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ARTICLE

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# GROWTH TRENDS AND FORECASTING OF HILSA (*TENUALOSA ILISHA*) LANDING AT FARAKKA, GODHAKHALI, AND DIAMOND HARBOUR IN RIVER GANGA, INDIA: INSIGHTS USING AUTO-REGRESSIVE INTEGRATED MOVING AVERAGE (ARIMA) MODEL

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*The study modelled and forecasted Hilsa fish landings at Farakka, Godhakhali, and Diamond Harbour in the river Ganga using the Auto-regressive Integrated Moving Average (ARIMA) model. Catch from 2019 to 2023 revealed ARIMA (4,2,4) as the most suitable model, supported by the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Root Mean Square Error (RMSE), and $R^2$ (R-squared) values. Forecasts for 2024 and 2025 predicted slight declines in landings, from 46.36 to 45.29 tons. However, catch landing data are projected to increase by 14.7% in 2024 and 12.05% in 2025 compared to the average landing data from 2019 to 2023.*

**Keywords:** *Hilsa, Fish landing, Growth trends, Forecast, ARIMA*

## Introduction

Hilsa (*Tenualosa ilisha*), belonging to the family Clupeidae and sub-family Alosinae, is an anadromous fish also known as Hilsa shad[1]. Widely distributed across seas, rivers, and estuarine ecosystems in South Asia, its marine range extends from the China Sea and Vietnam Sea to the Bay of Bengal, Arabian Sea, Red Sea, and Persian Gulf. Riverine habitats include the Ganga, Brahmaputra, Godavari, Narmada, Tapti, and their estuaries in eastern and western India, as well as the Padma, Jamuna, Meghna, Karnaphuli, and other coastal rivers of Bangladesh, the Irrawaddy in Myanmar, and the Indus in Pakistan[1-3]. In terms of nutrition, Hilsa is a rich source of omega-3 polyunsaturated fatty acids, including docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA)[4-6]. Millions of people in India, Bangladesh, and Myanmar depend on the Hilsa fishery for livelihood and income with its market valued over US$2 billion[5,7]. Hilsa fisheries have a significant socioeconomic impact on the Ganga, Brahmaputra, and Meghna basins in the northern Bay of Bengal, where approximately 250 million people rely on the species directly or indirectly. In West Bengal, India, Hilsa fishing supports the livelihoods of about 0.46 million fishers. In Bengali community, the consumption of Hilsa has the traditional significance especially during festivals, religious ceremonies and weddings[6]. The global annual Hilsa catch in 2021 was approximately 0.583 million tonnes, with Bangladesh leading at 0.565 million tonnes while India produces about 0.014 million tonnes[8]. Among the major Hilsa-producing countries, Bangladesh contributes about 76% of the total, followed by Myanmar at 15%, and India at 4%, with the remaining 5% from smaller producers like Pakistan, Iraq, Thailand, Malaysia, and Kuwait[6,9]. Hilsa makes up 20% to 25% of total fish landings in the Bhagirathi-Hooghly River system[1,10].

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The Ganga River flows from the Himalayas to the Bay of Bengal covering upland streams, warm water swamps, and deltaic environments, and is joined by several tributaries as it moves through the Gangetic plain. It flows through Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal before merging into the Bay of Bengal. After entering West Bengal, the main channel flows through Bangladesh as the Padma River, while a feeder canal diverges upstream of the Farakka barrage to join the Hooghly River at Jangipur, forming the Bhagirathi-Hooghly River system, which finally merges into the Bay of Bengal [10]. A significant decline in the Hilsa population in the Hooghly-Bhagirathi River system has been reported over the past two decades, with production in West Bengal dropping from 80,000 tons to 20,000 tons between 2001 and 2011[5,11]. This decline is attributed to several anthropogenic factors, including siltation at the estuary mouth that obstructs Hilsa migration and barrage and dam construction that reduces upstream movement of Hilsa that cause decline of Hilsa in the upstream. Additional challenges such as overfishing of juveniles and brood fish, inadequate compliance with mesh size regulations, ineffective fish passes, habitat loss due to water abstraction, and pollution further exacerbate the decline of Hilsa catches[5,6,10,12]. The Hilsa fisheries in West Bengal in India are regulated by the state government, implementing several conservation measures to address the declining Hilsa population[13]. These include mesh size restrictions on gill nets (90 to 110 mm mesh size should be used), a 10-day annual fishing ban in September or October based on the lunar cycle, and a general fishing ban from mid-April to mid-June. Awareness campaigns on Hilsa conservation began in 2010 and onwards. Regulations on harvesting, transporting, or selling Hilsa below 23 cm in length, particularly from February to April, and Hilsa fishing is banned within 5 sq. km of the Farakka barrage to protect spawning grounds. Overfishing, combined with the impacts of the Farakka barrage commissioned in the 1970s, has led to a significant decline in Hilsa population, which increases its market value due to reduced availability[10].

The present study focused on Hilsa fish landings downstream of the Ganga River at Farakka, Godhakhali, and Diamond Harbour. The ecological and geopolitical significance of the Farakka Barrage and its downstream influence on Hilsa populations cannot be overlooked. Sine, the construction of the Farakka barrage in 1971 severely disrupted Hilsa migration, impacting their habitats and the fisheries that depended on them[14]. By altering river flow and salinity, the barrage led to a 92% decline in Hilsa landings in the Ganga upstream, particularly at Allahabad, Buxar, and Bhagalpur[15-16]. Consequently, Hilsa populations are now confined to downstream areas. Many local fishers abandoned stretches of the Ganga after the 1970s, and fishing activities extended year-round except during the monsoon lean season. Historically, Hilsa fisheries thrived along the Ganga near Allahabad, peaking in October and November[17]. However, catches plummeted from an average of 33 tonnes annually between 1963 and 1972 to 0.96 tonnes post-barrage in 1975[18]. Upstream populations disappeared, while downstream, the Hooghly estuary recorded a significant increase in landings, rising from 1,427.6 tonnes annually (1957–1974) to 6,370 tonnes (1975–1999) due to diverted freshwater flows attracting Hilsa [15, 18]. Hilsa production in the Hooghly–Bhagirathi stretches between 2000 and 2011 ranged from 12,733 to 77,912 tonnes, peaking in 2004–2005 at 8,427 tonnes [19]. However, overfishing, including indiscriminate juvenile exploitation, has caused declines in recent years. The barrage has obstructed Hilsa breeding, contributing to long-term population challenges. The Farakka barrage has also fuelled tensions between India and Bangladesh over shared river flows and fisheries, with significant geopolitical ramifications.

Additionally, Godakhali, a prominent landing centre in the lower stretch of river Ganga and a suitable habitat for Hilsa fish (*T. ilisha*) reproduction. The area's contribution to the life cycle of this iconic migratory species accounts for both its ecological and economic significance. The anadromous fish Hilsa migrates from the sea to spawn in freshwater rivers such as the Ganga. Godakhali is an essential stop on this reproductive journey because of its location in the lower delta. A brackish water environment which is perfect for Hilsa spawning is produced by the combination of freshwater from the Ganga River and tidal influx from the Bay of Bengal. Hilsa larvae and juveniles grow in the ideal conditions found in the nutrient-rich waters of the delta. Crucial phases of the Hilsa life cycle, such as egg laying, larval development, and juvenile growth before to return to the sea, are supported in the area. The fact that Godakhali serves as a breeding habitat for Hilsa highlights the necessity of focused conservation initiatives to ensure the long-term viability of this species, which is both ecologically and commercially significant.

Also, Diamond Harbour's potential to strike a balance between revenue generation and environmental sustainability makes it a crucial location for Hilsa fishing. In addition to ensuring livelihoods, the conservation and management of this resource will protect this region's biological and cultural significance. It is a vital component of the local economy, supporting the livelihoods of thousands of fishermen and their families. Hilsa is ingrained in Bengal's culinary and cultural traditions, is reinforced by its significance in Diamond Harbour, where local fish are frequently praised for their flavour and excellence. Here, the Hilsa trade makes a substantial contribution to the local and Bengali seafood markets. The selling of Hilsa during the peak time of year increases the revenue of fishing communities and related enterprises, like transportation and fish processing.

Time series forecasting analysis of fish landings plays a crucial role in an economic system by providing accurate forecasts of fish availability, which can help stabilize fish prices and secure fishers' livelihoods. Unexpected fluctuations in fish landings can lead to price volatility, impacting both consumers and fishers. Fish landings recorded over time can be treated as a time-series process, revealing trends driven by underlying mechanisms. Examining this process helps identify patterns in fish availability, allowing researchers and policymakers to understand shifts in landings over time.

## Materials and Methods

***Data Collection:*** Data on Hilsa fish landings (in tonnes) at Farakka, Godhakhali, and Diamond Harbour for five years, from 2019 to 2023, were gathered from different landing centers. Fish landings were extrapolated to annual figures using random stratified sampling methods.

***ARIMA Model Development:*** Time series data are observations of a certain occurrence that are taken at regular periods. A basic principle in time series modelling is that past trends will probably continue in the future. In several studies, the univariate Box- Jenkins (ARIMA) model has been widely used. When a time series is differenced, the Autoregressive Integrated Moving Average (ARIMA) model is formed by combining the Auto-Regressive (AR) and Moving Average (MA) components[20]. A mathematical representation of an ARIMA model is ARIMA (p, d, q), where p stands for the autoregressive order, d for the degree of differencing, and q for the moving average order [21]. It has the following general form:

$$\varphi_p(B)\,\nabla^d Y_t = \theta_q(B)\,\varepsilon_t \quad (1)$$

where, $Y_t$ is the fish production at time t; $\varphi_p(B)$ and $\theta_q(B)$ are polynomials in f degree p and q, respectively; $\nabla^d = (1-B)^d$, B is a backshift operator such that, W.N. indicates White Noise.

The ARIMA modelling process involves four main steps: identification, estimation, diagnostic checking, and forecasting (Fig. 1). During the identification phase, data transformation and differencing are applied, followed by analysing ACF, PACF, and stationarity using the Augmented Dickey-Fuller (ADF) tests [22]. ACF and PACF plots help determine initial values for parameters p and q. If non-stationary, transformations and differencing are performed to achieve stationarity. The estimation phase involves fitting the ARIMA model, with the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) [23, 24] used to select the best fit. Diagnostic checks, including residual analysis and autocorrelation testing, ensure the model's adequacy. The forecasting phase predicts future fish landings, with accuracy assessed using R-squared ($R^2$) and Root Mean Square Error (RMSE). RMSE measures the average magnitude of the errors [25]. $R^2$ indicates the proportion of variance in the dependent variable that is explained by the independent variables [26].

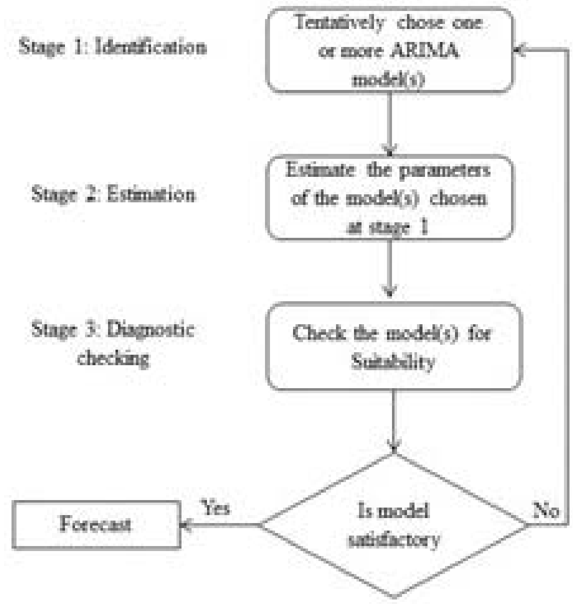


**Fig. 1:** A schematic diagram illustrating the iterative Box-Jenkins approach (adapted from Yadav et al., 2020)

***Fitting of ARIMA Model*:** This study aimed to forecast Hilsa landings at Farakka, Godhakhali, and Diamond Harbour by applying the widely used Box-Jenkins univariate Auto-Regressive Integrated Moving Average (ARIMA) model. Time-series data on Hilsa fish landings from 2019 to 2023 were obtained from ICAR-CIFRI for analysis. The ARIMA model was developed using data from 2019 to 2023 and forecasted over a two-year period from 2024 to 2025.

## Results

***Fish Landing at Farakka, Godhakhali, and Diamond Harbour:*** Farakka, Godhakhali, and Diamond

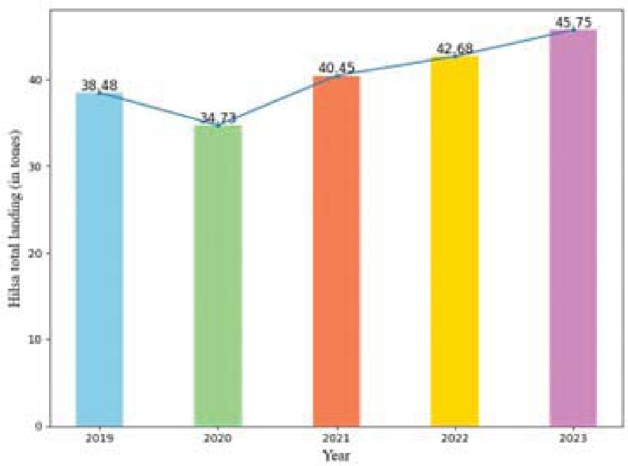


**Fig. 2:** Hilsa landing at Farakka, Godhakhali, and Diamond Harbour from 2019-2023

Harbour are key fish landing centers for Hilsa from the River Ganga. The yearly Hilsa fish landings at these locations over a five-year period from 2019 to 2023 show a notable upward trend. In 2019, the Hilsa landings were 38.48 tons, which slightly decreased to 34.73 tons in 2020, reflecting a decrease of 9.75%. However, there was an upward trend in the following years, with landings rising to 40.45 tons in 2021, an increase of 16.47%. This growth continued in 2022, where landings reached 42.68 tons, showing a further increase of 5.51%. By 2023, the Hilsa landings further increased to 45.75 tons, marking a 7.19% rise (Fig. 2). The data highlights a steady rise in Hilsa fish landings, particularly from 2021 to 2023, reflecting positive trends in the catch levels at Farakka, Godhakhali, and Diamond Harbour.

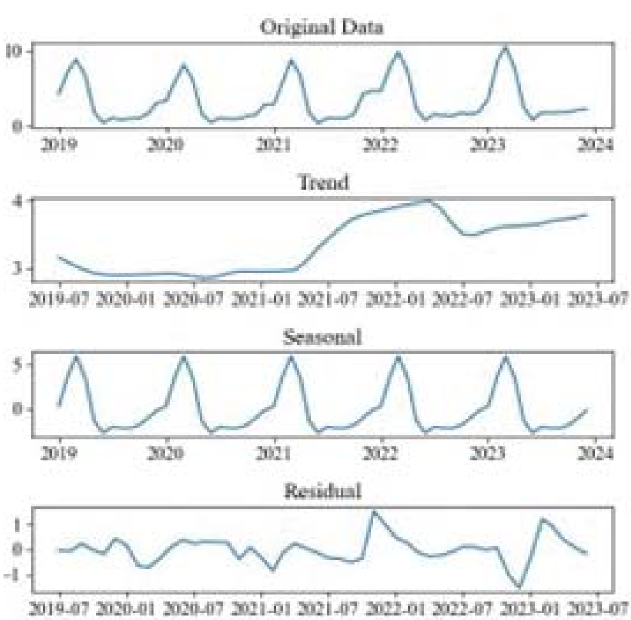


**Fig. 3:** Seasonal decompose of Hilsa landing data from 2019-2023.3.3 *ADF stationary test*

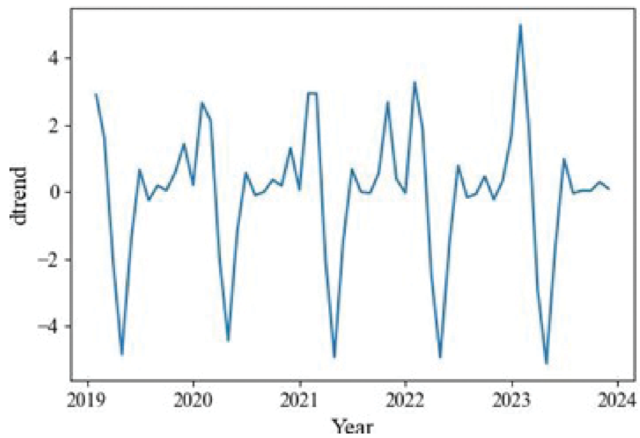


**Fig. 4:** 1st difference of the fitted Hilsa landing data

***Seasonal Decompose:*** To better understand the underlying patterns, including trends, seasonality, and residuals, we applied additive decomposition to the series.

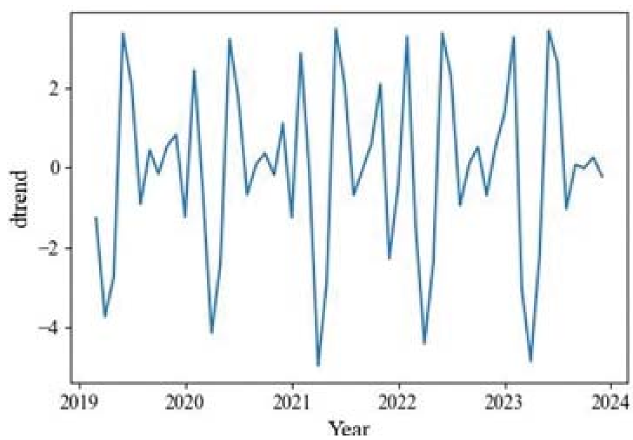


**Fig. 5:** 2nd difference of the fitted Hilsa landing data

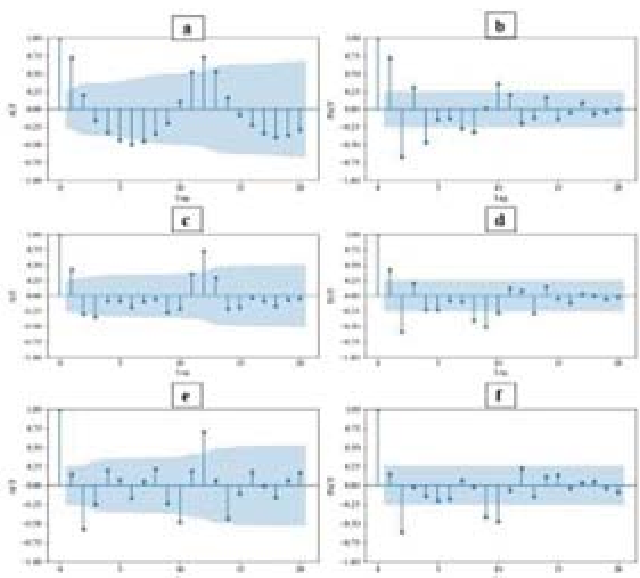


**Fig. 6(a-f):** (a) ACF and (b) PACF of the Hilsa landing data, (c) ACF and (d) PACF of the 1st difference Hilsa landing data, and (e) ACF and (f) PACF of 2nd difference Hilsa landing data, respectively

The decomposition revealed a significant upward trend in the data and a clear seasonal pattern. This indicates that the data is not stationary and requires differencing to convert it into a stationary series.

**Table 1. ADF test for stationary of Hilsa landing data series**

| Series | ADF | p - value |
|---|---|---|
| Level, I (0) | -0.643 | 0.861 |
| 1st difference, I (1) | -2.742 | 0.067 |
| 2nd difference, I (2) | -12.424 | 0.000 |

In the above seasonal decomposition (Fig. 3), it is evident that the data is not stationary. Therefore, the stationarity of the Hilsa landing data was evaluated using the Augmented Dickey-Fuller (ADF) test at different levels of differencing. In table 1, the results revealed that the series is non-stationary at the original level (I(0), ADF = -0.643, p = 0.861 (>0.05)) and after the first differencing (I(1), ADF = -2.742, p = 0.067 (>0.05)). However, the series achieves stationarity at the second differencing (I(2), ADF = -12.424, $p < 0.05$), indicating that two levels of differencing were required to stabilize the data (Fig. 4 & 5).

***Selection of appropriate model IMC, Major Catfish and Minor Catfish landing with ACF and PACF plot:*** In the Fig. 6(a) & 6(b) the ACF and PACF plots indicate that the time series data is non-stationary, as evidenced by the gradual decay of the ACF values over successive lags, which suggests the presence of a trend. In contrast, the PACF plot shows a sharp cutoff after lag 1 or 2, indicating that the series may follow an AR process with one or two lags. This pattern suggests the need for differencing to make the data stationary before applying the ARIMA model. Based on these observations, the ARIMA model is likely to require a differencing term (d = 1 or 2) and a low order for the AR (p) component. Additionally, from the Fig. 6(e) the ACF plot of the second-differenced data drops quickly to near zero after lag 1 and shows no significant spikes beyond the confidence interval. This indicates that the series is stationary. In the Figure 6(f) the PACF plot shows a sharp cutoff after lag 2, with a significant spike only at lag 2, suggesting that the series may follow an AR (2) process. The second differencing appears to have removed any trend or non-stationarity, making the series suitable for modeling with an autoregressive process of order 2.

***Model Selection and Estimation of Parameters:*** Based on the ADF test result, the Hilsa landing data series were stationary after $2^{nd}$ difference. After the stationary series various models were put to fit for further analysis. The proposed models for Hilsa fish landing at Farakka, Godhakhali, and Diamond Harbour include ARIMA (2,2,2), ARIMA (2,2,4), ARIMA (3,2,4), ARIMA (4,2,2) and ARIMA (4,2,4). The estimated parameters and their significance are presented in Table 2. The model ARIMA (4,2,4) has the lowest AIC (211.450) and BIC (229.994), indicating it is the most statistically efficient. This model also achieves the highest R-squared ($R^2$) value 0.74, suggesting it explains 74% of the variation in the Hilsa landing data. Additionally, its RMSE value of 1.430 indicates the lowest error, implying it provides the most accurate predictions. While other models, such as ARIMA (4,2,2), ARIMA (2,2,2) also perform well with lower AIC and BIC values, they have slightly lower $R^2$ and higher RMSE values. Overall, the model ARIMA (2,2,4) is the best fit for the data, providing the most reliable and accurate forecasts.

**Table 2. AIC, BIC, $R^2$ and RMSE of the fitted ARIMA models of Hilsa landing**

| Models | ARIMA order | AIC | BIC | $R^2$ | RMSE |
|---|---|---|---|---|---|
| Model 1 | ARIMA (2,2,2) | 223.053 | 233.355 | 0.66 | 1.62 |
| Model 2 | ARIMA (2,2,4) | 219.09 | 233.513 | 0.70 | 1.534 |
| Model 3 | ARIMA (3,2,4) | 221.064 | 237.548 | 0.70 | 1.534 |
| Model 4 | ARIMA (4,2,2) | 212.679 | 227.102 | 0.72 | 1.474 |
| Model 5 | ARIMA (4,2,4) | 211.45 | 229.994 | 0.74 | 1.43 |

After fitting the models, the goodness-of-fit to ensure adequacy was confirmed. The ACF and PACF plots of the model's residuals indicated that, while there are some minor spikes in the ACF and PACF, most of the correlations fall within the 95% confidence intervals (Fig. 7). This lack of significance suggests that the residuals are independent. This implies that the residuals are mostly uncorrelated, and the ARIMA (4,2,4) model fits the data reasonably well. Additionally, the Ljung-Box test using the Q-statistic [27] for the fitted model was not significant ($p > 0.05$), thereby indicating that the model effectively captured the time series dependencies. Overall, the diagnostic checks confirmed that the ARIMA (4,2,4) model for forecasting Hilsa landings was appropriate.

## *Discussion*

In this study, a time series ARIMA (4,2,4) model was developed to forecast Hilsa fish landings at Farakka, Godhakhali, and Diamond Harbour. Present and predicted Hilsa landings from 2019 to 2023 depicted in table 3. The present landings ranged from 34.73 tons (2020) to 45.75 tons (2023), with predicted values closely matching. Prediction errors were minimal, from 1.30% in 2019 to 0.26% in 2023, indicating a highly accurate model, especially in the last two years. In the table 4, the forecasted landings

**Table 3. Yearly Hilsa landing forecast using the ARIMA (4,2,4) model for the years 2019–2023 with prediction error at Farakka, Godhakhali, and Diamond Harbour**

| Year | Actual Hilsa landing (tons) | Predicted Hilsa landing (tons) | % prediction error |
|---|---|---|---|
| 2019 | 38.48 | 37.98 | 1.30 |
| 2020 | 34.73 | 33.63 | 3.17 |
| 2021 | 40.45 | 39.31 | 2.82 |
| 2022 | 42.68 | 42.29 | 0.91 |
| 2023 | 45.75 | 45.87 | 0.26 |

for 2024 and 2025 indicate a slight decline over the two-year period. Specifically, the Hilsa landings at these locations are projected to be 46.36 tons in 2024 and 45.29 tons in 2025, as per the ARIMA model analysis (Fig. 8 & 9). Time series forecasting is a widely used approach for predicting production, landings, and prices of aquaculture commodities. Traditional methods such as ARIMA, SARIMA, ARIMAX, and SARIMAX are commonly applied to analyse non-stationary time series data [28]. The Auto-Regressive Integrated Moving Average (ARIMA) model has become a widely used method in time series analysis for predicting trends and patterns across various fisheries sectors [29]. For instance, Yadav et al., [3] modelled Hilsa landings in the lower stretch of the Brahmaputra River (Assam, India) using seasonal ARIMA (SARIMA) and NNAR (Neural Network Auto Regression). Their study employed the SARIMA $(1,0,0)(0,1,1)_4$ model to forecast Hilsa landings for 2020, 2021, and 2022, with predictions of 3019.77 kg, 3037.47 kg, and 2950.32 kg, respectively. Similarly, Giri et al., [30] utilized the Bayesian Structural Time Series model to predict the monthly Hilsa catch in the Northern Bay of Bengal, incorporating chlorophyll concentration and rainfall as explanatory covariates. In Tamil Nadu, India, ARIMA (1, 1, 1) effectively modelled trends in marine fish production[31]. For the Jammu region of Jammu and Kashmir, Sharma et al., [32] constructed an ARIMA model to predict monthly Rohu fish arrivals using the Box-Jenkins methodology. Recently, Rajani et al., [33] employed ARIMA (0, 2, 1) and ARIMA (0, 1, 3) to analyse marine and inland fish production trends in India. According to author leveraged the SARIMAX $(1, 0, 0)(2, 0, 0)_{12}$ model in Chilika Lagoon, Odisha, incorporating environmental factors like salinity and temperature to improve forecasting accuracy[34]. On India's northeast coast, the Holt-Winters model outperformed ARIMA and NNAR in forecasting fish production[35]. In Andhra Pradesh, Stephen et al.,[36] utilized ARIMAX and NARX models, incorporating environmental variables like sea surface

**Table 4. Yearly Hilsa landing forecast with 95% confidence interval using the ARIMA (4,2,4) model for the years 2024–2025 at Farakka, Godhakhali, and Diamond Harbour**

| Year | Hilsa Forecast landing (tons) | Standard Error | 95 % CI | |
|---|---|---|---|---|
| | | | Lower (tons) | Upper (tons) |
| 2024 | 46.36 | 2.025 | 45.21 | 47.51 |
| 2025 | 45.29 | 0.233 | 45.16 | 45.42 |

temperature and wind speed, to forecast fish catches for the next 20 quarters. Beyond India, Saifuddin et al.,[37] identified ARIMA (1, 2, 1) and ARIMA (1, 1, 0) as the most reliable models for aquaculture and capture fish production forecasting in Bangladesh. A similar study by using the ARIMA (0,2,1) model to forecast total fish production in Bangladesh, predicting a total of 6,013,331 metric tonnes by 2028 [38]. ARIMA model was employed in Pakistan to forecast fish production from 2017 to 2026, identifying ARIMA (2, 1, 3) as the best model, projecting an increase from 619.624 tons in 2017 to 724.750 tons in 2026[39].

## *Conclusion*

In the present study, five years of Hilsa fish landing time series data from Farakka, Godhakhali, and Diamond Harbour were used to forecast the next 2 years. The average Hilsa fish landing at these locations is 40.42 tons from 2019 to 2023. The forecasted Hilsa landings for 2024 and 2025 show a slight decline. In 2024, the forecasted landing is 46.36 tons, with a standard error of 2.025 tons. The 95% confidence interval ranges from 45.21 tons to 47.51 tons, indicating a reasonable level of uncertainty. In 2025, the forecasted landing drops to 45.29 tons, with a smaller standard error of 0.233 tons. The 95% confidence interval for 2025 is more precise, ranging from 45.16 tons to 45.42 tons, suggesting higher confidence in this prediction. Based on the ARIMA (4,2,4) model, the landing rate of Hilsa is expected to increase by 1.33% in 2024 and decrease by 1.01% in 2025 compared to 2023. Additionally, the Hilsa landing rate is projected to increase by 14.7% in 2024 and 12.05% in 2025 compared to the average landing from 2019 to 2023.

Currently, the decline in Hilsa landings at Farakka, Godhakhali, and Diamond Harbour is primarily due to overfishing, habitat degradation, and the impact of climate change. Overfishing, particularly during spawning seasons, reduces fish stocks, while pollution from industrial waste

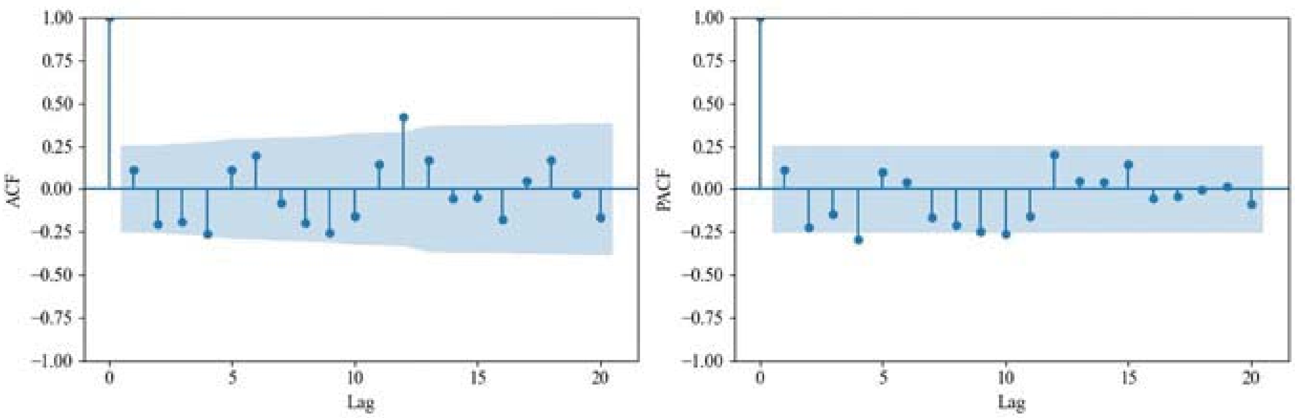


**Fig. 7:** ACF and PACF of the residuals of fitted Hilsa landing data

and agricultural runoff degrades aquatic habitats. Additionally, the construction of barrages and dams obstructs migration, disrupting breeding. Climate change affects water temperature and salinity, further hindering Hilsa's reproduction. Illegal fishing practices and ineffective fishery management also contribute to the decline, highlighting the need for sustainable practices and habitat restoration to protect the species. The government is advised to implement various policies like seasonal fishing bans during breeding periods, promoting sustainable fishing practices, and river ranching programs to replenish stocks river to ensure stable fish production from the Ganga River in and around the Farakka, Godhakhali, and Diamond Harbour. Additionally, local fishing communities are engaged in conservation through awareness programs, and the government collaborates with research institutions to develop effective management strategies. These measures aim to ensure the long-term sustainability of Hilsa fisheries while supporting local livelihoods. The present findings will also be an added reference for the fisheries planners and policymakers for sustainable management of Hilsa production.

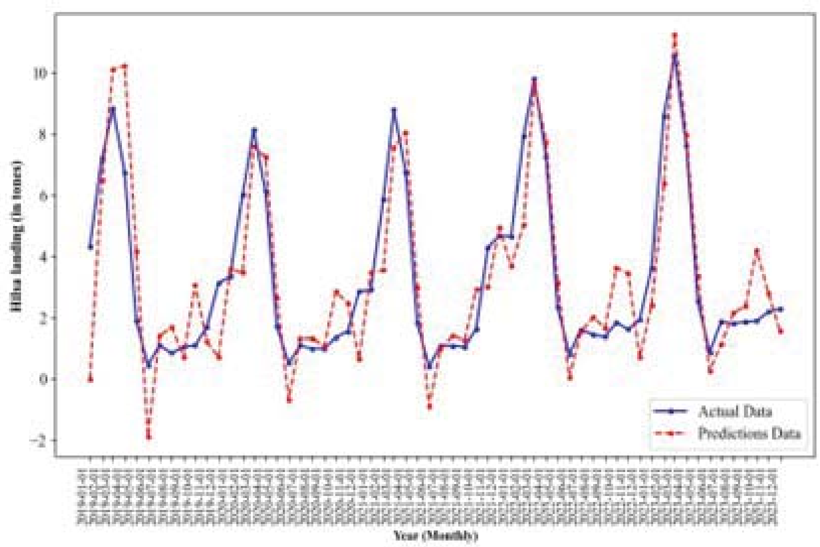


**Fig. 8:** Observed and predicted values of Hilsa fish landing

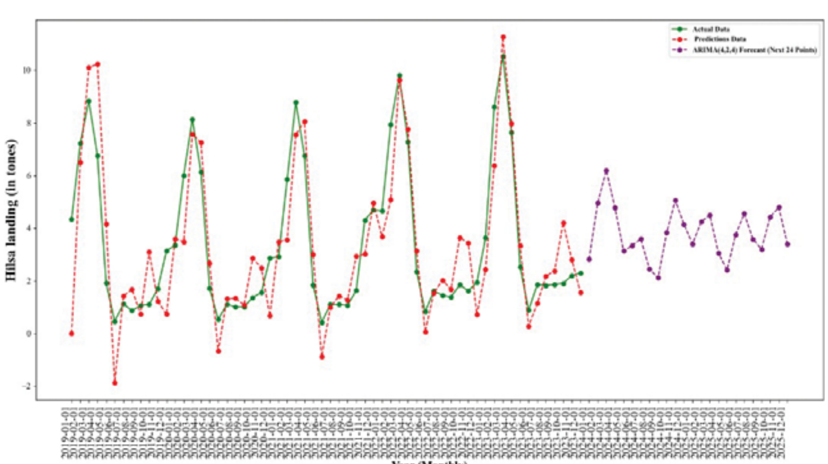


**Fig. 9:** Monthly fitted values and two-year forecasts produced by the ARIMA (4,2,4) model for Hilsa landing forecast at Farakka, Godhakhali, and Diamond Harbour


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