APPLICATIONS OF GIS MAPPING IN MARINE FISHERIES

Abstract

Geographic Information Systems (GIS) mapping plays a crucial role in fisheries management by providing tools to gather, analyze, and visualize spatial data related to fish stocks, fishing activities, and the marine environment. GIS can be used to assess the distribution and abundance of fish stocks. It helps fisheries managers understand where different species are located and how their populations are changing over time. This information is essential for setting catch limits and sustainable fishing practices. GIS allows for the mapping of critical fish habitats, such as spawning grounds, nurseries, and feeding areas. Identifying and protecting these areas is vital for the long-term health of fish populations. To implement GIS mapping in fisheries management, agencies and organizations collect and integrate data from various sources, such as satellite imagery, fishery surveys, vessel monitoring systems, and environmental sensors. The use of GIS technology helps improve the effectiveness of fisheries management practices, ensuring the sustainable use of marine resources.

Keywords: Geographic information system, GIS mapping, Spatio-temporal distribution, Marine fisheries, Resource management

Author

Susmita Jana
Department of Fisheries Resource Management
Faculty of Fishery Sciences
West Bengal University of Animal and Fishery Sciences
Kolkata, West Bengal, India
zmouaayu999@gmail.com

I. INTRODUCTION

In recent decades, marine fisheries are exploited due to technology advancements, population growth worldwide, and increased demand for fish. Marine fisheries are simultaneously working to achieve the level of sustainability that will ensure their long-term survival while also dealing with problems like overfishing, overcapitalization, stock depletion, bycatch and discards, IUU fishing climate change, fishing conflicts, pollution, and so forth. (Battista and Monaco, 2004; Jentoft *et al.,* 2007; Aswani and Sabetian, 2010; Dineshbabu *et al.,* 2015; Dineshbabu *et al.,* 2016). Fisheries managers have had to deal with a growing number of challenging issues as a result of both man made and natural disruptions, and, therefore, they must gather and combine a significant amount of data from numerous sources in order to make management decisions. Geographic information system (GIS) applications in marine fisheries management have been created in this need. Different types of geographic information, including digital maps, aerial photos, satellite images, and GPS data, can be integrated by using geographic information systems (GIS).

Previously, mapping the resource distribution from large data sets was difficult. The insufficiency of standard cartography methods for mapping and recording resource distribution for a big geographical region with rich resources leads to the development of novel mapping methods for huge data interpretation. Later, developments in computing, computer graphics, and computer-aided design helped to improve cartography so that it could be mechanised and utilised. During the 1970s, many institutions, notably Harvard University's SYMAP initiative, as well as GRID and GEOMAP, committed substantial resources in additional computer mapping research (Tomlinson, 1989). The first private, commercial software businesses introduced GIS for the huge potential of this technology in the 1980s (Meaden, 2004). According to Rahel (2004), GIS is a collection of computer hardware, software, data, and personnel used to gather, store, update, manipulate, analyse, and display spatially related information. Data for any issue, region, or time period can be collected and entered into the system. GIS-based mapping can address difficulties such as the intensity of fishing pressure, the sensitivity of ecosystems and species in deciding on the introduction and reduction of fishing fleets, the rationalisation of fishing operations, seasonal and geographical closure of fisheries, and so on. The majority of GIS output is in the form of maps, although it can also be in the form of tabular, statistical, or graphical representation. GIS is used to explore new ideas and solve geographical problems of complicated environmental relationships through graphical illustrations, which aid managers in decision making (Dineshbabu *et al.,* 2016).

II. GIS APPLICATION IN MARINE FISHERIES

Finding the spatio-temporal distribution of fish species offers basic data needed for stock assessment, which is then necessary for developing plans for fishery management and making decisions based on geographic information systems (Abdul Azeez *et al.,* 2016). Stock assessment is pre-requisite for managing and conserving the marine living resources. Coastal waters (up to a depth of 50 m) contribute the majority of the current fish production of the country (Nayak, 2004). Spatio-temporal constraints in those areas make it more difficult to analyse fishery data. Without spatial conceptions, only temporal study will produce inappropriate results, and vice versa (Zheng *et al.,* 2001).

The prevalence of spatio-temporal variability is a significant barrier to GIS applications in the maritime environment. Fishes having their patchy distribution on spatial scale makes a hindrance towards its management. Due to dynamic nature of marine environment, the spatial and temporal patterns of life histories of fish species can differ considerably. Fish species are capable of migrating both vertically and horizontally in the water column (Meaden, 2004).

An essential tool for determining fish populations, locations, and habitat utilisation is the trawl survey (Stoner *et al.,* 2001). Maps of the commercial trawling grounds around the Indian coast are being developed in order to determine the degree of fishing activity from various states in relation to their territorial waters as well as the extent of trawling activities along the Indian coast (Dineshbabu *et al.,* 2019). As a result of technical advancements, most of India's larger fishing boats are outfitted with advanced technology including global positioning system (GPS) that not only allows them to operate at greater depths and locate fish with greater efficiency but also provides the detailed data on fishing operations.

When fishing operations lasted more than a single day, the spatial or geographical component of the fisheries data became more significant. Lack of such information frequently results in erroneous estimations and false interpretations of species distribution (Meaden, 2004). It is challenging to gather information related to fisheries management for the marine environment, particularly in offshore areas. Tropical marine fisheries are very diversified in nature constituting many sectors, scales, gear types, locations, mobility and target species within a single fishery. Applications of GIS for fisheries management have become more challenging considering the heterogeneity of the world's fisheries (Meaden, 1996).

Fishery managers and policy makers use geographic information systems (GIS) extensively as proactive tool in decision making. Globally, spatial planning and the application of GIS to different stages of fisheries management have been in use for more than ten years; however, in India, the use of GIS in fisheries seems to be limited to inland water bodies and aquaculture. Fishery managers and policy makers in the marine fisheries sector have minimal opportunity to perform on-site monitoring of commercial fishing grounds, unlike in agriculture and confined water bodies.

The research and monitoring organisations collect very accurate data based on the distribution of the fishery from the landing pattern and carry out in-depth exploratory surveys to validate the data collected from different sources and suggests the proper management strategies when the depth zone for marine fisheries was limited to 30 metres. The assumptions on distribution of fishery became very difficult since fishing fleets operated in depths greater than 30 to 50 metres and fish were being taken from a vast array of fishing areas (Devaraj and Vivekanandan, 1999). Due to the high cost, it is difficult for government organisations to monitor fisheries from these areas through routine exploratory surveys. A comprehensive understanding of distribution and abundance of numerous marine fishing resources will be available to researchers and decision-makers as all mechanised fishing boats are equipped with GPS, making it easier and more accurate for the fishermen to collect the data. This will lead to meaningful fishery management policies that can be made acceptable to the fishermen as they are also collaborators in this participatory research (Dineshbabu *et al.,* 2016).

III. PARTICIPATORY GIS

The terms "public participation GIS" (PPGIS) or "participatory GIS" (PGIS) have been developed to describe the use of GIS with active participation of fishermen or stake holders. Through this, the stakeholders are actively engaged in planning and decision-making fisheries with the use of their traditional knowledge and expertise (Dineshbabu, 2013). Application of PGIS was suggested as a useful method for generating spatial databases on natural and socioeconomic resources with the involvement of fisher communities in India.

Participatory GIS concept in fisheries was first reported from Canada where geospatial data exchange between harvesters and governmental organisations was used to map the resources of Bonavista Bay, a popular fishing spot in Newfoundland (Macnab, 2002). In India, participatory GIS first set out in Karnataka coast where commercial fishing vessels collected the geospatial data on fishing, catch and fish samples. The collected data were then analysed by fishery and GIS experts of the research organization for making various management and conservation tools in this region. The study revealed details about a special habitat with reef species off the coast of Karnataka, which urgently needs to be conserved (Dineshbabu *et al.,* 2012).

The spatial and temporal data of catch from trawlers represents the distribution of resources virtually in the areas used for commercial fishing. With the active involvement of the fisherman, this information may be converted into a database that can be utilised for establishing management strategies (Dineshbabu *et al.,* 2016).

The government agencies responsible for making decisions about fisheries management had to rely on information from other sources, which frequently did not accurately reflect the state of the sea, unless the fishermen themselves chose to provide the information to the government authorities. The precision of the data used for the study determines the reliability of predictions and any associated fishing limits (Caddy and Carocci, 1999). Fishermen are the major stakeholder; therefore, it is the responsibility of the fishermen to assist the researchers and policy makers with the most precise sea truth data so that they can come up with the most appropriate regulations. As a result, the fishermen will be able to use their traditional knowledge and current fishing information to effectively influence decision-making in fisheries management and fishery resource conservation measures (Dineshbabu, 2013).

The results of the participatory trawling experiments in Gujarat, which were carried out by ICAR-CMFRI and ICAR-CIFT with the active participation of fishers revealed that fishers are more willing to work with researchers and are more concerned about the long-term viability of marine fisheries. The scattered and numerous spatio-temporal data based on geographic information can help in developing strategies for the enhancement of the fisheries in terms of fishing pressure, fishing ban etc. It is also possible for policy makers to identify and designate fishing grounds as “no fishing zones" and "marine sanctuaries" using spatio-temporal data on the distribution of fish (Dineshbabu *et al.,* 2012).

IV. SPATIAL TECHNOLOGIES APPLIED IN FISHERIES

Remote sensing (RS), Geographic Information Systems (GIS) and Global Positioning Systems (GPS) are widely used technologies for marine spatial planning. Remote sensing (RS) is acquiring the information of an object or phenomenon without making physical contact with the object. GIS enables the storage, management and analysis of large quantities of spatially distributed data collected through remote sensing. GPS is a satellite-and ground-based radio navigation system that enables the user to determine very accurate locations on the surface of the earth (Dineshbabu *et al.,* 2016). The market offers an extensive variety of softwares, many of them are proprietary, closed source and quite expensive. A variety of open-source programmes has been created including GRASS GIS, gvSIG, ILWIS, JUMP GIS, QGIS, SAGA GIS (Dineshbabu *et al.,* 2016).

V. GEOGRAPHIC INFORMATION SYSTEM (GIS) MAPPING IN FISHERIES

The majority of the early work on GIS was done by Kapetsky *et al.* (1987), with the first application appearing in the mid-1980s in the Gulf of Nicoya on the Pacific coast of Costa Rica. According to their observation, remote sensing and geographic information systems are economically viable for managing small water bodies for fisheries and aquaculture in north-east Zimbabwe. Caddy and Garcia (1986) addressed the importance of fisheries thematic mapping in the context of fisheries in general and the significance of resource mapping, particularly in the new exclusive economic zones of developing countries. They also recognised resource mapping as an essential preliminary stage to fish stock assessment, research vessel surveys, statistical and information-gathering systems, the preparation of fisheries resource management plans, coastal planning, and environmental impact assessments.

Fisheries and aquaculture-related GIS applications expanded in the 1990s, covering a wide range of areas including atlases, habitat mapping, productivity of marine ecosystem mapping, fisheries management, and human influences on fishery ecosystems. According to Meaden and Aguilar-Manjarrez (2013), in order to balance inland fisheries and aquaculture, around half of the GIS work went towards marine fishery challenges. Kraak and Ormeling (1996) employed the proportional mapping technique to map the fish catch per area in African countries with bigger circles indicating greater catch.

Using geographic information systems and statistical techniques, Wang *et al.* (2003) investigated the spatio-temporal distribution patterns of cuttlefish abundance and the relationships between their abundance and environmental variables in the Atlantic coast and surrounding waters. They noticed that the high abundance centre in offshore deep water changed from south to north during warm winters. Mature females and juveniles of *Octopus vulgaris* using trawl surveys were studied and mapped using geostatistics and spatial indicators to characterise the key elements of the spawning and recruitment stages from 1998 to 2003 off southern Morocco (Faraj and Bez, 2007). Spatial patterns of the spawning and recruitment phases could be distinguished clearly: juveniles were more dispersed in coastal areas, less geographically scattered, more anisotropically distributed, and patchier. They also found, the spatial pattern of the Dakhla stock was distinct from that of the other stocks of the same species in other habitats.

Meaden and Aguilar-Manjarrez (2013) noticed that modifications in the source of fish would continue to have a major and regionally variable impact on the marine and other aquatic habitats and opined that by using GIS and remote sensing techniques, such effects could be controlled. Spatial and temporal distribution patterns of larval sciaenids in relation to biotic and abiotic factors in the estuarine system and adjacent continental shelf off Santos, Southeastern Brazil showed the sciaenids larvae were widespread on the continental shelf and most abundant in March, and least abundant in September (Porcaro *et al.,* 2014). According to Cheng *et al.* (2016) the spatio-temporal distribution of *Oncomelania hupensis* was significantly influenced by natural factors like rainfall, land surface temperature, vegetation, and distance from water sources of Dongting Lake in China.

The dynamics of catch, effort, and catch per unit effort distribution patterns were emphasised by a GIS-based spatio-temporal analysis of yellow fin tuna (*Thunnus albacares*) caught in the eastern Indian Ocean near Sumatera. This analysis additionally demonstrated the yearly variations in geographic distribution and fishing pattern during 2014-2018. Fishing activity was seen in its highest concentration in 2014 and at its highest level of dispersion in 2017 (Gaol *et al.,* 2020).

VI. GIS APPLICATION IN INDIAN MARINE FISHERY

GIS enables the integration of several layers of data, such as bathymetry, sea surface temperature (SST), catch, catch per unit effort (CPUE), etc., which is not possible with conventional techniques. However, compared to terrestrial GIS, marine GIS applications (Valavanis, 2002) and related literature are considerably less developed (Hill *et al.,* 2005). GIS application has been far slower in India than in other countries. Aquaculture site selection and nearshore and inland fisheries management were the only GIS applications initiated in India in the beginning (Gupta, 1995; Salam *et al.,* 2003; Karthik *et al.,* 2005). However, over the years, GIS applications in marine fishery has considerably been progressed.

Selvaraj *et al.* (2007) analysed and visualized the distribution patterns of demersal fish in the northwest coast of India, which ranges from 17°45' to 23°00' N, in terms of both space and time. Seasonally, by aggregating data from 1997 to 2000, the catch per unit effort (CPUE) of threadfin breams (*Nemipterus* spp.), carangids (*Decapterus* spp.), lizardfish (*Saurida* spp.), catfish (*Tachysurus* spp.), and dhoma (*Johnius* spp. and *Otolithes* spp.) were mapped. Three seasons of CPUE distribution maps were created: pre-monsoon, monsoon, and post-monsoon. According to the spatial maps the occurrence of these five species was primarily shown in deeper seas along the Gujarati coast.

Mapping of fishery resources and monthly assessments of the catch, effort and species diversity of commercial catch and discards in trawling grounds along the Malabar-Konkan coast was done by Dineshbabu *et al.* (2011) during 2008-2009. Spatio-temporal distribution and abundance of commercially lesser known species was done by Dineshbabu *et al.* (2012). The study recommended the spatial and temporal limitations on fishing efforts in the regions and seasons with high rates of bycatch of juveniles and non-commercial organism based on the pattern of distribution and richness of marine resources for the sustainable marine fisheries along the Malabar and Konkan coast.

GIS mapping of the trawling grounds of Mangalore in 2008-2009 showed that the operational depth ranged from 5 to 167 metres. The fishing fields at 30 m off Mangalore to Panaji and the fishing grounds at 100 m off Malpe to Karwar were the sites of the most extensive trawling operations. The majority of fishing activity is confined within a 150 m depth zone, with the majority of extension occurring south or north of the shore (Dineshbabu *et al.,* 2015).

GIS based mapping of spatio-temporal distribution pattern and abundance of different life stages of ribbonfish, *Trichiurus lepturus* along Saurashtra coast showed that juveniles were found to be more numerous along the south, whereas subadults and adults were found in greater numbers in the waters off both the south and north coasts (Abdul Azeez *et al.,* 2016).

Bhendekar *et al.* (2018) reported spatial distribution and population trend of Indian squid off Maharastra during 2017-18. The Indian squid captured from trawl nets, both monthly catch and catch per hour, peaked immediately following the monsoon ban in August through October in the area between 15^0 N and 17^0 N latitude at a depth of 15 to 60 m off south Maharashtra. The landing reaches its second peak in the summer in the months of March and April.

GIS and its applications in marine fisheries conservation and management in Karnataka was done by Biswas *et al.* (2018) in the fishing grounds between 72°E to 76°E longitude and 10°N to 18°N latitude and bathymetric depth of the fishing grounds are minimum 10 m to maximum 150 m operated along the coast during 2010-2015. The study demonstrated that GIS-based studies aid in the development of management tools for limiting fishing effort, avoiding juvenile exploitation, reducing trawl bycatch, protecting biodiversity, identifying key ecosystems, defining fishery "refugia" and defining Marine protected areas (MPAs).

Spatio-temporal distribution analysis of smooth blassop (*Lagocephalus inermis*) using fishery and GIS was done by Saha *et al.* (2019) in south-eastern Arabian Sea from 2015 to 2017. The species abundance was analysed both spatially and temporally, with results ranging from 7 to 277 kg/hr (catch per hour) at depths between 20 and 100 m. Juveniles tended to congregate in clayey areas closer to the coast.

A study on spatial and temporal distribution of cephalopods off veraval coast, Gujarat was done by Tehseen *et al.* (2019), to understand promising fishing grounds of commercially important cephalopods using GIS mapping. The favourable fishing grounds for cephalopods were in the south off the coast of Daman and the Gir-Somnath district, at depths up to 30 m, which led to moderate to high CPUE throughout the year.

Bycatch from mid-water trawlers operating in the Arabian Sea off the northwest coast of India varied considerably in terms of its seasonal CPUE, with the highest values occurring during the post-monsoon period and the lowest during the pre-monsoon. In comparison to inshore waters, offshore waters showed lower minimum bycatch rates (Azeez *et al.,* 2021). Study on spatio-temporal analysis of commercial multiday trawl bycatch along the coast of West Bengal, India was done by Samanta (2021). The GIS based predictive map showed that maximum fishing operations were carried out in the south-east direction of the coast at a depth range of 25-30 m. Both overall discards per haul and discards per hour were maximum within 20 m depth in shrimp trawl; whereas in fish trawl both were beyond 20 m depth.

VII. CONCLUSION

GIS promotes an ecosystem-based approach to fisheries management, where the entire marine ecosystem is considered in decision-making. This approach takes into account the interdependence of different species and their habitats. GIS mapping plays a crucial role in marine fisheries by facilitating data collection, analysis, and decision-making processes. It helps to promote sustainable fishing practices, protect marine habitats, and ensure the long-term sustainability of fisheries resources.

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