Original Research Article

Effect of Climate induced changes in the ecosystem services of Chilika lake wetlands of Odisha from the perspective of agriculture and fisheries

ABSTRACT

Aims: The aim of the study is to find out the effect of climate induced changes in the ecosystem services of Chilika Lake of Odisha.

Study design: The study has been conducted in Chilika Lake, including the peripheral districts Khurda, Puri and Ganjam. Secondary data have been used for rice yield, fish production and for various weather parameters.

Methodology: The statistical analysis like Mann-kendall's test is used for trend analysis, Fixed panel data regression to find out the influence of climatic parameters on yield of paddy and multivariate multiple regression to study the effect of climate change on fish production has been used.

Results:
The fixed effect model was found relevant during panel data regression. The weather parameters annual mean rainfall and soil profile moisture were found positively significant at one per cent level of significance in influencing the yield of paddy. Whereas annual mean temperature, squared rainfall and root zone wetness were found negatively significant. Both the temperature and root zone wetness were significant at one and five percent level of significance respectively. Squared rainfall term is found negatively significant at the five percent level of significance which shows a quadratic relationship between rainfall and yield. The estimates of fish production, shrimp and crab production in the Chilika lake revealed that the water salinity and water temperature were found significant at five and ten percent level of significance respectively in the case of fish production. The water salinity founded negatively influences fish production. There were no parameters were found significant in the shrimp production in the lake for the period of 2000 to 2015. The variables water pH and dissolved oxygen were found positively significant at ten and five percent in influencing the Crab production of the lake. The parameter water transparency was found insignificant for all three independent variables viz. fish, shrimp and crab production.

Conclusion:
It is found that annual mean rainfall and soil profile moisture have a significant positive influence of paddy whereas temperature and root zone wetness have a significant negative influence on paddy yield. Only water salinity was found negatively significant for fish production. The parameters, water pH and dissolved oxygen were found to have a positive influence on Crab production in Chilika lake.

Keywords: Climate change, paddy, Chilika lake, weather parameters, fish production

1. INTRODUCTION

“Wetlands include permanently or seasonally inundated freshwater habitats ranging from lakes and rivers to marshes, along with coastal and marine areas such as estuaries, lagoons, mangroves and reefs. Wetlands are valuable and ecologically sensitive systems that occupy about 6% of the world’s land surface” (Turner et al.,2000) [1] Lake Chilika, the largest coastal lagoon on the east coast of India and lifeline of the state of Odisha, is a designated Wetland of International Importance (Ramsar Site under the Convention on Wetlands) [2] since 1981 Chilika, a brackish water coastal lagoon situated in Odisha, forms the base of livelihood security for more than 0.2 million fishers and 0.4 million farmers living in and around the wetland and its adjoining catchments. Chilika Lake, with its rich biodiversity and scenic beauty, is one of the important tourist destinations of the state, and accounts for 8-10% of the total tourist arrival into the state. Chilika is one of only two lagoons in the world that supports Irrawaddy Dolphin (*Orcaella brevirostris*) populations. Barkudia insularis, a limbless skink, is endemic to Chilika. Lake Chilika, with an enormous storage capacity of 1200 Million cubic mteters (MCM)of water (with a water level variation in excess of a meter) provides a huge capacity for buffering floods and impacts of extreme events.

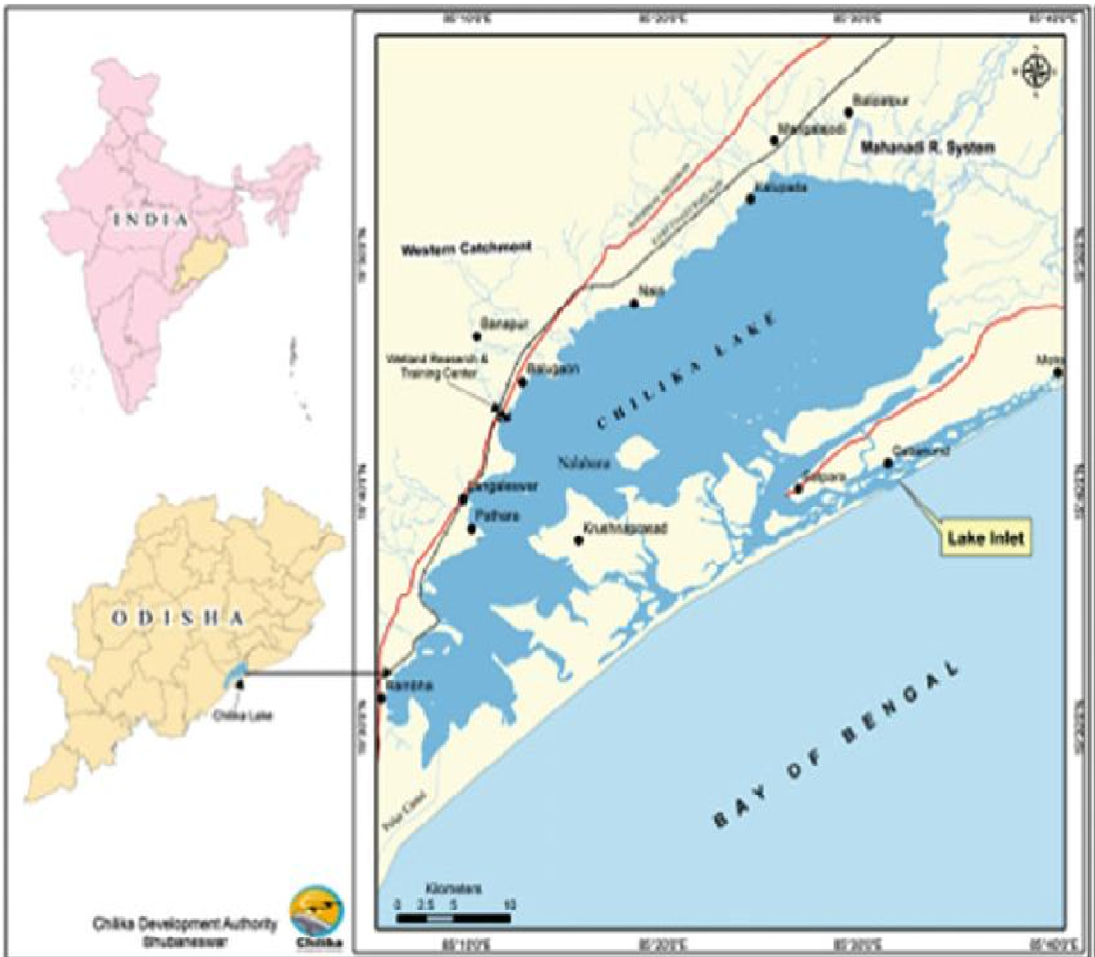
“Climate change (CC) is likely to intensify coastal hazards imposing significant challenges on coastal regions” (Adger et al., 2005). [3] “Odisha is the state which is very prone to natural calamities such as flood and cyclones. Quantitative estimations regarding the impact of climate change on wetlands are scarce in the literature, especially in developing countries where the primary data both on physical impacts and valuation are limited and difficult to obtain” (Mehvar et al., 2018b) [4] . The potential consequence of any climate change- driven variation in wetlands would be particularly high in developing countries due to the inherently low adaptation capacity, and the high dependence of local communities towards wetlands. This main objective of the study is to determine the effect of climate induced changes in the ecosystem services of Chilika Lake of Odisha. This study is an attempt to find the impacts of climate change on the paddy yield and fish production in Chilika Lake Wetlands, which supports the formulation of various contingency plans for the area.

2. METHODOLOGY

2.1 Study area

Chilika Lake (19°28‟N-19°54‟N and 85°6‟E-85°35‟E) lies in the districts of Puri, Khurda and Ganjam in the state of Orissa, on the eastern coast of India (Fig.1). Chilika lies on the main Madras-Calcutta highway (National Highway 5) and Madras-Howrah rail line passes the western bank, near Balugaon, Chilika and Rambha being the main stations along the Lake. Chilika lies about 50 km southwest of the city of Puri from where one can approach Satapara by road on the eastern bank of Chilika. It is 100 km away from Biju Pattnaik Airport, Bhubaneswar and 1 km from Balugaon railway station.

“The Lake is surrounded by a strip of silted and reclaimed land. On the northeast margin lies an extensive area of marshy land, some of which has been reclaimed for agriculture. Other silted-up lands around the northern and central margins have been reclaimed for agriculture and are separated from the Lake by bunds (dykes). The Lake margins are steeper in the central and southern sectors and rocky promontories jut out into the Lake at several places. The land is less flat and somewhat rocky, being part of the Eastern Ghats. The estuary of the Rushikulya River lies about 18 km down the coast and is separated from Chilika by lowlands, some of which are used as salt pans” (Rao *et al.* 1986).[5] The 21 km long Palur canal connects the Rushikulya estuary to the Lake.



Source: Chilika Development Authority

Fig.1 Map of Chilika Lake

2.1.1 Climate and rainfall

Chilika"s location on the coast in the tropical zone spares it from extreme temperatures. The rainfall over the area varies from 1007 - 1,146 mm, increasing towards the northeast having an annual average rainfall of 1202 mm. Source: (Chilika Development Authority, Report, 2001). "Most of the rain (80 %) occurs during the South West monsoon season. The Lake area experiences mean wind speeds ranging from 0.678 to 86.10 kmph at Chnadraput and Satapada" (CDA Report, 2001). However, the coastal areas experience higher wind speeds. Being on the Bay of Bengal, Chilika is also subjected to cyclonic activity during May – December. The Lake area experiences mainly three seasons, namely Summer (March-June), Rainy (July to October) and Winter (November to February). Two Automatic Weather Stations have been installed by CDA within the campus of the Visitor Centre, Satapada and Wetland Research & Training Centre (WRTC) at Chandraput to record various meteorological parameters (Air Temperature, Relative Humidity, Wind Speed & Direction, Solar Radiation, Rainfall) relating to the Lake area.

Rainfall in the region is contributed by southwest and northeast monsoons from June to September and November to December, respectively. About 75% of the annual rainfall is received during the monsoon months from June to September. Rainfall generally decreases from northeast to south-west. The monsoon starts by about the second week of June and withdraws early in October. Wind speed is higher from March to July and speed is low during the winter season.

2.2 Nature and sources of data

Secondary data on fish production, rice yield, weather data, tourist arrival and other relevant data were collected from the Department of Fisheries, Odisha, the official page of Special Relief Commissioner Odisha, All India Coordinated Research Project (AICRP) on, Agro Meteorology, OUAT, Chilika Development Authority, OTDC Bulletin and from other literature related to the study. Data on climatic variables were also collected from a NASA power web application.

2.3 Analytical techniques

<u>2.3.2 Mann- Kendall's test and Sen's slope parameter</u>

The trend analysis of the weather parameters, fish production and paddy yield is analyzed using Mann Kendal test and the Sen's slope estimator.

Mann-Kendall test was used to test the significance and direction of the trend has the following null and alternative hypotheses.

Ho: There is no significant trend in the variation of the variable.

H1: There is a trend in variation of the variable.

Mann- Kendall S statistic is calculated as

$$\sum_{i=1}^{n-1} \sum_{i=i+1}^{n} \operatorname{sign}(Tj - Ti)$$

Where Tj and Ti are variables in year 'j' and 'i' respectively given j>i.

$$\operatorname{sign}(Tj - Ti) = \begin{cases} -1 \text{ if } Tj < Ti \\ 0 \text{ if } Tj = Ti \\ 1 \text{ if } Tj > Ti \end{cases}$$

If the number of observations is greater than 10 then the Mann-Kendall statistic is assumed to follow a normal distribution with a variance equal to

$$\sigma^2 = \frac{n * (n-1)(2n+5)}{18}$$

The Z test was used to test the significance of the trend. The standard Z statistic Zs is

$$Zs = \begin{cases} \frac{S-1}{\sigma} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{S+1}{\sigma} \text{ if } S < 0 \end{cases}$$

If Zs>Z table value,then we reject the null hypothesis.

The magnitude of a time series trend was evaluated by a simple, non-parametric procedure developed by Sen. The trend is calculated by

Where β is Sen's slope estimate. β>0 indicates an upward trend in a time series. Otherwise, the data series presents a downward trend during the period.

2.3.2 Fixed panel data regression

To analyze the impact of climate on paddy yields of Puri, Khurda and Ganjam districts, we use a fixed panel data regression model which was found best fitting in the STATA software.

$$\ln Yit = Di + T + \beta Xi + \epsilon it$$

Where,
'i' denotes district and 't' denotes time
Di denotes the district specific effects that account for time-invariant district specific characteristics like soil fertility, water quality etc
'lnYit' denotes the log values of yields of paddy at the peripheral districts of Chilika lake.
'T' denotes the trend variable used as a proxy for capturing technological change over time.
X is a vector of climate parameters. The climate parameters included in our model are:
X1: Annual mean temperature
X2: Seasonal rainfall
X3: Seasonal rainfall squared term to capture the non-linear relationship between rainfall and paddy yields
X4: Wind speed
X5: Soil profile moisture
X6: Root Zone wetness

2.1.3 Multivariate multiple linear regression (MMLR)

Multivariate Multiple Regression (MMR) is used to model the linear relationship between more than one independent variable and more than one dependent variable. MMR is multiple because there is more than one independent variable.
The MMR is used to study the impact of climate induced changes in the fishery resources of Chilika lake using STATA software. The variable used in the model is given below

(Y1, Y2, Y3) = f (X1, X2, X3, X4, X5)

Where,
Y1 --- Fish production
Y2 -- Shrimp production
Y3- Crab production

X1– Water transparency
X2- Water pH
X3 – Salinity
X4 – Water temperature
X5- Dissolved Oxygen

3. RESULTS AND DISCUSSION

3.1 Climate-induced changes in the ecosystem services of Chilika lake

The effect of climate change in the yield of paddy for three coastal districts adjacent to Chilika lake viz. Khurda, Puri and Ganjam were analyzed for 22 years of data. The panel data regression was employed with selected weather parameters. Similarly, the fish production, shrimp production and crab production in the chilika were analyzed using Multivariate Multiple Regression with selected parameters influencing the fishery resources and water quality.

3.1.1 Climate induced changes in the rice yield

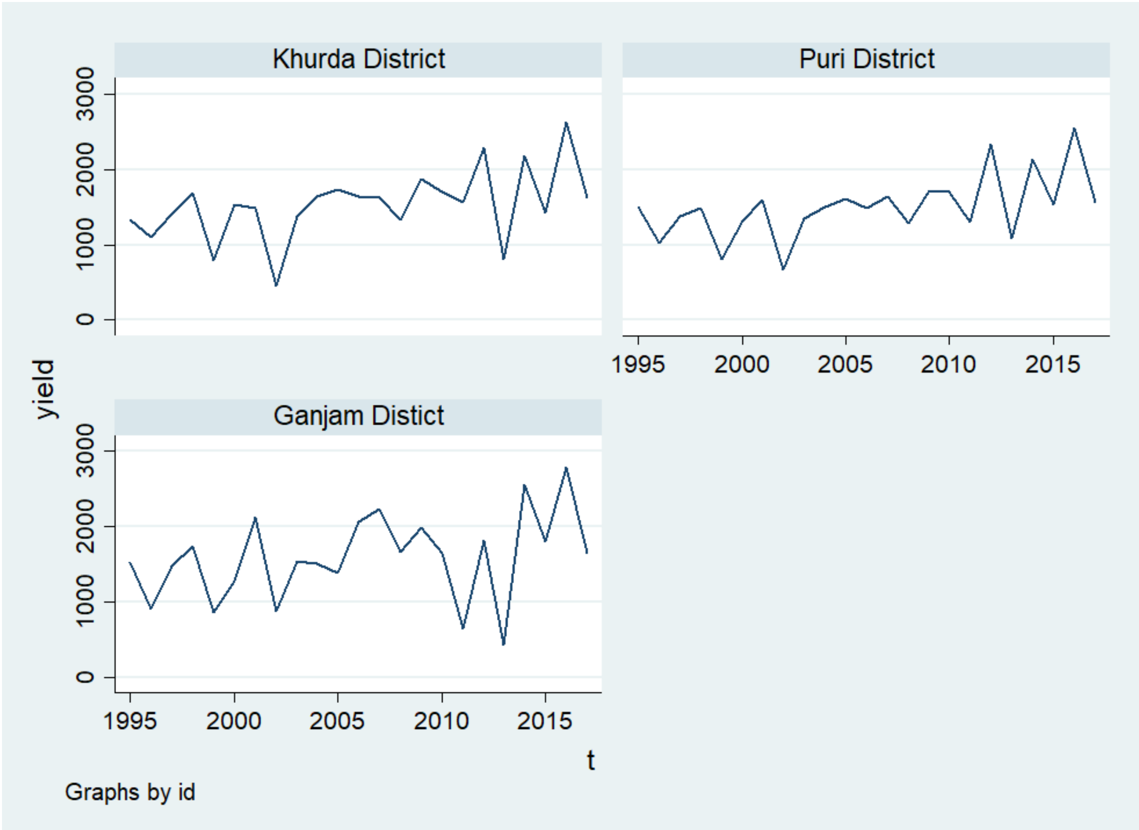
The yield of paddy for the districts Khurda and Puri were found to follow an increasing trend which was significant at one percent level of significance. (Fig.2) .The sens slope of paddy yield for the Khurda and Puri was 30.75 and 27.64 respectively. Among the weather parameters, only wind speed was found to be a decreasing trend which was significant at five percent level of significance for all three districts. The summary of Mann-Kendall's test is shown in Table 1

Table 1: Summary of trend analysis of rice yield and weather parameters

Series	**Kendall's tau**	**p-value**	**Sen's slope**	**Kendall's tau**	**p-value**	**Sen's slope**	**Kendall's tau**	**p-value**	**Sen's slope**
	Khurda			**Puri**			**Ganjam**		
Rice yield	0.336**	0.026	30.75	0.36**	0.016	27.64	0.249	0.103	31.22
Temperature (◦C)	0.111	0.459	0.010	0.060	0.692	0.004	0.10	0.508	0.007
Rainfall (mm)	-0.012	0.958	-0.183	0.087	0.561	3.692	-0.020	0.917	-1.507
Wind speed (m/s)	-0.341**	0.024	-0.008	-0.341**	0.024	-0.008	-0.325**	-0.032	-0.006
Soil Moisture	0.004	0.979	0.000	0.004	0.979	0.000	-0.079	0.612	0.000
Root zone wetness	0.017	0.915	0.000	0.017	0.915	0.000	-0.057	0.710	0.000

Note: ***, **and *implies significanceat1%, 5% and 10% respectively

Source: Author, 2022



Source: Author, 2022 * Yield in Kilograms

Fig. 2. Trend of paddy yield (1995 -2017)

Rice is cultivated in all the districts (30) of Odisha under varying Agro-ecological and climatic conditions. Being the most important food crop, it plays a pivotal role in the diet, livelihoods and culture of the state. Odisha has hectares - 3.89 million area under rice cultivation out of a total cultivated area of 5.8 million hectares. The state is located in the subtropical belt of India. The state broadly falls under hot and dry sub humid, warm and humid, hot and humid, and hot and moist sub-humid regions and experience four major seasons: winter (Dec-Feb), summer (Mar-May), rainy (Jun-Sep), and autumn (Oct- Nov). The monthly average minimum and maximum temperatures range between 14 °C recorded in December to 38 °C recorded in May. Whereas the mean maximum temperature is 32 °C in the coastal districts of the state, it sometimes goes up to 42° C in hilly areas. The location of the state, near the Bay of Bengal, moderates the temperature and adds humidity to its climate. The relative humidity of the state varies from 36% to 98%; the average bright sunshine hours range between 3.7 hours/day (3 hours and 42 minutes per day) in July-August to 8.8 hours/day (8 hours and forty-eight minutes per day) during March to May.

The yield of paddy for the districts Khurda and Puri were found to follow an increasing trend which was significant at one percent level of significance. (Fig. 3). The sens slope of paddy yield for the Khurda and Puri was 30.75 and 27.64 respectively. Among the weather parameters, only wind speed was found to be a decreasing trend which was significant at the five percent level of significance for all three districts. The study area Chilika Lake wetland belongs to the agro-climatic zone east and southeastern coastal plain. The agro-climatic zone,coastal region is about 15% of the geographical area of the state and it runs along the coastline with width varying from 24 km to 72 km from the sea coast. The soils are alluvial, both deltaic and coastal. The deltaic alluvial soils are generally fertile but low in Nitrogen and Phosphorus. The coastal alluvial soils within 10 km of the sea coast show high total soluble salts, mainly sodium chloride due to tidal inundation. The coastal belt has about 1.70 million hectares of rice land constituting about 38% of the total rice area. The rice land generally suffers from serious waterlogging problems and is flood prone.

Total rice production in the coastal region is estimated to be 2.68 million tons with 1,577 kg/ha. Rice is cultivated on an area of 3.94 million hectares, which may be classified into six different ecosystems: irrigated Kharif (27.4%), rainfed upland (19.1%), medium land (12.4%), shallow lowland (22.5%), semi-deep (7.9%), deep (3.4%), and irrigated rabi (7.4%). (IRRI, Rice production manual, 2021)

The fixed effect model was found relevant during panel data regression and the results are given in Table 2. The weather parameters annual mean rainfall and soil profile moisture were found positively significant at one percent level of significance in influencing the yield of paddy. Whereas annual mean temperature squared rainfall and root zone wetness were found negatively significant. Both the temperature and root zone wetness were significant at one and five percent level of significance respectively. It is found that the relationship between the yield per hectare and rainfall is quadratic; i.e., as rainfall increases, yield per hectare initially increases, reaches the peak, and then declines. The results are in line with the findings of Saravanakumar *et al.,*(2022) in districts of Tamil Nadu. An increase in annual mean temperature above the optimal level of temperature for paddy rice production resulted in a decrease in yield significantly. Similar findings were reported in rice production in the adjacent state, Andhra Pradesh (Barnwal and Kotani 2013) and in Malaysia by Gumel *et al.,* (2017). The root zone wetness was found negatively significant and the results are in line with the findings of Y. Xiaoguang *et al.* (2005) in aerobic rice in different regimes of China.

Table 2 Estimates of panel data regression for Paddy yield (Fixed effect model)

Yield (Y_1)	**Coefficient**	**t value**	**P>|t|**
Temperature (X_1)	-18747.6***	-2.67	0.010
Rainfall (X_2)	2.0448***	2.71	0.009
Squared Rainfall (X_3)	-0.0006**	-2.47	0.014
Wind speed(X_4)	815.393	1.33	0.188
Soil moisture(X_5)	10257.97***	3.09	0.003
Root zone wetness(X_6)	-7383.855**	-2.41	0.019
Constant	-43233.21***	-7.60	0.000
No. of observations	**69**		
No. of groups	**3**		
R^2 within	**0.96**		

sigma_u	297.315
sigma_e	104.628
Rho (ρ)	0.889

Note: ***, **and *implies significanceat1%, 5% and 10% respectively

Source: Author, 2022

3.1.2 Climate induced changes in the fishery resources of Chilika lake.

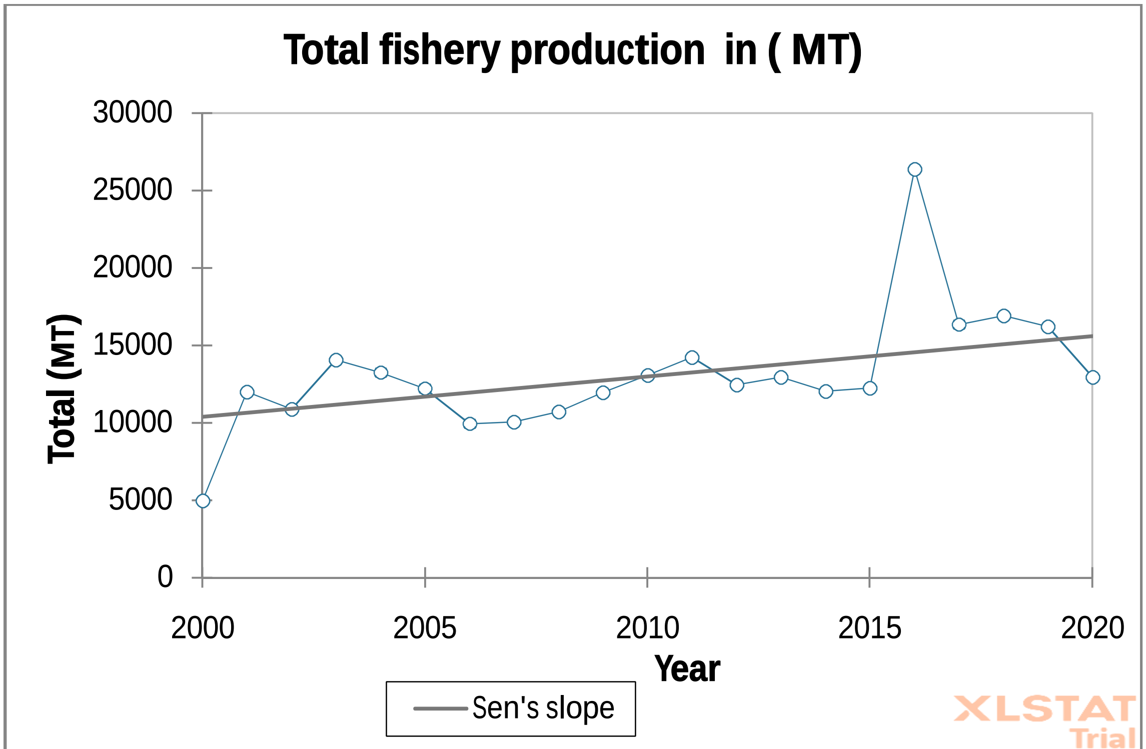
The results of Mann Kendall,s tests to study the trends in fish production revealed that Crab and total fish production has increased significantly at one percent level of significance, Whereas shrimp production followed an increasing trend with five percent level of significance. (Table 3). It was also observed that there is no significant increase found in fish production other than crab and shrimp in the Chililka since 2000 (fig 3).

Table 3 Summary of trend analysis of Fish production in Chilika

Series\Test	Kendall's tau	Sen's slope	p-value
Crab (MT)	0.571***	13.702	0.000
Shrimp (MT)	0.352**	125.576	0.027
Fish (MT)	0.076	87.068	0.655
Total fish production (MT)	0.438***	261.113	0.005

Note: ***, **and *implies significanceat1%, 5% and 10% respectively

Source: Author, 2022



Source: Author, 2022

Fig. 3 Total fishery production in Chilika (2000-2020)

“The rate of chemical reactions generally increases at higher temperatures, which in turn affects biological activity. An important example of the effects of temperature on water chemistry is its impact on oxygen. Warm water holds less dissolved oxygen than cool water, so it may be saturated with oxygen but still not contain enough for the survival of aquatic life. Some compounds are also more toxic to aquatic life at higher temperatures. Temperature changes affect aquatic life as it determines which organisms will thrive and which will diminish in number and size. For each organism, there is a thermal death point. Also, there is a range of temperatures that produce optimal abundance. The effects of temperature on the life of a cold-blooded are profound. These animals have coped with temperature problems in different ways. Not only the organism's survival but growth and reproduction of each organism have critical temperature ranges. Each organism must be favoured by the proper temperature if the individual or their population are going to survive” (Jain *et al*., 2013).

Table 4 Estimates of fish production in Chilika lake

Fish production (Y_1)	Coefficient	t	p> | t |
Transparency (cm)	8.3856	0.07	0.947
pH	7077.424	1.80	0.102
Salinity	-851.5284**	-3.10	0.011
Water Temperature	2744.454*	1.87	0.091
Dissolved oxygen	2612.177	1.72	0.117

Constant	-139275.5**	-3.20	0.010
R^2	**0.91**		
Shrimp production (Y_2)			
Transparency (cm)	-79.71838	-0.61	0.552
Ph	3505.479	0.85	0.413
Salinity	-287.141	-1.00	0.341
Water temperature	2382.56	1.55	0.152
Dissolved oxygen	1807.678	1.14	0.282
Constant	-96544.78*	-2.12	0.060
R^2	**0.88**		
Crab production (Y_3)			
Transparency (cm)	-7.07115	-1.39	0.194
pH	353.2115*	2.20	0.053
Salinity	13.26494	1.18	0.265
Water temperature	-73.98701	-1.23	0.247
Dissolved oxygen	147.8512**	2.37	0.039
Constant	-1314.582	-0.74	0.478
R^2	**0.968**		

Note: ***, **and *implies significance at 1%, 5% and 10% respectively

Source: Author, 2022

Multivariate Multiple Regression has been used to study the estimates of fish production, shrimp and crab production in the Chilika. It was found that the water salinity and water temperature significant at five and ten percent level of significance respectively in the case of fish production. The water salinity found to be negatively influences fish production. There were no parameters were found significant for the shrimp production in the lake for the period of year 2000 to year 2015. The results depicted in Table 4 reveals that the variables water pH and dissolved oxygen were found positively significant at ten and five percent in influencing the Crab production of the lake. The parameter water transparency was found insignificant for all three independent variables viz. fish, shrimp and crab production. The results are in accordance with the findings of Downing and Plante, (1993).

Climate resilient varieties and various agronomic measures such as Integrated farming systems, planning the sowing time etc. may be practised to cope with climate change for agriculture.

Even though the total fish production shows an increasing trend we need to maintain an optimum salinity level to have a check over the balance on fresh water and marine fish species since the water salinity negatively influences the fish production in the lake..

4. CONCLUSION

The fixed effect model was found relevant during panel data regression. The weather parameters annual mean rainfall and soil profile moisture were found positively significant at one percent level of significance in influencing the yield of paddy. Whereas annual mean temperature, squared rainfall and root zone wetness were found negatively significant. Both the temperature and root zone wetness were significant at one and five percent level of significance respectively. The Squared rainfall term is found negatively significant at five percent level of significance which shows a quadratic relationship between rainfall and yield.

Multivariate Multiple Regression has been used to study the estimates of fish, shrimp and crab production in the Chilika. Water salinity and water temperature were found significant factors at five and ten percent level of significance respectively in the case of fish production. The water salinity was found to be negatively influence fish production. No parameters were found significant for the shrimp production in the lake for the period of 2000 to 2015. The variables water pH and dissolved oxygen were found positively significant at ten and five percent in influencing the crab production of the lake. The parameter water transparency was found insignificant for all three independent variables viz. fish, shrimp and crab production.

Climate resilient areas may be piloted in the Chilika with end-to-end support from agriculture technology transfer, infrastructure, inputs, implements and weather advisory services to develop understanding and confidence of the farmers as well as fishermen community to adapt to new technology and practices addressing climate and environmental change. Similarly comphrensive approaches may be adopted to prevent dwindling of fish species due to increased salinity as well as due to environmental changes in the Chilika lake wetlands.

REFERENCES

1. Turner RK, van den Bergh JCM, Soderqvist T, Barendregt A, van der Straaten J, Maltby E, van Lerland EC. Ecological-Economic Analysis of Wetlands: Scientific Integration for Management and Policy, Ecological Economics, 2000; 35, pp. 7-23

2. Ramsar Convention on Wetlands, Information sheet on wetalands Ramsar. [Briefing Note]. The Secretariat of the Convention on Wetlands, Gland, Switzerland. 1992 December.

3. Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J. Social-ecological resilience to coastal disasters. Science 309 (5737), 2005; 1036–1039.

4. Mehvar S, Filatova T, Dastgheib A, de Ruyter van Steveninck E, Ranasinghe R.. Quantifying economic value of coastal ecosystem services: a review. J. Mar. Sci. Eng. 2018a: 6 (1), 5.

5. Rao DP, Subramanian SK, Sudarsana R. Geomorphic analysis of Chilika Lake and adjoining area using remotely sensed data, Photonirvachak. J Indian Soc Remote Sens 1986; 14:53–60

6. CDA Report on Chilika: environmental monitoring,. Chilika Development Authority, Bhubaneswar. 2001; vol 103.

7. International Rice Research Institute. Rice production Manuel. . 2021.

8. Saravanakumar V, Lohano HD, Balasubramanian R.. A district-level analysis for measuring the effects of climate change on production of rice: evidence from Southern India. *Theoretical and Applied Climatology*, 2022; 1-13.

9. Barnwal P, Kotani K. Climatic impacts across agricultural crop yield distributions: an application of quantile regression on rice crops in Andhra Pradesh, India. Ecol Econ 2013; 87:95–109.

10. Gumel DY, Abdullah AM, Sood AM, Elhadia RE, Jamalani MA, Youssefa KAAB.. Assessing paddy rice yield sensitivity to temperature and rainfall variability in Peninsular Malaysia using DSSAT model. *International Journal of Applied Environmental Sciences*. 2017;*12*(8), 1521-1545.

11. Xiaoguang Y, Bouman BAM, Huaqi W, Zhimin W, Junfang Z, Bin C.. Performance of temperate aerobic rice under different water regimes in North China. *Agricultural Water Management*. 2005; *74*(2), 107-122.

12. Jain S, Sharma G, Mathur YP. Effects of temperature variations on fish in lakes. *International Journal of Engineering Research & Technology*. 2013; *2*(10), 2516-2523.

13. Downing JA,Plante C. Production of fish populations in lakes. *Canadian Journal of Fisheries and Aquatic Sciences*.1993;*50*(1), 110 120.