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ARTICLE

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SUSTAINABLE GANGA FISHERIES FOR LIVELIHOOD AND ECONOMIC EMPOWERMENT

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This study examines the ecological and socio-economic dynamics of fisheries along the River Ganga, which spans over 3,700 km and encompasses five Indian states. A total of 190 fish species were recorded, with spatial variations in species diversity and catch patterns. Trends indicate a decline in major carps and catfishes between 2017 and 2019, followed by a gradual recovery, supported by interventions such as river ranching. Socio-economic analysis revealed increased fisher income and dependence on fisheries. The findings highlight the role of sustainable fishery practices under the Namami Gange Programme in enhancing ecological health and empowering riverine communities through the Arth Ganga framework.

Introduction

The Ganga River Basin, stretching over 2,500 kilometres, is one of the largest and most ecologically significant river systems in the world[1]. As a significant source of livelihood, River Ganga is the culturally significant and a central focus for many social and religious traditions in the Indian subcontinent[2,3]. Covering nearly 26% of India's geographical area and supporting around 43% of its population, the basin spans 11 states and sustains an estimated 10 to 13 million riverine fishers across thousands of fishing villages[4]. From its glacial origins in the Himalayas to its deltaic expanse into the Bay of Bengal, the Ganga hosts a diverse range of habitats, glaciers, mountain streams, floodplains, wetlands, and estuaries, making it a hotspot for aquatic biodiversity. The first comprehensive report on Gangetic fish fauna was documented by Hamilton in the year 1822[5], describing a total of 260 fish species, but in the year 2012, Sarkar et al.[6] recorded only 143 species. A new record of fish diversity has been recently reported, with 190 species recorded from the River Ganga, including the endangered Ganges River Dolphin (*Platanista gangetica*)[7]. Fishing remains the primary occupation for many riverine communities along the Ganga, contributing to nearly 70% of total household income in several stretches[8]. It plays a pivotal role in ensuring food and nutritional security, especially among rural and marginal populations. However, this lifeline is under growing threat. Anthropogenic pressures, such as habitat fragmentation, over-extraction of water, pollution from untreated sewage and industrial effluents, and unsustainable fishing practices, have led to significant declines in fish stock and aquatic biodiversity[9-11].

To assess and respond to these challenges, comprehensive studies have been undertaken under the National Mission for Clean Ganga (NMCG), which emphasise the link between ecological rejuvenation and livelihood enhancement[12,13]. A recent assessment employed mixed-methods approaches, combining quantitative data collection and qualitative fieldwork, to evaluate changes in the livelihood patterns and economic conditions of Ganga fishers across multiple states. The findings underscore the continued dependence on fisheries as a stable source of income, while also highlighting areas for policy support and sustainable growth. In this context, the Arth Ganga framework, introduced under NMCG, represents a paradigm shift from project-based interventions to a people-centric,

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Fig 1. Fishing in River Ganga a. Gill net operation b. Bag net operation

circular economy model. It envisions the river not just as a cultural and ecological entity, but as a driver of economic prosperity. Central to this vision is the promotion of fisheries as a core component of enhancing livelihoods, conserving biodiversity, and managing resources sustainably.

Methodology

Survey Sites of River Ganga and Collection: River Ganga flows through the western to the eastern parts of the country stretching across 77°58′ 47.44″ E longitude to 88°30′ 37.89″ E longitude and 22°18′ 6.43″ N latitude to 31°2′ 49.31″ N latitude, travelling a vast distance of 3795 km. Nineteen different major fishing sites sprawling over four different states along the river was selected for the study. The entire course is divided into four segments the upper stretch (Harshil to Haridwar), middle stretch (Bijnour to Varanasi), lower stretch (Buxar to Godakhali) and estuarine stretch (Diamond Harbour to Fraserganj). Quarterly field surveys were performed for the collection of data within a span of 8 years from 2017 to 2025 covering approximately 2600/ km. Fresh fish specimens were collected by using local crafts and gears (Fig. 1) and kept ice-preserved for assessing ichthyofaunal diversity.

Data Analysis: The identification of the fish specimen from various sites of river Ganga was conducted based on morphometric and meristic taxonomical measures[14,15,16]. The catch per unit effort (CPUE) was evaluated as the weight or number of individual fish yielded during specified period of effort. The CPUE was estimated as follows;

CPUE = Total weight of the fish (Kg) / Time taken for harvest (hr)

Time series data analysis and future forecasting of

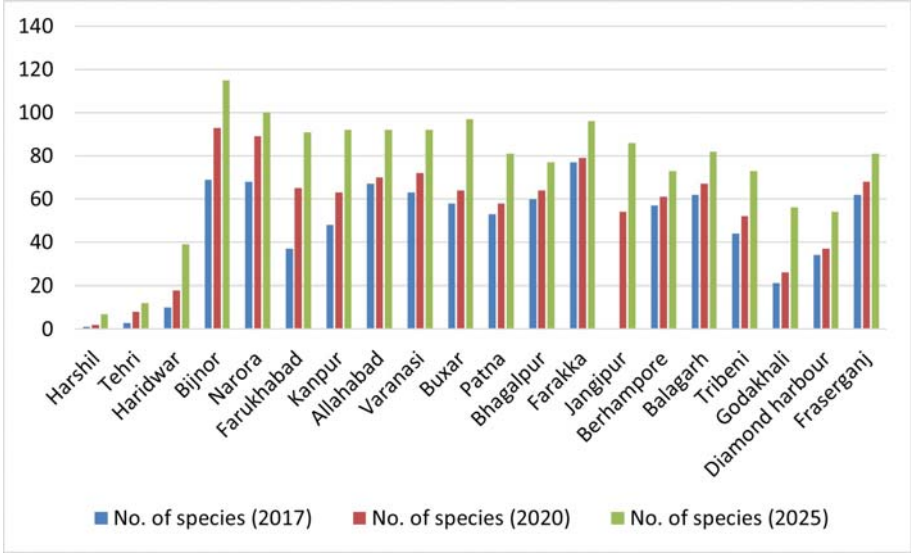

Fig 2. Number of fish species recorded from the different sampling sites of the river Ganga during 2017-2025

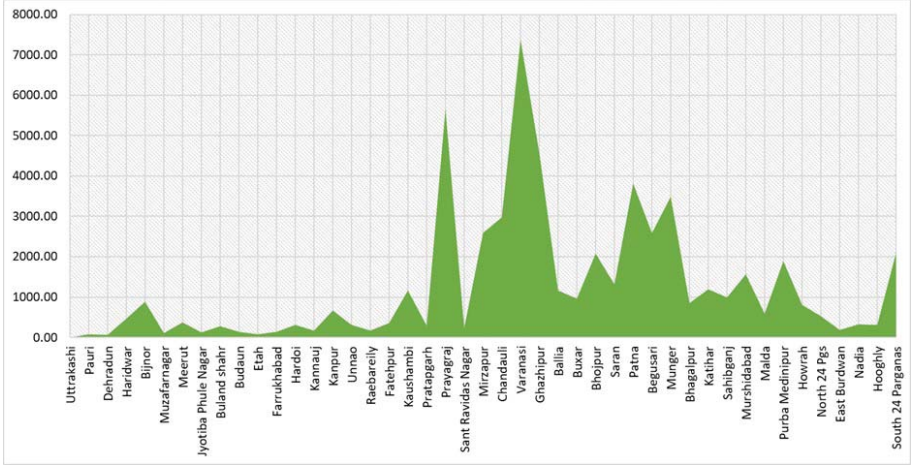

Fig 3. District-wise annual fish catch landings (tonnes) of river Ganga

fish catch trend analysis done by using Seasonal Autoregressive Integrated Moving Average (SARIMA) modelling[17].

Socio-economic Data Collection: To assess the socio-economic status of fishers dependent on the Ganga River, ICAR-CIFRI conducted a comprehensive study along 3,795 km of the river, covering 379 fishing villages across 47 districts in Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal. The study employed both qualitative and quantitative methods, guided by the core principles of participatory approaches. Data were collected from 684 fishers using a multi-stage stratified random sampling technique. Primary data were gathered through direct observations, household surveys, focus group discussions, and semi-structured interviews, while secondary sources supplemented the findings. A semi-structured interview schedule was designed to capture socio-personal and socio-economic variables, and the collected data were subjected to statistical analysis[18].

Results

Species Diversity: A total of 190 fish species (182 indigenous and 8 exotics) belonging to 133 genera, 62 families, and 23 orders from the upper Ganga (Harsil) to the river mouth of the Hooghly estuary (Fraserganj) were recorded from 2016 to 2019 through systematic re-explorations (Fig. 2). Among the recent 190 recorded species highest diversity was found at Bijnor and lowest at Harshil. When comparing this period with previous years, a gradual increase in species diversity was observed. Fish production in the Ganga has witnessed a gradual increase over the decades. The dynamics of the riverine output have also been significantly impacted by a noticeable decrease in major carp landings and an increase in exotic species. Among the exotics, the upper, middle, and lower stretches were dominated by tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*). Significant dominance of major and minor catfish was found, followed by small native fishes. The most diverse orders are Cypriniformes (barbs and danio), Siluriformes (catfish), and Perciformes (perciform fish), comprising about 50%, 23%, and 14% of the total fish species, respectively.

Fish Catch Trend: Fish catch along the Ganga River varied significantly across regions. In the present study the annual catch recorded from 45 Ganga basin districts of India and presented in Fig 3. In the upper stretch, Haridwar recorded 470 tonnes. The middle stretch in Uttar Pradesh was most productive, with Varanasi reporting 7,380 tonnes, Prayagraj 5,657 tonnes, and Ghazipur 4,566 tonnes. In Bihar, Patna and Munger recorded 3,806 and 3,492 tonnes, respectively, while Jharkhand's Sahibganj contributed 998 tonnes. West Bengal's South 24 Parganas and Purba Medinipur accounted for 2,095 and 1,898 tonnes respectively. Indian Major Carp (IMC) production has shown an encouraging trend, especially in Uttar Pradesh and Bihar. At Prayagraj, the catch rose to 14.59 tonnes in 2022–23, and in Varanasi, IMC landings increased from 1.959 to 4.09 tonnes, a 41% jump. Patna's IMC catch increased from 0.38 to 0.49 tonnes, attributed to river ranching efforts. In Uttarakhand, Tehri recorded the highest IMC catch at 13.62 tonnes. Prayagraj had the highest IMC share (21%) in total fish landings among all middle-stretch sites. These steady increases indicate a positive growth trajectory, and with sustained efforts such as ranching and conservation, IMC landings are expected to rise further. Between 2017 and 2024, there has been a visible upward trend in fish catches, particularly in the middle and lower stretches of the Ganga River.

To demonstrate possible future trends, time series data from two key landing centres: Patna (for major inland species) and Farakka, Godhakhali, Diamond Harbour (for Hilsa) have been analysed. These examples serve to demonstrate how available time series data can be utilized to forecast future potential across the Ganga fisheries. In Patna, SARIMA modeling shows a promising outlook for Indian Major Carps and major catfish (Fig. 4). IMC landings are expected to rise from 1.23 tons in 2024 to 1.83 tons in 2026, with narrow confidence intervals (1.63–2.03 tons) indicating high prediction reliability. Major Catfish are projected to increase from 7.29 tons to 7.93 tons during the same period. Minor Catfish show an increase from 6.06 tons in 2024 to 6.36 tons in 2025, followed by a slight dip to 6.13 tons in 2026, still within stable predictive bounds. These forecasts suggest steady growth in inland fish resources, with potential for enhanced resource planning and livelihood resilience.

Hilsa landings at Farakka, Godhakhali, and Diamond Harbour grew from 38.48 tonnes in 2019 to 45.75 tonnes in 2023, a 19% increase in five years. Forecasts for 2024 and 2025 suggest continued growth, with predicted landings of 46.36 and 45.29 tons, respectively. The forecasted values have narrow confidence intervals, particularly in 2025 (45.16–45.42 tons), pointing to high reliability and low variability. This trend reflects stable and promising prospects for Hilsa fisheries in the lower Ganga.

The time series analysis from these key landing centres reveals an overall positive trajectory for major fishery groups, including Indian Major Carps, catfishes, and Hilsa. Based on this evidence and model-based

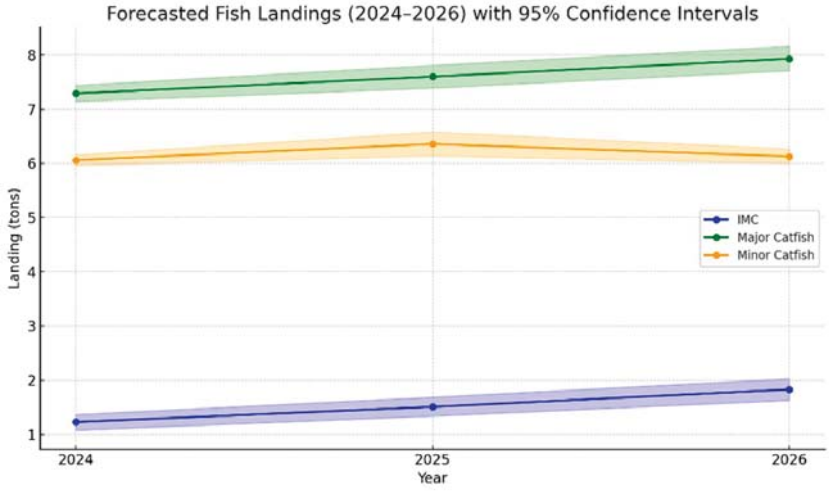

Fig 4. Forecasted fish landings based on SARIMA time series modelling

Fig 5. Fish catch (Kg/fisher/month) along the river Ganga across the various stretches

forecasts, we can expect a sustained increase in fish production from the Ganga by 2030. This growth holds significant promise for enhancing livelihoods and boosting the incomes of riverine fishing communities. The upward trends highlight the impact of ecological restoration, habitat enhancement, and fishery development programs.

Catch and Income of Fishers: The average monthly fish catch per fisher exhibited notable spatial variation along the Ganga River. The lower stretch recorded the highest average catch at 305.4 kg, followed by the upper stretch at 221 kg, and the middle stretch at 197 kg (Fig. 5). The comparatively higher fish availability in the lower stretch has contributed to a stronger dependence on fishing as the principal livelihood activity among local communities, thereby reducing reliance on alternative income sources.

A comparison between the income levels of fishers in 2017 and at present shows significant growth. The upper stretch recorded a 36.94% increase in income, the middle stretch 43.7%, and the lower stretch 54.8% (Fig. 6). These improvements are linked to initiatives such as increased fishing effort, targeted conservation, species adaptation, and key policy interventions under programs like Namami Gange.

Discussion

The present study revealed a marked decline in commercially important fish species, particularly Indian major carps and catfishes, from 2017 to 2019, followed by a gradual recovery in Indian major carp landings in subsequent years. This trend aligns with recent findings indicating a significant reduction in the annual fish yield of the Ganga River during this period[18,19]. The Ganga River ecosystem has been severely impacted by anthropogenic pressures such as dam construction, pollution, sand mining, and overfishing, leading to habitat degradation and consequent declines in fish diversity and abundance[6,20]. Notably, the upstream presence of warm-water tank gobies suggests a shift in their natural habitat, possibly in response to altered hydrological conditions or rising temperatures. This shift reflects broader ecological changes affecting species

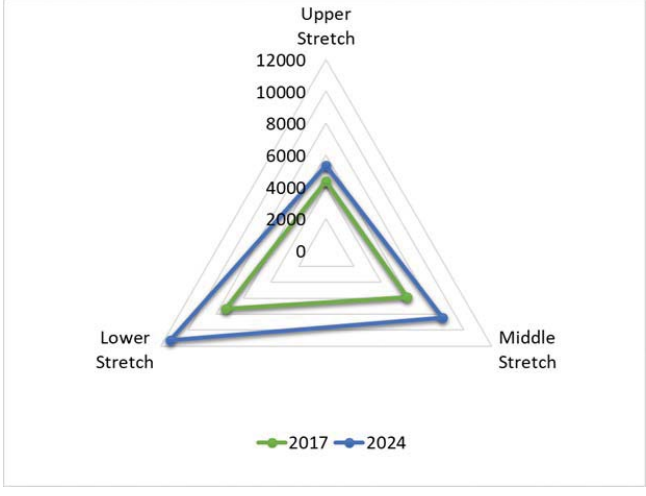

Fig 6. Comparative average monthly income of fishers

composition and distribution. Despite the complex interplay of stressors influencing fish diversity, ongoing and systematic surveys are essential. Detailed taxonomic and ecological studies are also critical to address species-level ambiguities and to support conservation planning[21]. Recent studies have highlighted changes in site-specific abundance and habitat use, emphasizing the need for focused research on critical habitats to determine species-specific vulnerabilities and to understand the effects of environmental drivers on community structure and spatial distribution. Interventions under the NMCG such as river ranching, habitat restoration, pollution mitigation, and promotion of sustainable fisheries have made measurable progress in revitalizing the river's ecological integrity. However, these efforts must be expanded and strengthened to ensure the long-term sustainability of Ganga fisheries, maintain ecological balance, and enhance the livelihoods of dependent communities.

Conservation Measures

Fish ranching and habitat restoration are two recent initiatives that have been successfully demonstrated. For instance, the ICAR-Central Inland Fisheries Research Institute (CIFRI) released advanced fingerlings into the Ganga to bolster fish populations. Such initiatives aim to rejuvenate fish stocks and support the livelihoods dependent on them. The Namami Gange Programme by the Indian government has played a crucial role in addressing the ecological issues facing the river by focusing on pollution abatement, biodiversity conservation, and community engagement, facilitating the revival of several fish species.

To ensure sustainable fisheries in the Ganga:

- *Strengthen Monitoring*: Regular assessments of fish populations and water quality are essential.
- *Promote Sustainable Practices*: Encouraging eco-friendly fishing methods can reduce overexploitation.
- *Enhance Community Engagement*: Empowering local communities through education and alternative livelihoods can foster stewardship.
- *Implement Policy Measures*: Enforcing regulations on pollution control and habitat protection is crucial.

Challenges and Future Directions: Despite positive trends, challenges persist. Native biodiversity is at risk from invasive species like tilapia and common carp. Additional threats come from the effects of climate change, such as changed river flows and warmer temperatures. Moreover, infrastructural developments like dams and barrages disrupt migratory pathways of key species.

Conclusion

The ICAR-CIFRI has been instrumental in translating the goals of *Arth Ganga* into action. Through annual river ranching programmes, ICAR-CIFRI has replenished depleted fish stocks by releasing native and commercially important species bred from Gangetic brooders. Awareness campaigns on overfishing, habitat conservation, and dolphin protection have engaged over 42,000 fishers since 2017. In addition, capacity-building workshops have trained fishers in climate-resilient and sustainable practices, including the use of eco-friendly gear and seasonal fishing bans to protect breeding cycles. ICAR-CIFRI has also championed sustainable aquaculture development, particularly in floodplain wetlands, through the introduction of cage and pen culture technologies. These innovations have diversified income sources, improved household resilience, and aligned traditional practices with modern ecological standards. Fishers have also benefited from skill development initiatives aimed at increasing value-addition, post-harvest management, and market linkages. The Ganga River's rejuvenation must center not only on ecological restoration but also on inclusive economic development. Fisheries, embedded in the cultural and economic fabric of the basin, represent a scalable and sustainable pathway to achieving this vision. A sustainable Ganga ecosystem can be accomplished by integrating scientific research, community participation, and robust policy frameworks. ❐

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