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ORIGINAL ARTICLE

Assessment of Socio-technical Constraints of Marine Fishers in the Utilisation of Marine Fishery Advisories in Southern Odisha, India

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Abstract
Sustainable marine fishing practices are often hindered by local-level factors in areas with high fishery potentials, such as Odisha, India. Scientific services to fishing, such as Marine Fishery Advisories (MFAs) on the Potential Fishing Zone (PFZ) and weather information in the form of Ocean State Forecast (OSF) advisories provided by INCOIS, India, are valuable knowledge products which can help the fishers to overcome several socio-technical constraints (STCs) to effective fishing practices. The present investigation provides a critical analysis of five STCs prevailing in 4 districts (Kendrapara, Jagatsinghpur, Puri and Ganjam) of Southern Odisha which can possibly hinder the effective assimilation of the MFAs. These five STCs are the hierarchy of fishers in fishing operations, pathways of transition to new fishing technologies, the adaptive capacity of the fishers to use scientific advisories, the need to achieve economic resilience from fishing as well as the contribution to the preservation of ecosystem sustainability. Stakeholder mapping based on the ground-based observations revealed that inadequate transitions pathways, varying hierarchical positions and low adaptive capacities contributed to higher STCs in general. Sensitivity of the fishers to achieving economic as well as environmental sustainability in their enterprise leads to lower STCs and greater assimilation capacities. The analyses of STCs presented here provide a robust methodology to manage the social cost of carbon which can be useful to achieve sustainability targets with respect to marine fisheries by adopting regular use of MFAs.

Keywords Socio-technical constraints · Marine Fishery Advisories · Potential Fishing Zone advisories · Stakeholder mapping · Transitions pathways · Southern Odisha

1 Introduction

Marine and coastal ecosystems provide diverse services, where fishery operations from a major part in sustaining the lives and livelihoods of the marine fishing community apart from the significant contribution to global food security (); Arkema et al. 2015; Hamilton et al. 2021however, overexploitation of marine resources and underestimation of marine environment owing to the usages of bottom trawling, overcapacity of the fishing boat and continuation of government subsidies to the mechanised crafts etc. are major concerns at present for marine fisheries in India (Filipe et al. 2013; Ray and Garada 2018).

Sahu and Pradhan (2017) reported that overfishing in the marine fisheries sector also included by-catches and trash landings simultaneous to the depletion of commercially important fish species as well as diminish in the overall catch. Therefore, it is very crucial to optimise the fishing effort factoring in the demand to ensure sustainable fishery resources. Ray and Garada (2018) also stated that apart from the ineffective use of motorised fishing crafts, water body contamination and ecological degradation in coastal surroundings aggravated the processes such as social displacement and ecological alternation in the country such as India. However, it has been recognised that human-induced positive interventions on the beneficial flow of coastal and

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marine ecosystem services can be enhanced by the engagement of local stakeholders (Arkema et al. 2015). Despite the availability of such examples, investigations on the constraints in the effective management of socio-ecological units of marine ecosystems and the associated communities of fishers need to be studied in detail for Indian scenarios.

In this context, the uses of technological and scientific advancements can offer pathways for transitions and adaptations to marine fishers to utilise scientific advisories, such as marine fishery advisories (MFAs), including Potential fishing zone (PFZ), developed and disseminated by the Indian National Centre for Ocean Information Services (INCOIS). The MFAs are disseminated regularly except during the fishing ban period are useful for locating the large fish aggregation in the open sea with the reduction of time and fuel consumption (ESSO-INCOIS 2020b). In addition, INCOIS also disseminates ocean state forecast (OSF) advisories to all the fishers to make a smooth and hassle-free fishing expedition by proving reliable and timely weather forecasts (ESSO-INCOIS 2020a). However, the assimilation and usages of PFZ and OSF advisories in states such as Odisha is currently irregular compared to their mainstreaming in fishery practices of other states in India (e.g., Tamil Nadu, Kerala, Gujarat etc.; NCAER 2010, 2015, 2020). This can be attributed to the presence of various socio-technical constraints (STCs) associated with the fishing, which remained unexplored.

Odisha has the sixth largest coastline in India and third largest fisherfolk population, but stands eighth in marine fish production due to the lack of infrastructural facilities, especially for the lesser numbers of mechanized fishing crafts and fuel bunk, technical illiteracy, low level of socioeconomic condition inferred from low per capita income, high level of debt etc. (CMFRI 1987; Nayak and Mishra 2008; Government Of Odisha 2015). Moreover, Nayak and Mishra (2008) found that fishers were often forced to dispose-off their catch to the middlemen in the lower coast due to the non-availability of good market system. As per a recent report (OXFAM India 2017), the emergence of extreme weather events for, e.g., tropical cyclones, storm surges occurred mostly in every annual in Odisha as this state is vulnerable to climate change and is located in the cyclone-prone regions in India (Priyadarshi et al. 2019), contributed towards the backwardness of the Odiya fishing community. Kundu and Santhanam (2021a, b) provided comprehensive accounts of the devastating combined effects of the COVID-19 pandemic and recent cyclonic impacts on Odisha. Furthermore, global observations have revealed accelerated heating over the North Indian Ocean since 2000 under the heating influence of the Pacific Ocean (Cheng et al. 2021). This could in turn have compounding negative effects on the vulnerable coasts of Odisha.

In addition, the presence of eco-sensitive zones in southern coastal Odisha such as the Gahirmatha marine sanctuary (situated in Kendrapara district), Olive Ridley nesting areas (mainly in Devi and Rushikulya river mouth) etc. need closer regulation of fishing activities which are prohibited in most of the period in a year within the sea radious of 20 km (Mathew 2004; Shanker et al. 2004; Government of Orissa 2010). Illegal fishing due to the mesh size violation as well as intersectoral conflicts in between mechanised and motorised crafts for fishing in the inshore traditional zones have also been reported from Odisha (Pramod 2010). Therefore, while it is crucial to protect the coastal sensitive areas of Southern Odisha from human-induced losses on one hand (MPEDA 2018), attention also needs to be paid to improving the lives and livelihood of marine fishers on the other (Dimech et al. 2009; Mudliar et al. 2019). These considerations provide the scope for the identification and assessment of these STCs to suggest beneficial socio-ecological pathways for the marine fishers of Odisha to attain sustainable livelihoods, circular economy and technology-based transitions. Thus, the identification and assessment of STCs could enable the people and the administrators of Odisha to achieve the targets of Sustainable Development Goals (SDG) 14 by 2030 as set by United Nations. The present investigation is an attempt in this direction to analyse and report the nature and mechanism of the operations of these STCs prevalent in Southern Odisha.

2 Study Area

Odisha has a 480 km long coastline which is approximately 8% of the total Indian coastline, while the available exclusive economic zone (EEZ) for the state is about 0.17 sq. km which is around 8.4% of the country's EEZ, considered as highly fertile for marine fish production (Government of Orissa 2010). Southern Odisha comprising of four coastal districts (out of total six districts), namely, Kendrapara, Jagatsinghpur, and Puri, Ganjam (north to south; as shown in the study area map) covering a distance of 350 km along the coastline have been considered as the study area for the present research.

While the northern part of Odisha has an extended continental shelf (up to 120 km) along with extensive river deltas and tidal areas, its southern part consists of narrow shelf (up to 40 km) and open sandy beaches (FAO 1984; CMFRI 1987) which do not naturally favour the operation of the mechanised boats. The Rushikulya river mouth in Ganjam and Gahirmatha Beach in Kendrapara are one of the largest well-known mass nesting sites in the world for the Olive Ridley turtle, where gillnetting had been banned in the Odisha coast since 2003 (ICSF 2011). In 1997, Gahirmatha Marine Sanctuary was designated as a zone of conservation for breeding and nesting habitats owing to protect the sea turtle in Odisha. The fishing activities in this region had

been reduced in terms of prohibition of big fishing crafts, minimising the fishing grounds as well as decreasing the number of fishing days to protect the breeding and nesting habitats which directly and indirectly affected the livelihood of the marine fishers. The study conducted by the International Collective in Support of Fishworkers, Chennai (ICSF 2011) reported that higher levels of indebtedness, cases of mental illness, and suicides were increased due to the lower income owing to the restriction in fishing. Apart from the 38 km long Gahirmatha beach stretching from the Maipura river mouth to Hansua river mouth, Rushikulya and Devi river mouths in Odisha are also famous for major mass-nesting sites of Olive Ridley turtle.

Due to the protection practices, year around regulation of "No fishing zone" with 20 km seaward radius in the Gahirmatha Marine Sanctuary had been implemented, while "No mechanized/motorized fishing" is performed within 10 km distance into the sea during November 01 to May 31 every year in Devi River mouth (ICSF 2011). The southern coast of Odisha differs from the northern coast not only in terms of oceanographical and ecological features, but also cultural and ethnic origins of the people who settled down on the coast for their livelihoods are also different in two coastal parts (Kalavathy 2004). In the case of the southern coastal part of Odisha, i.e., Ganjam, Puri, and Jagatsinghpur, marine fishers belong to Telegu community also known as 'Noliyas' who came for fishing more than 1000 years ago (Kalavathy 2004). According to the study conducted by Kumar et al. (2010) found that 22% of the total coastline in Odisha comprises the districts of Puri and Jagatsinghpur which are classified as high risk or vulnerable zones due to flooding attributed to storm surges. For the present study, all four districts were considered for analysing the STCs associated with the marine fishers.

Figure 1 shows the location of six fish landing centres (FLCs), where a field survey was conducted among the marine fishers, i.e., owner, labourer, motorised boat fishers, and non-motorised boat fisher to identify the STCs for the usages of PFZ and OSF advisories in southern Odisha. The FLCs were selected by excluding the presence of big river mouths and sensitive coastal zones, i.e., marine sanctuary, mass-nesting sites etc. to carry out the present study exclusively on the communities of fishers dependent on the marine fisheries.

One FLC each was selected from two districts of Kendrapara (Kharinasi) and Jagatsinghpur (Noliasahi), while two FLCs each were selected from Puri (Chandrabhaga and Penthakata) and Ganjam (Markondi and Ramayapatna) districts. Furthermore, the survey considered all prevalent types of fishers' categories, i.e., mechanised, motorised, and non-motorised in all the FLCs in southern Odisha. However, due to the absence of big rivers in proximity to the FLCs studied, the present survey did not consider the populations owning or operating mechanised crafts, which were absent in the FLCs investigated.

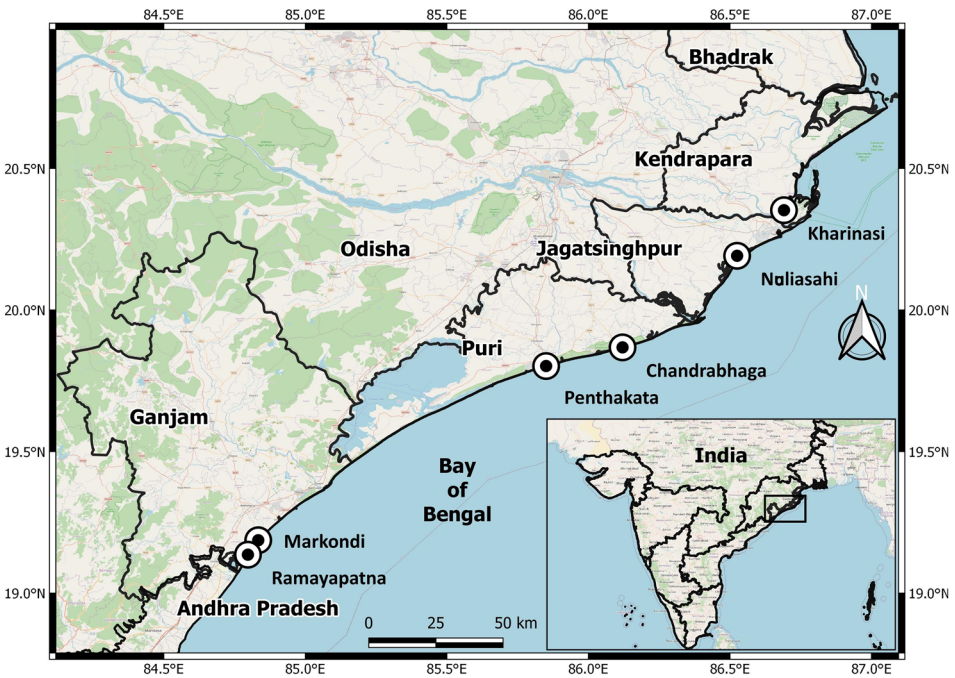

Fig. 1 Study area map of southern Odisha comprising of four coastal districts, namely, Kendrapara, Jagatsinghpur, Puri, and Ganjam (from north to south). Pointed mark shows the locations of six fish landing centres (FLCs), where the field survey was conducted

3 Data Sets and Methodology

3.1 Data Sets

An extensive field survey of the MFA usages and socio-economic statuses of about 125 fishers was conducted during the post-pandemic periods of 2021. Different categories of marine fishers such as owner, labourer, mechanised, motorised, and non-motorised craft fishers associated with six FLCs were interviewed (Table 1). Apart from marine fishers, stakeholder consultations were held with office bearers of the marine fisheries co-operative societies in each FLC (the secretary, president, desk assistants). Later, the primary data from the questionnaire survey collected was converted into a database and analysed to identify the local scale factors for, e.g., STCs which influence the assimilation of PFZ and OSF advisories by the marine fishers in Odisha.

3.2 Methodology

To identify the STCs in the assimilation of MFAs in southern Odisha, the overall methodology (as shown in Fig. 2) for the present study deals with the consideration of marine fisheries stakeholders (, e.g., owner, labourer etc.) as well as identification of STC parameter (e.g., hierarchy, transition, adaptation etc.) by scrutinising criteria/indicators considered for the field survey conducted in March and April, 2021.

The specific methodology adopted for the mixed-methods survey undertaken at Southern Odisha is shown in Fig. 3.

Table 1 Details of fish landing centres (FLCs) and sample sizes considered for the current socio-technical survey in southern Odisha

S. no.	Fish landing centres (FLC)	Districts	Numbers of fishers surveyed
1	Kharinasi	Kendrapara	31
2	Noliasahi	Jagatsinghpur	30
3	Chandrabhaga	Puri	18
4	Penthakata		14
5	Markondi	Ganjam	19
6	Ramayapatna		13
Total			125

Among the various stakeholders' types associated with marine fishing, the present study focussed on the frontline group of marine fishers associated with the fishing expedition with the usages of MFAs. Apart from the one-to-one questionnaires survey with the marine fishers, at least one focused group discussion (FGD) among various stakeholders in each FLC in southern Odisha was also conducted. Five STC parameters, namely, (1) hierarchy and social statuses, (2) level of transitions towards technology including innovation, (3) levels of adaptation to technological use including the use of indigenous or novel techniques for fishing, (4) economic status and resilience (at individual scales), and (5) sensitivity to environmental resilience and sustainability, were identified to examine the nature and intensity of the reception and utilisation of MFAs by different classes of marine fishers. Since mechanised crafts did not operate at the FLCs, where the present investigations were undertaken, the present survey did not include them.

Furthermore, several criteria/indicators have been considered under each STC parameter to determine the impact of the usages scenario with respect to the MFAs. Based on questionnaires prepared for the data collection from field survey, list of criteria/indicators are analysed corresponding to five STC parameters for the present study. To map the stakeholders as per their STCs, their responses to the questionnaire were provided by the matrix score analysis for each criterion /indicator (score ranging from 0 to 5 for each of five parameters) versus individual scores (starting from 0 to 5) provided to each type of marine fishers, i.e., owner, labourer etc. as represented in Eq. 1. Therefore, sum of the STC scores for each type of marine fishers (Si) derived as arithmetic mean using the following formula:

$$S_i = \sum_{i=1}^{5} (I_O + I_L + I_N + I_M). \quad (1)$$

where S_i denotes the sum of the scores with respect to the success in the usages of MFAs accrued under the five STC parameters, i.e., hierarchy, transitions level, level of adaptation, economic status and environmental sustainability which represented by '*i*' for each group of marine fishers, denoted by I. The respective scores (e.g., 0 = nil; 1 = very low; 2 = low; 3 = medium; 4 = high; 5 = very high) were assigned to each five marine fishers' group (e.g., O = permanent

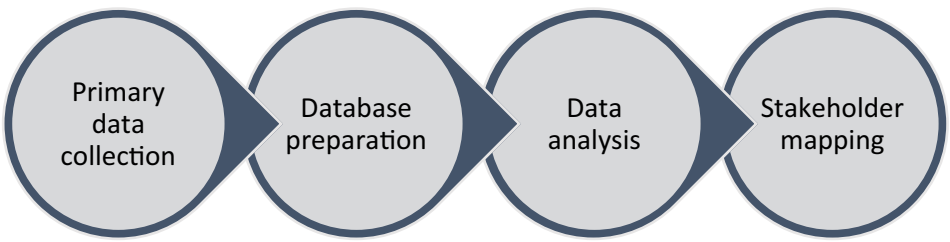

Fig. 2 Schematic representation of primary data collection using marine fisheries stakeholder consultation to prepare stakeholder mapping by creating database preparation and data analysis

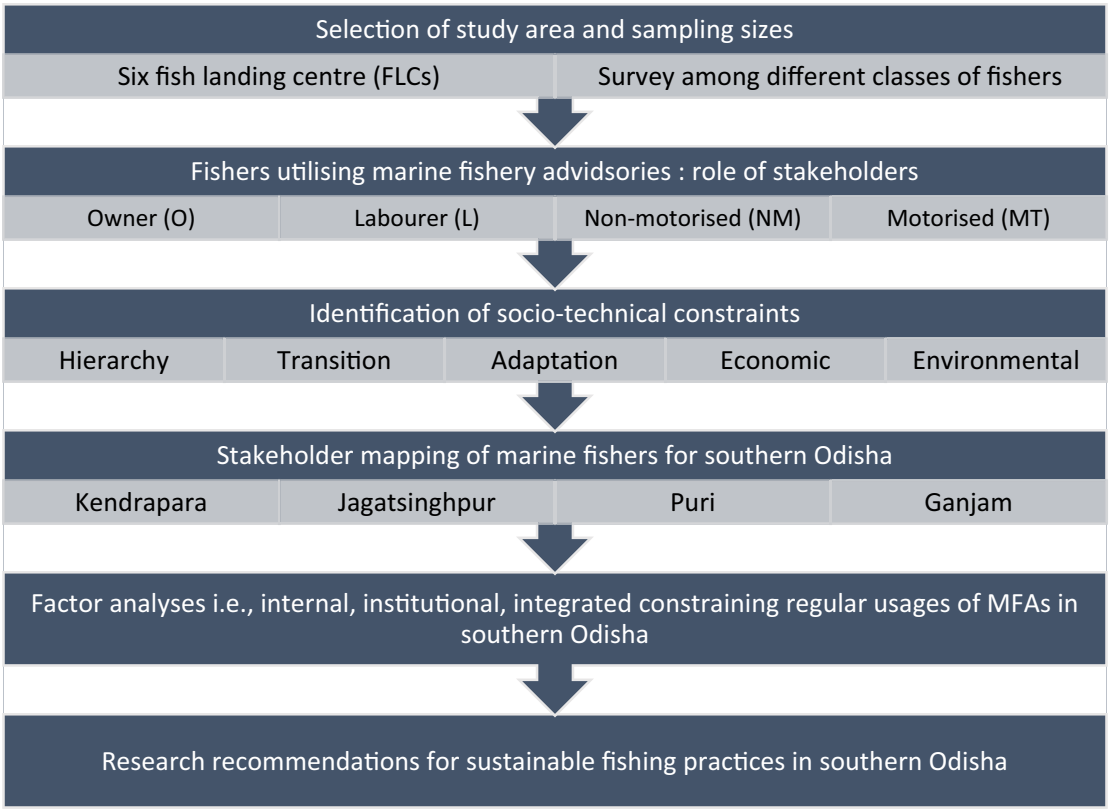

Fig. 3 Methodology adopted for the present study for the identification of socio-technical constraints (STCs) on the use of marine fishery advisories (MFAs) in southern Odisha

owners of fishing crafts and gears; L = labourers including natives and migrants; N = fishers using non-motorised crafts; M = fishers using motorized crafts) based on the qualitative analyses of the responses recorded during the field survey in southern Odisha. Thus, S_i also represented the relative influences of five STCs on the usages of the MFAs, with higher scores indicating a greater level of overcoming the STCs and higher usages of the MFAs.

Furthermore, stakeholder mapping of marine fishers for southern Odisha, i.e., Kendrapara, Jagatsingpur, Puri, Ganjam districts was attempted based on the results obtained from field investigations. As the present study focused on the reception and utilisation of MFAs, several factors which constrain the usages among marine fishers were also considered.

Figure 4 illustrates a compilation of the various internal, institutional as well as integrated factors which may directly and indirectly play a vital role in the reception and utilisation of MFAs in southern Odisha. These factors were considered for the present investigation as part of the qualitative surveys at the ground level to understand the scenarios associated with the reception as well as utilisation of MFAs by the marine fishers. For example, the internal factors which are related to the fishers' perceptions and experience along

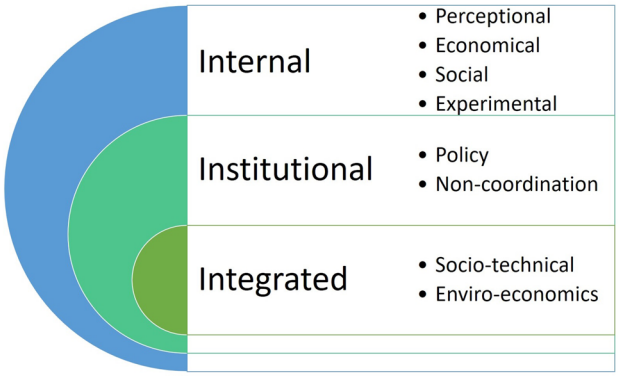

Fig. 4 Factors associated with the reception and utilisation of marine fishery advisories (MFAs) in southern Odisha which were considered for identifying the various socio-technical constraints (STCs)

with their socio-economical statuses influence the reception, assimilation, utilisation efficiency of MFAs among fishers. On the other hand, the existing policies and lack of coordination of the dissemination agencies may further impact how the fishers receive the advisories, with less scope for improvement from the stakeholder perspective. Integrated factors such as various socio-technical as well

as enviro-economics issues of the fisher communities usually impact the usages of the MFAs in relation to the STCs identified in the current study.

4 Results and Discussion

In the present survey, active fishers of four stakeholder categories (described in Sect. 3, methodology) were interviewed. The respondents were found to be exclusively only males who identified themselves as taking part in active fishing operations ($n = 125$). The work participation of the male fishers was comparable across all the FLCs with nil participation of the females in active fishing as identified through the ground-level surveys. The population surveyed consisted of respondents who had received secondary level education (having basic to moderate level of computing and linguistic skillsets; at least 10–12 years of formal education since childhood) present within all stakeholder groups as recorded during the interview. The profits obtained from fishing were observed to be different across the different stakeholders and that was based on the type of fishing units (gear and crafts) used in the fishing operations.

The fishers who were surveyed, across all the four major stakeholder groups, belonged to any of the following major social caste categories prevailing in Southern Odisha:

1. Unreserved category (fishers with no caste identification or socially forward groups; UR; $n = 8$),
2. Other Backward classes (fishers who identified as belonging to socially backward class; OBC; $n = 94$) and
3. Scheduled castes/tribes (fishers who identified as belonging to ethnic minorities; SC/ST; $n = 23$)

These caste designations have been reported here as per the official caste categorisation prevalent in Odisha state, India during the time of the survey. Thus, the effects of caste on the influence of MFAs access and usages were normalised alongside the educational statuses of fishers with basic formal education across the population surveyed to derive the actual usages among fishers of similar castes and educational backgrounds.

Three factors, i.e., caste, educational statuses and profits made from fishing, were observed to influence the hierarchy and economic statuses of the fishers. Hence, these factors were provided closer attention for the discussion on the impacts of hierarchy as well as statuses of economic resilience of the fishers. The responses of the fishers on their pathways to transitions, adaptations as well as the importance provided to ecosystem sustainability were interestingly found to be unrelated to their hierarchical statuses (e.g., owners or labourers) or the craft-types operated (non-motorised or motorised). The discussions on the same largely are also a reflection of the cumulative inter-generational transfer of fishing knowledge and experiences (e.g., importance to fish stock preservation, use of improvised traditional methods to identify fish accumulation zones etc.).

4.1 Identification of the STCs from Ground Surveys

Figure 5 shows the relative influence of the five socio-technical constraints (STCs; levels of hierarchy, transitions, adaptability as well as resiliencies with respect to economy and marine ecosystem) on the overall use of the MFAs among all the four classes of stakeholders considered in the present study for the southern Odisha districts. It is evident that there are differences in the structure and intensity of operation of these five constraints as observed in Fig. 5a–d.

Among the six FLCs, the highest sum of scores was obtained for Chandrabhaga FLC, followed by Penthakata FLC (Fig. 5a–d). These two FLCs also recorded the highest number of fishers across all the four districts, who were able to both access and use the MFAs. Correspondingly, the relative distributions of the scores across all the 5 STCs were second lowest for the Puri district indicating lower constraints on the usages. Comparable scores were obtained for the rest of the four FLCs investigated, i.e., Noliasahi and Kharinasi FLCs (Jagatsinghpur and Kendrapara); Markondi and Ramayapatna FLCs (Ganjam). However, interestingly, the relative distributions of these scores across STCs of the FLCs showed differences at district levels. Kendrapara showed the lowest distributions implying the low influence of constraints on the fishers. Furthermore, the distributions within the 5 STCs also seemed uniform among these fishers. At the district level, the STCs seemed to influence the fishers of both Jagatsinghpur and Ganjam comparably with varied relative distributions of the scores across the 5 STCs. These results suggest that there is a need to examine the relative roles of STCs themselves in accessing/using the MFAs. The results of this investigation are detailed in the section below.

4.2 Assessment of the Roles of the STCs among Different Categories of Fishers

Figure 5e shows the relative scores for different categories of fishers evaluated over the five STCs on a scale of 0 to 5. The higher scores indicated a higher degree of influence of the STCs on the fishers' approach to the fishing activity.

In the case of the owners of fishing crafts, it is evident from the field survey that constraints such as hierarchy, adopting new transitions pathways as well as emphasis on economic resilience impacted the fishing behaviour and the usages of fishery advisories. Less emphasis was given to adaptation transformation to the use of new technologies as well as pursuing sustainable fishing practices In contrast the fishing labourers considered the ecosystem-based fishing

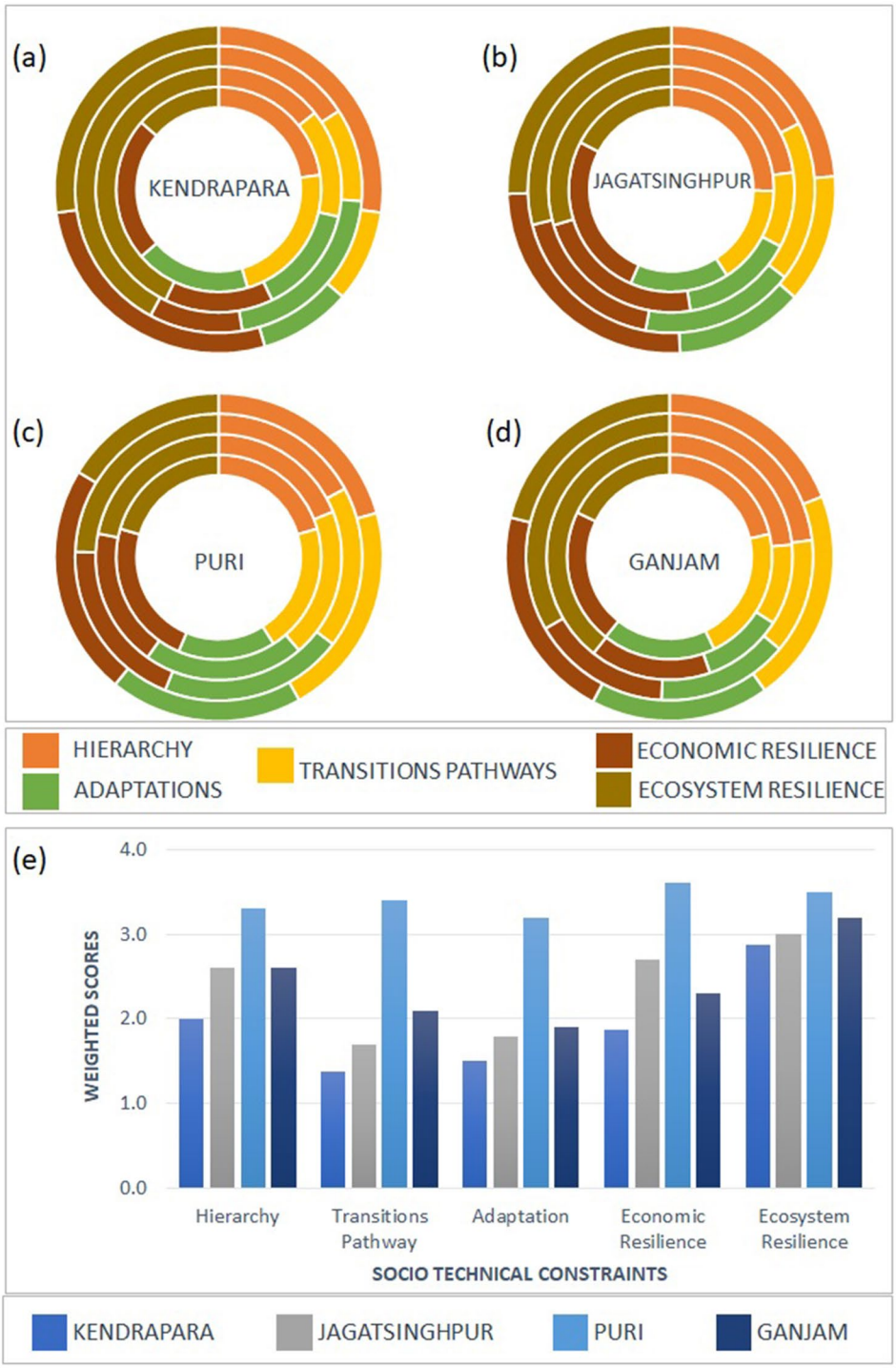

Fig. 5 Differences in the sum of scores for the five socio-technical constraints (STCs) towards the use of Marine Fishery Advisories (MFAs) in southern Odisha as quantified from the survey. **a**–**d** Represent the relative distributions of the scores across the different districts of Odisha and **e** shows the overall sum of scores for the four districts as per the six FLCs studied

approaches as significant factors which influenced their existing fishing methods, stressing on the need for adaptative co-management to tackle the low stock availability in the recent years.

These two contrasting scenarios impact the rates of usage of technology-derived advisories for locating the PFZ. For example, while the owners placed greater emphasis on the use of MFAs as means to achieve higher yields of fish, the labourers stressed on their relevance to lowering the search times and lower consumption of fuel. However, achieving economic resilience in fishing takes precedence, in connection with their higher capital investments and operating costs of crafts as well as labour charges, especially in a post-pandemic scenario (Kundu and Santhanam 2021b). However, the economic resilience here is not inclusive of the goals to achieve environmental

sustainability, rather stressing on the financial statuses alone. In contrast, the non-owners and fishing labourers, perceive economic resilience as inclusive to environmental resilience. To this effect, they prefer the use of traditional fishing grounds, where the yields are lower but assured over longer periods of time. These classes of the fishers hence perceive the use of MFAs quite differently.

Among the non-motorised categories, the lower scores for STCs were observed related to the preservation of the ecosystem services in terms of stock preservation and adopting sustainable fishing practices. Despite their low turnovers and less profits, the non-motorised craft fishers equated the use of non-motorised crafts and the traditional gears to higher stock preservation and low impact on the environmental quality during the interviews which is an interesting observation. These perceptions are shared by some of the motorised fishers as well; thus, the STCs towards achieving economic resilience and environmental sustainability equally influenced the manner in which the MFAs are assimilated among the motorised fishers.

4.3 Study of the Internal and External Factors Which Transformed into STCs at Local-Scales

Table 2 summarises the transformative potentials of the various local-scale factors presented in the above sections into the actual STCs for usages among the fishers. These factors can be considered as the causative factors limiting the successful assimilation and the usages of the MFAs.

It was observed from the interviews with the fishers that the internal factors associated with hierarchical economic, social as well as environmental factors related to marine fishers were largely responsible for the assimilation of MFAs (which were represented in Fig. 3). As shown in Table 2, local-level factors not restricted to only the non-availability of smartphones, but also the medium for reception such as

Table 2 Local scale factors emerging from qualitative studies that transform into socio-technical constraints (STCs) for the usage of marine fishery advisories (MFAs)

Socio-technical constraints (STCs) identified	Qualitative observations from the ground-level surveys that correspond to factorwise STCs
Hierarchy	Castes within village is prevalent and influence the ownerships of crafts
	Education restricted to secondary level in most respondents, did not impede assimilation of PFZ information
	Influential persons were able to obtain loans easily and invested more capital into fishing enterprise
	Provisions of "fishery Sim cards" (FSCs) to fishers from a private telecom company were arbitrary and offered to fisher representatives. These individuals further distributed them among selected fishers largely based on the perceived levels of usage for the fishers as described during the field survey. As a result, mostly fishers with mobile phones received them, but not distributed amongst the others who did not possess a mobile phone at the time of distribution or were not aware/present during the time of distribution of the FSCs. This led to inequitable distributions without sustained usages in the post-distribution period
Transition	Despite possessing the FSCs, which are available to some fishers, they did not show interest in using the PFZ advisories over their traditional knowledge of the PFZ areas (perceived to be highly reliable)
	Co-instrumentation lead to successful complementary use of MFAs to improve the yields per trip
	Infrastructure and co-facility creation are necessary steps in transitioning to sustainable fishing
Adaptation	Use of new technology such as underwater camera, bamboo stick apart from traditional knowledge was rated more useful to the actual use of MFAs
	Types of craft/gear used in fishing and its seasonal changes in the range of fishing activities were not optimised towards the use of the PFZ information provided, making it redundant for few periods in the last 5 years
	Fishers were able to better access OSF advisories (in the form of familiar weather information) disseminated through recorded voice calls in the area and easily adapted it for planning fishing trips. In comparison, adaptation to use PFZ in the form of text and images was lesser as this was not regularly disseminated or used. As a result, the fishers' adoption of the advisories for planning the fishing operations was also either irregular or absent
	Market adaptations: adapting catches with respect to the demand side, providing value-added products etc
Economic	Investment in nets although quite costly, was provided more attention which was related to obtaining a good catch rather than adopting MFAs as means of improving the catch rates
	Total operational cost varied with seasons and could not be planned well for fishing in the PFZ areas
	Usages of MFAs to locate and harvest PFZ has not caused any significant changes to total income or profits compared to non-use of PFZ advisory
	Use of PFZ information neither alleviated the debt-status among the fishers nor helped to procure further loans facilities across all FLCs
Environment	Reduction in the amount of fuel consumed per trip was perceived to be positively related to the environmental sustainability via the changes to social cost of carbon

specialised FSCs issued influenced the non-reception and usages of MFAs by the fishers. On the other hand, despite receiving MFAs, many fishers did not utilise the same while mostly basing the identification of the PFZ on their traditional knowledge for fishing expeditions. Lack of co-ordination between developmental agencies and dissemination agencies of MFAs along with grassroots level fishery policies were found to be associated with the institutional factors in the assimilation of MFAs, while both internal and institutional factors created integrated factors which have the potential to enhance MFA usages in southern Odisha.

Among the different modes of dissemination, the limited Fishery Sim Cards and the absence of EDB/DDS increased the STCs associated with the usages. The limitation of technology due to the non-availability of remotely sensed data in cloudy weather resulted in the non-dissemination of the advisories to all FLCs. This lead to irregular dissemination and reception increasing the STCs further towards the usages.

4.4 Discussion

Socio-technical analyses are diverse and complex for different stakeholder types and the results of such studies depend on the specificity and the relevance of the factors considered for the analyses. For example, Permien and Enevoldsen (2019) identified various social constraints (i.e., building, landscape conservation areas, national parks, sports and leisure facility, landscape–aesthetical potential etc.), environmental constraints (biosphere reserve, flora and fauna habitat, natural monuments, wetlands etc.), technical constraints (infrastructure, slopes, airports, water bodies, glaciers and permanent snow etc.) to inform German wind industry stakeholders regarding the current restriction produced by socio-technical wind atlas. However, a more diverse study among multiple stakeholders is reported in Dimitrovski et al. (2021) stressing on the critical significance of multi-stakeholder engagement to understand the coastal and marine tourism sustainability in the Nordic coastal region. The present investigation adopts a moderate stakeholder engagement approach to determine the actual issues at a ground-level for the access and usage of MFAs through one-to-one interviews with respondents as well as FGDs across the four districts of Southern Odisha and six FLCs.

Normalising the levels of education, castes and profits provided the opportunity to assess the actual perceptions of the fishers with respect to their levels of transitions to new technology such as mobile phones, adaptative capacities towards usage of new scientific content of the MFAs concurrent with the importance attached to the ecosystem sustenance. The level of transitions of the FLC-wise fishers was also closely observed to be reflected on the level of adaptation for locating and using information related to fish aggregation zones apart from the use of MFAs. Interesting examples were observed in two villages in this regard, which are described here. In the remote FLC of Noliasahi (for location, see Fig. 1) hollow bamboo sticks of variable heights (2–5 m) were observed to be used as 'fish finders' during fishing expeditions by traditional craft fishers exclusively. The method used was to scout for fish aggregation zones by placing them in the water column at expected heights of fish aggregation (determined by traditional knowledge transfer and experience) with the bamboo poles jutting out of the water on the surface. The fishers put their ears close to the hollow poles and wait for the sound reflections produced by the fishes in the water column. Wherever the sound signals were strong, the area was determined suitable for laying the nets. Contrary to this traditional approach, in the village of Markondi (for location, see Fig. 1), the fishers with motorised boats adapted their methodology using modern technological aids by fixing underwater cameras on the boats to detect the presence or absence of fish aggregation during the fishing expeditions in the sea.

In FLCs where such novel technologies were not adopted, PFZ detection was simplified through cooperative communication using wireless units between fishers at the sea, engaged in active fishing. Thus, it was interesting to note that there were different levels of adaptability to technology among the different FLCs which were indicators of their socio-technical transitions towards scientific fishing. While some of these methods can be complementary to the use of MFAs, other traditional means or indigenous methods were favoured by fishers operating NM and MT crafts for their simplicity, ease of operation, and inexpensiveness. Qualitative investigation also indicates that the fishers perceived the use of such indigenous knowledge as value-addition to their enterprises, alongside offering the opportunities to contribute towards fishery stock preservation at local scales. However, they were less cognisant of the co-benefits of the usages of MFAs towards maintaining the ecosystem sustainability with reference to global climate change phenomena such as decrease in the emissions of carbon dioxide (CO_2) due to saving of diesel for relatively lesser search time.

The present study revealed that the assimilation of PFZ and OSF advisories by the Odiya fishing community was bounded by the various institutional as well as integrated factors, i.e., pertaining to the administrative policy at local to state-levels, which can complicate the challenges of overcoming the STCs detailed here. Recently, Sahu and Pradhan (2017) proposed collective action by all the fishing community as a means to remedy the various issues ranging from overfishing to mangrove protections in coastal Odisha. The STCs identified herein can offer greater insights to policy-making with respect to the craft operation to aid in this stakeholder-based approach.

Reduction in the various STCs detailed in Table 2, especially those related to transitional pathways and adaptations to MFA-based fishing effort optimisations can also lead to greater cooperation among stakeholders and hence strengthening the management efficiency, reducing the burden of the government in fisheries management associated with the sharing of management cost with the other stakeholders (Sahu and Pradhan 2017). In this way, the evolution and implementation of a Community Based Fisheries Management plan in cooperation with the government may factor in the usage of MFAs to promote cooperative fishing practices. The engagement of local communities can also be engaged as stakeholders to protect the coastal sensitive areas, e.g., marine sanctuary as well as in sustainable fishing practices (e.g., Chhotray 2016) can be planned as a bottoms-up approach with the regulatory usages of MFAs when STCs are minimised (e.g., Kundu and Santhanam 2021b).

During the survey, the fishers of Southern Odisha, who predominantly own or operate non-motorised and/or motorised crafts, summarily identified four basic challenges to an effective fishing enterprise:

1. Unpredictability in the fish yields which need innovative inventions to locate PFZ regions
2. Declining fish stocks and the need to overcome other environmental problems related to overfishing and marine pollution, which directly impacted their yields
3. Economic challenges due to cumulative impacts of intergenerational poverty attributed to debt, local effects of the pandemic and impacts of cyclone-induced flooding leading to extensive loss of crafts and gears.
4. Forsaking their fishing operations on a seasonal basis with the growing sensitivity to eco-conservation of turtle nesting and protected mangrove areas proximal to their native fishing grounds.

Under the circumstances, despite their varied socio-economic profiles, all types of fishers accepted the significance of the advisories to plan for effective fishing expeditions which will lead to sustainable fishing as well as livelihoods. However, STCs such as hierarchy, transition to new fishing technologies, adaptation to scientific fishing, achieving economic resilience while being mindful of contributing to ecosystem sustainability, hindered the best-use scenarios of MFAs.

With respect to the environmental sustainability perspective, it is important to consider the social costs of carbon (SCC) which is a direct measure of avoided social cost of greenhouse gas emissions (Clarkson and Deyes 2002; Nordhaus 2011). This value was reported by (Kavi Kumar et al. 2016) considering the provisioning, regulating as well as recreational services (in Indian Rupees per tonne of carbon dioxide; INR/tonne CO_2). Overall, the coastal and marine ecosystem services have been assessed to be to the tune of ~ 1.5 trillion INR for India; however, the average value of the provisioning services of marine fisheries alone valued as per the direct market pricing had been assessed to the tune of ~ 294.48 billion INR (Kavi Kumar et al. 2016). In terms of regulating the ecosystem services, the average benefit transfer of the services in terms of coastal protection alone (mangroves) was reported to be 693.58 billion INR on average. Carbon sequestration services including the social cost of carbon had been reported to increase the regulating values to (Nordhaus 2011; Kavi Kumar et al. 2016); ~ 1.7 times the provisioning services).

Under the circumstances, (Tummala et al. 2008) reported that the use of PFZ advisories is helpful to save 166 crore litres of diesel per annum. Considering that saving one litre of fuel can reduce emissions of CO_2 by 2.63 kg (NCAER 2015), it emerges that the corresponding base-run SCC for India from the use of PFZ using the projected estimates reported by (Kavi Kumar et al. 2016) would be to the tune of approximately INR 136.25 crores for 2025 and INR 209.73 crores for 2035.

In the case of Odisha, marine ecosystem services evaluation for fisheries is not well-constrained in terms of SCC although the direct protection benefits attributed to the presence of mangroves in Bhadrak, Kendrapara, Jagatsinghpur (in areas affected by the 1999 Super cyclone) provided by one km width of mangroves to be Rs 9,75,800/- (USD 23,233; Das 2009). However, the reduction in the STCs reported herein will have a direct impact on the increase in the SCC as well as the economic benefits for both provisioning and regulatory services. Thus, the reduction in STC is well correlated with SCCs and the value of avoided damages as a result of a unit reduction of carbon dioxide or its equivalent emissions and hence positively impacting the environment.

5 Conclusions

The present investigation helped to establish the socio-technical constraints with respect to the assimilation and usages of the MFAs, especially the PFZ advisories for marine fishers of the Southern Odisha. A profit-based approach to achieve economic resilience among motorised fishers was observed to correlate with a low STC scenario, whereas the higher usages of MFAs can potentially threaten sustainable yields due to lesser fish stocks in the short-term. Such as trend can heavily disadvantage the non-motorised fishers, who stressed more on maintaining ecosystem sustainability through subsistence fishing. The socio-ecological system services can be strengthened by accounting for the STCs with respect to regularised use of MFAs at local levels, which can be correlated directly with the Social Cost of

Carbon (SCC) assessment. Taking cognisance of the trends in the STCs, policies must be evolved with respect to stakeholder involvement in optimising craft and gears operations and thereby regulating an SCC in which the use of scientific advisories will play a major role.

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Data Availability Data archiving is not mandated but data will be made available on reasonable request.

Declarations

Conflict of Interest The authors declare no conflict of interest.

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