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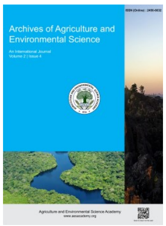

ORIGINAL RESEARCH ARTICLE

# Exploring economic viability: A study on profitability and resource efficiency in Polycarp production within the fish super zone of Dhanusha district, Nepal

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## ABSTRACT

Dhanusha district of Nepal is recognized as a fish hub of the country still operative fish farming in a semi-commercial level. This study evaluated and analyzed the profitability and resources utilization efficiency in the Polycarp production within the fish super zone of Dhanusha district. Along with it, the study covers socio-demographic characteristic of respondent, determine the factor affecting fish production, rank such challenges based on farmer's experience, and evaluate returns to scale fish production of this site. 64 farmers were randomly selected and surveyed through a semi-structured questionnaire. In order to collect primary data, pre-tested interview schedule, focus group discussion, key informant Interview, and field survey were conducted. Secondary data were collected by reviewing relevant publications. Analysis of socio-demographic data revealed a predominantly male participation rate (98.44%), with overall aged between 30 and 50 years, among whom the Yadav caste showed maximum engagement (27%). Regarding land ownership, the majority (68.76%) leased land for this activity. Carp polyculture exhibited an average water surface area of 1.55 hectares. The average yearly cost of producing carp fish was Rs.1069644.00, or Rs. 891370.00 per hectare of water surface, per year with fixed costs 15.55% and variable costs 84.45%. Notably, feed costs constituted the largest expense at 49.87%, followed by labor (15.52%) and fingerlings (9.40%). Silver carp emerged as the primary market contributor, comprising 22.96% of total production (6010 kg), followed by common carp, Grass carp, Rohu, Naini, Bighead carp, and Bhakur. Net returns per hectare was Rs. 2,24,348.87, with a resulting B:C ratio of 1.33, indicating economic viability. Challenges identified in the study area included the timely unavailability of fingerling, high feed cost and theft.

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## INTRODUCTION

Aquaculture stands out as a prominent sector in global food production, meeting the nutritional needs of people worldwide through increased productivity and rich nutrient content. Fish, known for its high protein, vitamin, amino acid, omega-3, folic acid, and micronutrient content, caters to individuals of all age groups (Gupta, 2007). Additionally, the omega-3 fatty acids present in fish play a preventive role against heart diseases, hypertension, and the likelihood of arrhythmias (Whelton, 2017). The rise of the blue revolution has brought aquaculture to the forefront. While traditional fisheries have a long history, the inception of aquaculture dates back to the early 1950s. Nepal, endowed with approximately 500,000 hectares of water resources, ranks second globally in water wealth, presenting enormous potential for fish farming. The country consists of 252 fish species, with 236 being indigenous and the remaining 16 as exotic species (Shrestha *et al.*, 2019). Among commercially cultivated fish species in Nepal, there are 7 carp species, 1 perch (Tilapia), 2 catfish, and 1 rainbow trout species (Shrestha, 2019). Notable carp species in Nepal include indigenous varieties like Naini (*Cirrhinus mrigala*), Bhakur (*Catla catla*), and Rohu (*Labeo rohita*), as well as exotic species such as silver carp (*Hypophthalmicthys molitrix*), Common carp (*Cyprinus carpio*), Bighead carp (*Aristicthys nobilis*), and Grass carp (*Ctenopharyngodon idella*). Carp contributes significantly, constituting approximately 95% of the total fish production. This underscores its substantial potential to generate income, particularly through exports, offering a promising avenue for rural economic development

Nepal holds a noteworthy position in the global landscape, contributing approximately 2.27% of the world's fresh water reserves (CFPCC, 2021). The country's expansive water resources, covering 800,000 hectares of land t in the form of rivers, lakes, reservoirs, marginal swamps, irrigated paddy fields and ponds, serve as the primary foundation for the development of aquaculture and fisheries (CBS, 2015). A recent statistical data reveals the total fish production in Nepal was 77,000 tons, with aquaculture accounting for a substantial 72%, while the remaining 28% is derived from capture fisheries (Kunwar & Adhikari, 2020). It has been expanded to 55 districts of our country. As of 2015/16, domestic fish production contributed a significant 90% to the total national fish consumption, with the remaining 10% sourced from imports. Recent data reveals that aquaculture now constitutes 1.34% of the total Gross Domestic Product and 4.29% of the Agriculture Gross Domestic Product, reflecting its growing economic significance (CFPCC, 2021). The agricultural sector's economic growth is estimated at 2.7%, a testament to the diverse agroclimatic zones and abundant water resources that support various fish species, contributing to biodiversity balance and generating income for marginalized, landless farmers. Despite these strides, Nepal still faces challenges in meeting the per capita demand for fish, leading to substantial fish imports valued at NRs 3 billion from India (MoALD, 2022). While agriculture remains the livelihood for two-thirds of the population, its contribution to the overall GDP is limited to one-third (MoALD, 2022). In 2021, Nepal imported 7,882 tons of fish, a decrease from the 11,176 tons recorded in 2014/15, as reported by the Agriculture Diary (2079). These dynamics highlight the evolving landscape of Nepal's aquaculture and fisheries sector, underlining both achievements and areas for further development.

Dhanusha district, situated in the terai region of Nepal, emerges as a prominent hub for fish production, offering substantial potential for income generation and rural development. The district consists of 2,846 ponds, contributing to a total fish production of approximately 6,734 metric tons, with an impressive yield of 5,200 kg per hectare (CFPCC, 2021). The predominant farming practice in this super zone involves polyculture fish farming, with farmers predominantly raising a mix of exotic and indigenous species, alongside chichilid (Tilapia) and catfish (Pangasius). The key to achieving profitability in fish production lies in effective oversight and management encompassing aspects such as feeding, environmental conditions, nutrients, diseases, and facilities. Concurrently, the present emphasis on intensifying fish culture relies entirely on having access to a nutritionally balanced and cost-effective compounded feed (Kathayat & Tam, 2021). The success of fish farming in Dhanusha can be attributed to favorable climatic conditions, abundant water resources, and elevated temperatures, resulting in a notably high production rate compared to other regions. A good market channel and availability of most of the things in this region to sustain fish production is a building block for the development of aquaculture sector.

Despite being recognized as a production hub, fish farming in Dhanusha operates at a semi-commercial level. According to 2022 data from the Ministry of Agriculture and Livestock Development (MoALD), around 2,300 farmers engage in aquaculture, supported by 20 hatcheries distributing seeds nationwide. While the district contributes significantly to Nepal's aquaculture, it faces challenges in productivity, largely due to limited technological adoption, insufficient technical knowledge, and unscientific feeding practices. Although demand for fish is rising, production remains low, and farmers struggle with market access, theft, and competition from Indian imports. Additionally, the high cost and inconsistent availability of feed, along with fish diseases and a lack of sustainable fingerling supply, hinder progress.

This study aims to evaluate the profitability and resource efficiency of Polycarp production in Dhanusha by examining the socio-demographic profile of farmers, assessing production across locations, identifying production constraints, estimating returns to scale, and ranking challenges. Despite its potential for commercial fish farming due to favorable climatic conditions, the district has yet to fully realize this potential. The findings will assist planning and extension authorities such as PMAMP, GOs, NGOs, and other stakeholders in improving fish farming practices and supporting farmers. By promoting better farming practices and adopting improved technologies, farmers can enhance fish production and profitability in Dhanusha.

## METERIALS AND METHODS

### Description of the study domain

The study was conducted in Madhesh Pradesh, Dhanusha which is also called as the fish hub and super zone of the fish. It lies between 60.89-609.73m above sea level with headquarter at Janakpur. It has a total population of 8,67,747 with an area of 1,180 sq.km (CBS, 2021). It is surrounded by Siraha, Mahottari, Sindhuli district of Nepal, and India from East, West, North and South respectively. Its latitude is 27 $^{0}$34'01.1" N and longitude is 84$^{0}$33'28.2" E. Area covered for this study are Janakpurdam sub -municipality, Aurahi rural municipality, Janaknandani rural municipality, Dhanauji rural municipality, Laxminiya rural municipality and other municipality such as Hansapur, Bideha, Sahidnagar, Kamala, Sawailla, Chhireshwarnath, Mithila Bihari and Dhanusha dham municipality of Dhanusha. These are under the Prime Minister Agriculture Modernization Project

(PMAMP) situated at Murlichowk. In this area, majority of farmers are engaged in aquaculture. But there was significant difference in yield across the different farms of the farmer due to unequal access of the resources.

## Sampling and data collection

Out of 13 local bodies, one rural municipality, two municipality and one sub-metropolitan city was selected as a sampling site with the procedure of cluster sampling. Out of 176 registered farmers/ cooperatives, etc., 64 respondents were selected randomly. Simple random technique provides an equal chance of selection from the given sampling frame (Scheaffer *et al.*, 2011). Sampling procedure also helps to maintain cost and provides good result (Casey & O'brien, 2020). Then we calculated the sample of this research by using Taro Yamane formula having 95% level of confidence (Yamane, 1973). It is given as:

$$n = N/1+N(e)^2$$

where, n=sample size required and e = allowable error (%)

Both primary and secondary data were collected for this study. Primary data were collected through pre-tested questionnaire, KII, focus group discussions. Secondary data were collected from (PMAMP), Agriculture Knowledge Centre (AKC) Dhanusha, district annual report, annual progress report, district profile, various reports from MoAD and CBS, various NGOs and INGOs, Central Bureau of Statistics, cooperatives, bulletins, books and publications of various governmental and non-governmental organizations, journals, websites, etc.

## Data analysis

By using various statistical tools such as MS-Excel, and Statistical Package for Social Science (SPSS) program (Version 25.0). Collected data and information were edited, tabulated and analyzed. These data were analyzed by descriptive analysis of variables like family size, size of land holdings, education status, management practices, etc.

## Cost, return and profitability

The sum of all expenditure involved in the production process is the cost of production. Fixed cost like pond rent per year and the depreciation of various machineries and equipment that are used in farms such as fishing net, aerator, generator, etc. and variable inputs like fertilizer, lime, labour, feed, etc. will be taken into consideration and properly valued for the purpose of calculation of the cost of production. Total cost can be calculated by using the formula:

$$TC=TFC + TVC$$

Where, TC= Total cost, TFC= Total fixed cost, TVC= Total variable cost

$$TVC= C_{\text{labour}} + C_{\text{fertilizer and lime}} + C_{\text{feed}} + C_{\text{others}}$$

Where, $C_{\text{labour}}$ = Total cost of labour in NRs.

$C_{\text{fertilizer and lime}}$ = Total cost of fertilizers and lime in NRs., $C_{\text{feed}}$ = Total cost of feed in NRs.,

$C_{\text{others}}$ = Total cost of electricity, medicine, transportation, irrigation, seed, etc. in NRs.

$$TFC= C_{\text{land rent}} + C_{\text{depreciation}}$$

Where, $C_{\text{land rent}}$ = Total land rent per year in NRs.

$C_{\text{depreciation}}$ = Total depreciation cost in NRs. (Depreciation charge= 10%/annum)

The product of the quantity sold and unit price of the produce is the gross revenue (Total revenue).

$$\text{Gross revenue} = \text{Unit price}^* \text{ Total quantity sold}$$

Gross margin can be calculated by using formula (Okeoghene, 2013):

$$\text{Gross margin (NRs/Kg)} = \text{Gross revenue/kg} - \text{TVC/kg}$$

Net margin can be calculated as:

$$\text{Net margin (NR/kg)} = \text{Gross margin/kg} - \text{TFC/kg}$$

B:C ratio helps to determine whether the investment made on the resources yield the reasonable return or not. This method is fast, simple and easy to know farm's economic performance (Dhakal *et al.*, 2015). The benefit-cost (B/C) ratio will be calculated as:

B/C ratio= Gross return/Total cost

## Production function

Production function expresses a functional relationship between input and output quantities (Jhingam, 1997). This shows that how and by what extent output changes with input variables. Form of production functions to examine resource productivity, efficiency and return to scale are as follows:

$$Y = aX_1^{b1} X_2^{b2} X_3^{b3} X_4^{b4} X_5^{b5} X_6^{b6} e^u$$

Taking log on both sides, we get:

$$\ln Y = \ln a + b_1\ln X_1 + b_2\ln X_2 + b_3\ln X_3 + b_4\ln X_4 + b_5\ln X_5 + b_6\ln X_6 + u$$

Where, Y= Gross return (NRs/ha) = Total quantity produced (KG/ha) * Price of fish (NRs/kg)

a = constant function, $X_1$= labour cost (NRs/ha), $X_2$= fertilizer and lime cost (NRs/ha), $X_3$ = feed cost (NRs/ha), $X_4$ = other cost (NRs/ha), $X_5$= land rent/ year (NRs/ha), $X_6$ = Depreciation (NRs/ha), u = errors, and $b_1, b_2, b_3,$ = coefficient of respective variables

## Resource use efficiency

Resource use efficiency is the condition when the value of product is greater than the cost of added amount of the input/

resource used in producing it. It was calculated by dividing Marginal Value Product (MVP) by Marginal Factor Cost (MFC). It is denoted by 'r'. MVP is calculated by multiplying AVP of inputs with its elasticity of production (b). Their relation are shown as follows (Goni *et al.*, 2013):

For the $i^{th}$ resource/ input, $AVP_{Xi} = \bar{Y} / \overline{X1}$

$MVP_{X1} = b_i * AVP_{Xi}$

Where, $\bar{Y}$ = Geometric mean value of Y, $\overline{X1}$ = Geometric mean value of Xi, Efficiency ratio (r) = MVP/ MFC

criteria for making decisions are as follows:
r=1 means optimum use of resources, r>1 means underutilization of resources, and r<1 means overutilization of resources.

## RESULTS AND DISCUSSION

### Socio-demographics study

Out of a total of 64 respondents, the majority (98.44%) were male, while the rest (1.56%) were female. Three age categories were created for the respondents: under 30, 30 to 50, and above 50. The bulk of responders (65.5%) were in the 30 to 50 age range, followed by 50+ (21.9%) and then <30 (12.5%). The mean age was found to be 40.68, with a standard deviation of 8.37. The maximum and minimum age were 26 and 56, respectively. It was noticed that the majority of the respondents were Yadav (27%), followed by Mukhiya, Kewat, Mahato, Sahani, and Mandal, comprising 27%, 17%, 12%, 11%, and 2%, respectively. The most important socio-demographic factor driving social and cultural changes is education. It directly affects the level of awareness and adoption of technologies. The majority of the respondents had attained a secondary level of education (36.7%), equivalent to the 12th standard, followed by a graduate level (26.7%), basic level (20%), equivalent to the 8th standard, literate (13.3%), and post-graduate level and illiterate, both 1.7% each. The majority of the respondents were involved in fisheries (50%) as their major occupation, followed by crop-based agriculture (32%), livestock farming (5%), service (8%), and industrial business (5%). The study revealed that 23.43% of the respondent's own land, 7.81% operate farms on partnership, and the remaining 68.76% have leased land. The average water surface area was 1.55 hectares, with a maximum and minimum water surface area of 8 hectares and 0.2 hectares, respectively. Most farmers in this region practice carp polyculture. This is because carp polyculture excels in intensive fish farming by satisfying protein requirements with natural fish food, avoiding the expense of external protein sources such as fish meal (Kathayat *et. al.*, 2021). Seven species were reared, including Bhakur, Bighead carp, Naini, Silver carp, Rohu, Common carp, and Grass carp. Among the respondents, 16 (25%) reared all 7 species, 32 (50%) reared 6 species, 10 (15.63%) reared 5 species, 4 (6.25%) reared 4 species, and 2 (3.12%) reared 2 species. In contrast, the 6 species rearing system excludes Naini, the 5 species rearing system excludes Bhakur and Silver carp, and the 4 species rearing system excludes Bhakur, Rohu, and Common carp. Similarly, the 2 species rearing system includes just silver carp and Common carp, respectively. The average stocking density was found to be 15,307 per hectare of water surface area, which is greater than the recommended 13,500 per hectare.

### Farm characteristics

Fish farmers in the study region were categorized into two groups based on the depth of their ponds: <1.5metres and 1.5-2 meters. The depth of the pond plays a crucial role in influencing the growth and survival of fish. As indicated in the findings, 25% (16) of the participants had ponds with depths below 1.5 meters, while the majority, constituting 75% (48), maintained ponds with depths falling within the recommended range of 1.5 to 2 meters for optimal fish cultivation. The majority of respondents (53.1%) purchased fingerlings from private hatcheries, while 39.1% obtained them from both government farms and private hatcheries, and 7.8% relied solely on government farms. Single harvesting per year was the practice followed by most respondents (58.33%), with the remaining 41.67% opting for biannual fish harvesting.

### Cost of production

The average annual cost of producing carp fish amounted to Rs. 10,69,644 or Rs. 8,91,370 per hectare of water surface per year. Fixed costs constituted 15.55% (Rs. 1,66,224) of the total production costs, while variable costs accounted for the remaining 84.45%, totaling Rs. 9,03,420. The most substantial cost was attributed to feed, representing approximately 49.87% of the overall expenses, followed by labor (15.52%) and fingerling costs (9.40%). Other costs, such as fertilizers, medicine, lime, electricity and fuel, transportation, and miscellaneous, comprised 4.75%, 0.97%, 1.94%, 1.51%, 0.97%, and 0.47%, respectively. Fixed costs included land value, depreciation value, and pond renovation, making up 6.59%, 4.28%, and 4.68% of the total cost, respectively. The breakdown of the carp fish production costs per year is detailed in Table 1. The total returns from carp polyculture amounted to Rs. 11,37,657.84 per hectare per year, with observed minimum and maximum returns of Rs. 423,456.95 and Rs. 3,326,734.67, respectively. Similarly, the net return was calculated to be Rs. 2,24,348.87, ranging from a minimum of Rs. -15,21,637.84 to a maximum of Rs. 12,73,421.45 per hectare per year. The negative sign indicates that some farmers were experiencing losses.

Gross margin= Total returns -Total variable cost

= 11,37,657.84 – 7,52,850.00 = 3,84,807.84 per hectare

Cost per ha = cost / land area in ha = 10,69,644/ 1.192 = 8,91,370

## Benefit and cost ratios

It was observed that the B:C ratio averaged 1.33. Ponds with a water surface area greater than 1 hectare showed a relatively higher B:C ratio of 1.70 compared to ponds with a water surface area less than 1 hectare, where the ratio was 1.27. A B:C ratio exceeding 1 indicates the profitability or benefit of Polycarp farming. An experiment conducted in Chitwan, Nepal, aimed to assess the B:C ratio in various culture systems. Three different practices were studied: carp polyculture, carp polyculture integrated with pigs, and carp polyculture integrated with ducks. The study suggested a B:C ratio of 1:3 without integration, while with integration, the ratios were suggested to be 1.65 and 1.6 with pig and duck integration, respectively (Kathayat *et al*., 2021; Banmali *et. al*., 2021).

## Cost, return, profitability and productivity analysis

In comparison to larger water surface areas (>1 ha), the productivity of the carp polyculture system was found to be higher for smaller water surface areas (<=1 ha), with larger ponds having a productivity of 4.71 and smaller ponds of 5.58, respectively. A t-value of 2.02 at the 5% level of significance indicated significant differences in productivity. Larger water surface areas were found to incur higher annual operating costs (Rs. 12,99,844.64) than smaller water surface areas (Rs. 6,52,432.63). A highly significant result was revealed at the 1% level of significance, with a t-value of -3.08. In terms of net returns, larger water surface areas (Rs. 62,987.29) outperformed smaller water surface areas (Rs. 64,367.67). The t-value of -4.34 at the 1% level of significance indicated highly significant results. Moreover, larger water surface areas (B:C ratio of 1.7) exhibited a greater B:C ratio compared to smaller water surface areas (B:C ratio of 1.27), with a mean difference of 0.43 and an overall B:C ratio of 1.33. A t-value of -3.96 was obtained, indicating highly significant results at the 1% level of significance.

**Table 1.** Item wise cost of production per year.

| Particulars | Cost (Rs.) | Percentage (%) |
|---|---|---|
| **Production cost** | | |
| Fingerlings | 100540.36 | 9.40 |
| Feed | 523458.95 | 49.87 |
| Fertilizers | 50783.64 | 4.75 |
| Labor | 165984.69 | 15.52 |
| Medicine | 10342.12 | 0.97 |
| Lime | 20735.45 | 1.94 |
| Electricity and fuel | 16203.41 | 1.51 |
| Transportation | 10367.93 | 0.97 |
| Miscellaneous | 5003.45 | 0.47 |
| TVC | 903420.00 | 84.45 |
| Fixed cost | | |
| Pond renovation | 50023.20 | 4.68 |
| Land | 70437.85 | 6.59 |
| Depreciation | 45762.95 | 4.28 |
| TFC | 166224.00 | 15.55 |
| Total cost | 1069644.00 | 100 |
| Total cost per ha | 891370.00 | |

**Table 2.** Cost, return, profitability and productivity comparison based on water surface area.

| Variable | Water surface area | | Overall | Mean difference | t-value | p-value |
|---|---|---|---|---|---|---|
| | <1 ha (N=24) | >1 ha (N=40) | | | | |
| Productivity | 5.58 | 4.71 | 5.1 | 0.87 | $2.02^{**}$ | 0.032 |
| Operational cost | 652434.63 | 1299844.64 | 890432 | 647410.41 | $3.08^{***}$ | 0.001 |
| Net returns | 64367.67 | 762987.29 | 42367.3 | 698620.02 | $4.34^{***}$ | <0.001 |
| BCR | 1.27 | 1.7 | 1.33 | 0.43 | $3.72^{***}$ | <0.001 |

**Table 3.** Description of variables used in regression.

| Variables | Description | Mean | S.D. |
|---|---|---|---|
| Ln gross returns | Annual gross returns obtained from carp fish farming (Rs.): Dependent variable | 12.8612 | 0.61249 |
| Ln area | Total water surface area under carp fish farming (ha) | 0.2642 | 0.75438 |
| Ln feed cost | Total annual cost on feed (Rs.) | 12.1682 | 0.86539 |
| Ln fingerling cost | Total annual cost on fingerlings (Rs.) | 11.5183 | 0.97531 |
| Ln labor cost | Total annual cost on labor (Rs.) | 12.0864 | 0.88654 |
| Ln fertilizers cost | Total annual cost on fertilizers (Rs.) | 10.7456 | 0.99087 |
| Ln stocking density | Average number of fingerlings stocked per ha of production pond (per ha) | 9.6552 | 0.54388 |

**Table 4.** Regression estimates of factors affecting gross returns from carp polyculture.

| Variables | Unstandardized coefficients |  | Standardized coefficients | t-value | p-value |
|---|---|---|---|---|---|
|  | B | Standard Error |  |  |  |
|  | 10.376 | 1.013 |  | 10.082*** | 0.000 |
| Ln area | 0.483 | 0.046 | 0.504 | 6.273*** | 0.000 |
| Ln feed | 0.345 | 0.034 | 0.398 | 5.912*** | 0.000 |
| Ln fingerlings | 0.047 | 0.042 | 0.057 | $0.519^{ns}$ | 0.621 |
| Ln labor | -0.063 | 0.027 | -0.075 | $-1.183^{ns}$ | 0.284 |
| Ln fertilizers | 0.216 | 0.023 | 0.159 | 2.374** | 0.022 |
| Ln stocking density | -0.101 | 0.063 | -0.071 | $-1.285^{ns}$ | 0.148 |

**Table 5.** Correlation results between variable costs and gross returns from carp polyculture.

| Variables | Correlation | p-value |
|---|---|---|
| Fingerlings | 0.592*** | <0.001 |
| Feed | 0.763*** | <0.001 |
| Fertilizers | 0.582*** | <0.001 |
| Labor | 0.243 | 0.061 |
| Medicine | 0.813*** | <0.001 |
| Lime | 0.395*** | 0.003 |
| Electricity and fuel | 0.623*** | <0.001 |
| Transportation | 0.784*** | <0.001 |
| Miscellaneous | 0.426*** | 0.004 |

### Production function analysis

To investigate the impact of various factors on the gross income of Polycarp production, the Cobb-Douglas model was employed. Explanatory variables in the model included water surface area, labor cost, feed cost, fingerlings cost, stocking density, and fertilizer cost. All explanatory factors, except for labor cost and stocking density, exhibited positive coefficients. The coefficient for the water surface area under the carp polyculture system was positive and highly significant, suggesting that a 1% increase in the area may lead to a 0.504% improvement in gross income, ceteris paribus. Similarly, positive and highly significant coefficients for feed costs were observed, indicating that a 1% increase in feed expenditure may result in a 0.398% rise in gross income, ceteris paribus. Fertilizer costs also showed significance at the 5% level, signifying that a 1% increase in fertilizer expenditure may lead to a 0.224% increase in gross income, ceteris paribus. Although the cost of fingerlings had a positive coefficient, it was determined to have non-significant effects on gross income. Negative and non-significant coefficients were obtained for labor cost and stocking density. The sum of regression coefficients obtained from the Cobb-Douglas production function was 0.972, indicating decreasing returns to scale. The returns to scale value of 0.972 suggests that a 1% increase in all inputs included in the production function may result in a 0.972% increase in income. Regression estimates for different factors are provided in table 4. For the carp polyculture system, the coefficient of multiple determination ($R^2$) of the model was determined to be 0.892. This means that the explanatory variables used in the production function model accounted for 89.2% of the variation in the gross income from carp polyculture, as reflected by the $R^2$ value of 0.892. The adjusted $R^2$ value, which considers the model's useful independent variables, indicated that 87.3% of the variation in the dependent variable could be explained (adjusted $R^2 = 0.873$). The model demonstrated the best fit with an F-value of 50.134, highly significant at the 1% level, indicating that all the inputs were relevant in explaining the variation in total returns from carp polyculture in the research region.

### Resource use efficiency

It is the condition when the value of products surpasses the cost of the additional amount of resources used in its production. Labor and feed costs are overused, as their value (MVP/MFC) is smaller than 1. In contrast, other costs have a value greater than 1, indicating that they are considered underused.

## Conclusion

Carp polyculture emerged as the dominant fish farming system in the study area, with 50% of respondents relying on it as their primary occupation. The average water surface area used was 1.55 hectares, yielding a net annual return of Rs. 224,348.87 per hectare and a production cost of Rs. 891,370 per hectare. Feed costs represented the largest expense, while labor and fingerling costs had no significant impact on gross income. Key factors influencing gross income were water surface area, feed costs, and fertilizer costs. Smaller ponds demonstrated higher productivity, while larger ponds showed greater operating costs, net returns, and profitability. The B:C ratio of 1.33 confirmed the economic viability of carp polyculture, with silver carp as the main species produced. Despite its profitability, challenges such as inconsistent feed and fingerling quality, theft, insufficient fertilizers, and water scarcity were prevalent. Addressing these issues through timely supply of inputs and enhanced technical support will be critical for improving productivity and sustainability in carp polyculture.

## DECLARATIONS

**Author contribution statement:** Conceptualization: B.R. and K.G.; Methodology: B.R., K.G.; Software and validation: BR.; Formal analysis and investigation: B.R and S.P.; Resources: K.G.; Data curation: B.R. and S.P.; Writing—original draft preparation: BR and HK; Writing—review and editing: B.R., S.P., H.K., and K.G.; Visualization: B.R., K.G.; Supervision: K.G.; Project administration: B.R., H.K. and K.G. All authors have read and agreed to the published version of the manuscript.

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