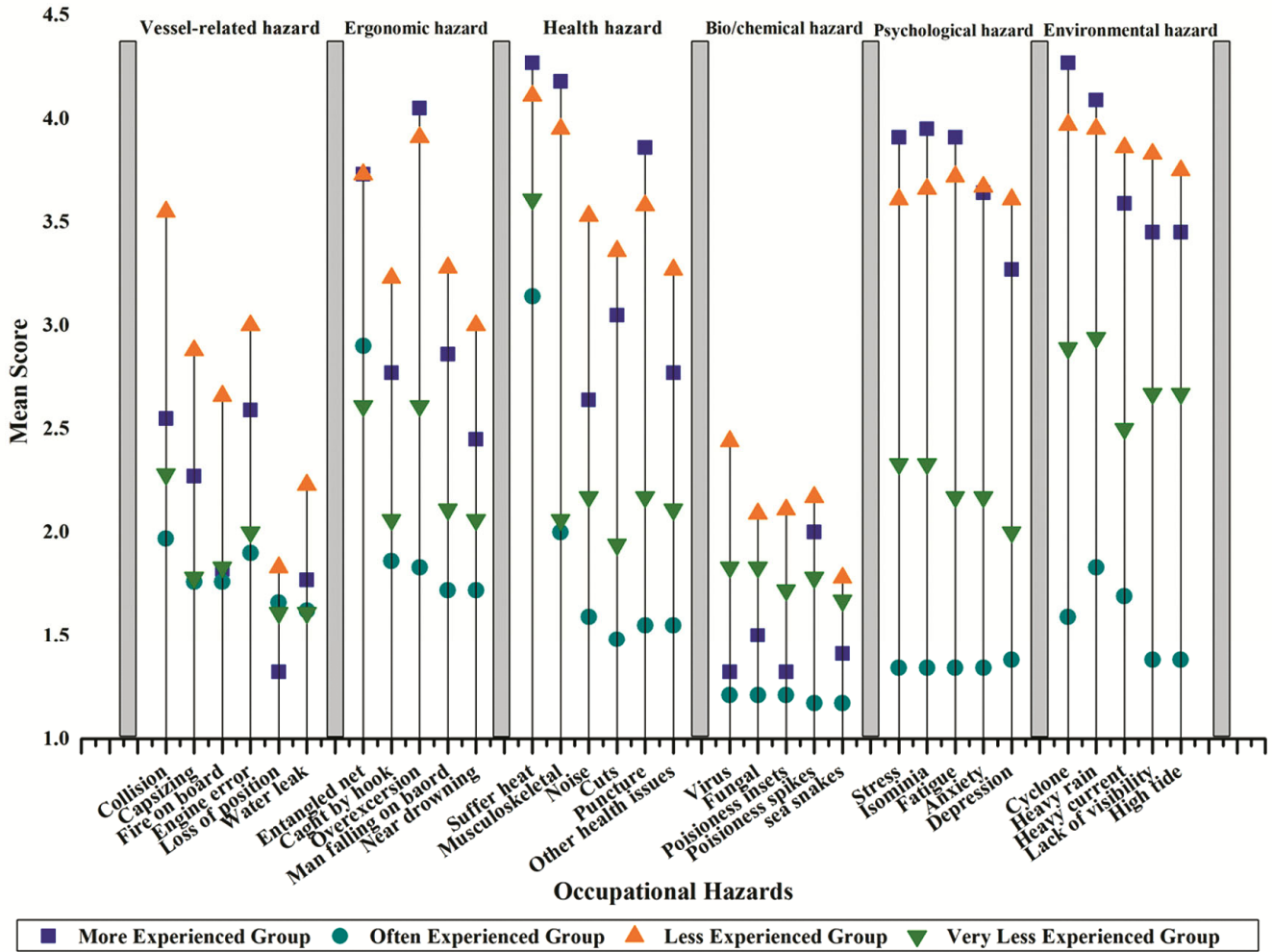


Fig. 5 — Observed mean score value of each latent class of occupational hazards

hazards have the most substantial impact on the overall work environment of the fishers. Importantly, Figure 5 consistently reveals a minimal impact of biological and chemical hazards across all four fishermen subgroups.

**Discussion**

The study analysed various commonly encountered occupational hazards/accidents while fishing at sea. The main objective of the present study was to identify the most important hazards met by fishers while fishing at sea based on their observed probabilities. This study provides valuable insights into the characteristics of small-scale motorized crafts being operated in the Southern Indian Ocean and the occupational hazards faced by fishermen who operate them. The results demonstrate a varied range of vessel types, crew sizes, and fishing gears employed, reflecting the diverse nature of the fishing sector in

study regions. The broader implications arising from the study for safety, equipment standards, and training are also discussed in detail.

The data on fishing crafts show notable distinctions among SD OBM, MD OBM, and MD IBM. The crafts' average lengths, crew sizes, horsepower, and capital expenditures reflect the diverse scale and scope of fishing operations. The majority of these vessels are constructed from Fibre-Reinforced Plastic (FRP), with the MD IBM vessels being significantly larger and more powerful than their smaller counterparts. Previous studies indicate that the type and design of fishing vessels (crafts) significantly influence the occupational hazards faced by fishermen. Thus, differing characteristics of the fishing crafts and their varying fishing operations indicate a range of operational capacities, suggesting that safety and maintenance requirements might differ across the fleet.

The study identifies several categories of occupational hazards, highlighting significant risks associated with fishing. Health hazards, ergonomic hazards, psychological hazards and environmental hazards were prominent. Collisions with other vessels, engine errors, and limited visibility due to fog or darkness present notable threats to fishermen's safety. This result aligns with the earlier findings of Pei *et al.*<sup>24</sup>. This also shows the need for robust navigation training, regular equipment maintenance, and proper safety protocols.

Ergonomic hazards, such as entanglement in nets and injuries from hooks, are common and pose serious risks. The frequency of "Man falling onboard" incidents further indicates the dangers of working on a moving vessel with slippery surfaces and limited space due to small craft size. These findings suggest a need for enhanced safety gear, better deck maintenance, and increased safety training. Environmental hazards, including cyclones, strong currents, and heavy rain, create unpredictable and hazardous conditions at sea. Timely weather forecasts are crucial for these fishermen; however, communication challenges often leave them unaware of the approaching dangers. The vast distances they operate in further exacerbate this issue, making them more vulnerable to environmental disasters. Proper vessel design, weather monitoring systems, and adherence to safety protocols are essential to mitigate these hazards. The identified health hazards, like heat stress and musculoskeletal problems, point to the physically demanding nature of fishing, emphasising the need for regular breaks, adequate hydration, and proper ergonomic support.

The LCA model showed optimal fit and complexity, as indicated by the lowest AIC (17927) and BIC (19746) values. The model's high entropy (0.998) and highly significant *p*-value ( $< 0.001$ ) support its robustness and classification accuracy. The identification of four distinct fisher classes provides valuable insights into varying occupational hazard exposures in the sector. 50 % of fishers experience at least one hazard regularly. Distribution of hazards across classes highlights the need for tailored interventions. Some groups face elevated risks due to factors such as inadequate safety measures, training deficiencies, or extreme weather conditions. These findings highlight the importance of targeted safety initiatives and training programs to address the specific needs of different fisher populations.

Operational ocean services provided by the Indian National Center for Ocean Information Service (INCOIS) on potential fishing zone advisories, ocean state forecasts (waves, currents, temperature, salinity, etc.), storm surges, early tsunami warnings, etc. and weather forecasts provided by IMD directly or/and through the fisheries departments, and state agencies are crucial for supporting the fishing community. These services enhance fisher safety, operational efficiency, and economic sustainability. Accurate and timely weather forecasts and warnings help fishers avoid hazardous conditions, significantly reducing the risk of maritime accidents. Although 60 % of fishers can access weather forecasts and advisories via mobile phones, there is limited use of mobile apps for obtaining sea condition reports before venturing out. Sea condition reports, including wave height and current data, are essential for safe operations. Fishery zone advisories, derived from oceanographic data and satellite imagery, help identify optimal fishing grounds, saving time and fuel. However, fishers generally lack a comprehensive understanding of oceanographic parameters like sea surface temperature, salinity, and chlorophyll concentration and utilise that to enhance their understanding of fish behaviour. Early warning systems for natural disasters like tsunamis and cyclones are vital for timely evacuation. While many fishers are aware of these threats through local bodies, coastal police, and religious institutions, the use of rescue operation tools such as Distress Alert Terminal (DAT) beacons or Vessel Monitoring System (VMS) is nonexistent among this fishing community. By effectively utilising available ocean services and addressing the identified gaps, the fishing community can improve safety, efficiency, and sustainability.

For a sustainable fishing environment, a focus on the safety and well-being of fishers is necessary. The analysis of these hazards underscores the need for a multi-pronged approach to ensure safety and well-being of fishermen. This includes: 1) Enhanced training and safety awareness: Regular training sessions focused on safety protocols, proper handling of fishing gear, and emergency procedures shall reduce the risk of accidents and injuries; 2) Enhanced safety measures by equipping the vessels with modern navigation equipment, life-saving gear, and weather monitoring systems are crucial; 3) Focus on Ergonomic design: Research and development should focus on designing fishing gear and equipment that

minimises physical strain and reduces the risk of injuries; 4) Technological upgrades like the adoption of advanced communication and navigation technologies, Automatic Identification Systems (AIS), and satellite phones can enhance safety by providing real-time information and improved communication; 5) Targeted safety programs based on the LCA findings need to be tailored to address the specific risks faced by each class of fishermen. This approach can ensure that interventions are both effective and efficient; 6) Mental Health Support: By providing access to mental health professionals and creating a supportive work environment can significantly improve fishermen's well-being; 7) Investing in improved Equipment and Maintenance of safety gear, life jackets, life buoys, and non-slip footwear can help mitigate the risks; and 8) Implementation of regulatory reforms, strict safety regulations and enforcement of safety measures shall improve the safety and health of the fishers.

### Conclusion

The present study discussed the diverse occupational hazards faced by small-scale motorised fishermen in Southern India, encompassing vessel-related risks, ergonomic dangers, environmental threats, and more. An analysis based on Relative Importance Indices (RII) identifies three main hazard categories with the most substantial influence on fishers: health, environmental, and psychological. Among specific hazards, heatstroke, musculoskeletal problems, cyclones, heavy rain, and insomnia emerge as the most significant according to item-wise RII. LCA revealed four distinct classes of fishermen based on hazard exposure, illustrating the varied risk profiles within the fishing community. Key findings indicate the need for improved safety training, regular equipment maintenance, and investment in advanced technologies like AIS and satellite phones. The results suggest that targeted safety programs tailored to each class of fishermen can effectively address the identified hazards. By focusing on these key areas, stakeholders can significantly improve the safety and well-being of fishermen in Southern India. Enhanced safety measures will not only protect lives but also support the sustainability of the fishing sector in the region, fostering a safer and more secure working environment.

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### Conflict of Interest

The author declares no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

### Author Contribution

MS: Conceptualisation, methodology, data curation, analysis, and writing; VPP: Data mining and analysis; and SP: review & editing.

### Ethical Statement

This study was conducted in accordance with established ethical guidelines and principles. Informed consent was obtained from all participants before data collection, ensuring voluntary participation and confidentiality.

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