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Research Article

Physico-chemical characteristics of water of tribal community ponds and their efficacy in carbon recovery

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Abstract

Carbon recovery from fish ponds typically involves the utilization of organic waste generated within the pond system. Six perennial rain-fed tribal ponds in Gumla district, Ranchi, were selected and divided into two categories based on feeding (Kapardar P1; Daldali P2 & Suri P3) and non-feeding (Kari P4; Umra P5 & Tilaidih P6) type fish farming. Indian Major Carps (IMC) fingerlings were stocked @ 12,000 ha^{-1} in P1-P2, 6,450 ha^{-1} in P3 and 10,500 ha^{-1} in P4. IMC fry was stocked @ 7,500 ha^{-1} in P5 and P6. Pelleted feed was applied in ponds (P1-P3) @ 4% of the fish biomass. Pond management and harvesting in all experimental ponds were performed by pond owners. The mean values of water quality parameters were within the optimum range, and 16 species of phytoplankton and 6 species of zooplankton varied in all ponds (240-10,488 no./L). Carbon recovery efficiency in feeding ponds varied from 0.045-0.086 kg/ kg fish production. For 1 kg carbon retention in fish biomass, 0.381 kg, 0.746 kg and 0.585 kg carbon was fed through feed in P1, P2 & P3 ponds, respectively. In the present study, carbon retention in IMC varied from 2.07 to 6.49% and 1.01 to 1.45% in the water at the time of fish harvest.

Keywords: Carbon efficiency, Carbon retention, Feeding pond, Fish harvest, Physico-chemical

Highlights

- Carbon recovery efficiency in feeding ponds varied from 0.045-0.086 kg/ kg fish production.
- Carbon retention in IMC varied from 2.07 to 2.79% in non fed ponds compared to 3.81 to 6.49% in fed ponds.

INTRODUCTION

Fish farming in tribal ponds is traditionally practiced by certain indigenous or ab-origin communities. In terms of production, tribal fish ponds in India contribute around 10% of the total fish production (Lekshmi et al., 2014). They generally don't use any fertilizer and manure except lime for preparation of their fish ponds. Although fish production largely depends on the pond productivity, augmented by the fertilizer and manure (Lekshmi et al., 2014). Application of fertilizer, manure and fish feed in aquafarming attributes emission of carbon dioxide (CO_2) which is also a major concern to the environment due to greenhouse gas emissions along with methane (CH_4) (Adhikari et al., 2018). Aquaculture ponds contain about 45-50% carbon as primary source of all organic matter. Ponds bury or sequester carbon in their sediments, accumulated as organic matter.

Shape of fish pond is considered as an important factor in determining the fish growth (Imsland et al., 2006). Temperature on the other hand, affects the rate of metabolism including growth rate, egg formation, maturation, food consumption and digestion, etc. (Jonassen et al., 1999, Chen et al., 2022). The dynamics and management of water quality must be considered for a successful aquaculture venture (Sikoki & Veen, 2004). The importance of physico-chemical factors in maintaining healthy aquatic environment and producing enough fish food organisms in ponds to increase fish production is well established (Bhatnagar & Devi, 2013).

Limited field-based studies are available regarding the physico-chemical characteristics of traditional tribal fish ponds and carbon recovery (Sarker et al., 2018).

In the global carbon cycle, ponds can play a dual role. They have the capacity to store carbon through sedimentation, as well as important greenhouse gas emitters (Girard et al., 2024). Girard et al. (2024) also reported that carbon sedimentation was higher than emissions in fish ponds under water, but also a dry year was characterized by important C emissions. Fish

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feed carbon recovery was reported to be 24.5%, and carbon dioxide sequestration was 1.4 times higher than the feed carbon in an aquaponics system (Zhu et al., 2022). Gumla district in Ranchi, Jharkhand, is home to a diverse range of tribes, including the Santhal, Munda, Oraon, and Ho, each with unique cultural practices and traditions. Presently, aquaculture is expanding in these areas. Earlier, people used to stock only fish seeds. Now they are using fish feeds also for the growth of the fish. The fish feed mainly contains carbohydrates, protein, fats, and minerals. Carbon is the base component of carbohydrates. The uneaten fish feed may act as an important factor for global warming because of carbon's presence in the feed. Thus, the conversion of carbon in fish feed into fish flesh is very important. In the process of carbon conversion into fish flesh, the physico-chemical parameters of water could play a vital role. After recognizing the important water quality parameters, different management practices could be evolved for the enhancement of carbon conversion into fish flesh. In this way, the chance of global warming will be reduced from aquaculture practices. Thus, the present investigation is undertaken to study the efficacy of physico-chemical parameters of water in carbon recovery through fish production in these tribal ponds in Gumla, Ranchi.

MATERIALS AND METHODS

This study was conducted to assess the physico-chemical condition of water & soil in tribal fish ponds in Gumla, Ranchi. Six fish farming ponds were randomly selected in different residential area. In category-1, feeding ponds were Kapardar pond (P1), Daldali pond (P2), Suri Pond (P3) and in category-2, the non-feeding ponds were Kari Pond (P4), Umra pond (P5), and Tilaidih pond (P6) (Table 1). Monthly sampling of physico-chemical parameters was done from January 2022 to December 2022 in all six ponds for abiotic [temperature, pH, dissolved oxygen, free CO_2, total alkalinity, hardness, transparency, dissolved organic carbon (DOC) and conductivity] and biotic (plankton and fish) parameters. In accordance with the American Public Health Association [APHA] (2022), water samples were collected for the analysis of various physico-chemical parameters. To obtain the plankton sample, 50 L of water were strained through a plankton net made of bolting silk no. 25 (0.064 mm mesh size). The plankton samples were then preserved by adding 2-4% formaldehyde solution for further study.

In the present investigation, the morphological characteristics of six culture ponds were studied (Table 1). All the ponds were perennial and fed with only rainwater. Other than fish farming, ponds were used for human & cattle bathing and cloth washing purposes. Six ponds were used for the present study in this area, among which three ponds received some feeds for the culture, while the other three ponds did not receive any inputs except fish seeds. The carbon recovery was done for the ponds where feed was applied. Other ponds were not considered for carbon recovery as these ponds did not receive any inputs other than fish seeds. The feed contained 30-32% carbon.

IMC fingerlings (Catla, Rohu & Mrigal) were stocked @ 12,000 ha^{-1} in P1-P2; 10,500 ha^{-1} in P4 and 6450 ha^{-1} in P3. IMC fingerlings were stocked @ 7500 ha^{-1} in P5 & P6 by the selected fish farmers. In the tribal area, few farmers were practicing fish culture. Accordingly, the ponds were chosen randomly. The stocking ratios of three fish species were (C-15: R-80: M-5); (C-40: R-30: M-30) and (C-15: R-80: M-5) in feeding ponds P1, P2 & P3, respectively. In non-feeding ponds, fish stocking ratio was (C-40: R-30: M-30) in P4, (C: 35, R: 35, M: 30) in P5 and P6. The weight of stocking fish fingerlings in P1-P2 was as follows: Catla (46.33 g±7.63), Rohu (35.33 g± 9.29) & Mrigal (20.33 g±6.80). Fish fry of Catla (5.65 g±0.21), Rohu (4.4 g±0.28) & Mrigal (3.5 g±0.14) were stocked in P5 & P6 based on traditional fish farming practices. Stocking density of

Table 1. Morphology of the selected ponds and name of the farmers

Pond Name	Feeding/ Non-feeding	Farmerscode Number	Shape	Water area (ha)	Nature of Bottom	Mean depth (mt)
Kapardar (P1)	Feeding	P1 F1	Rectangular	1.62	Muddy	1.8
Daldali (P2)	Feeding	P2 F2	Rectangular	1.62	Muddy	1.5
Suri (P3)	Feeding	P3 F3	Square	0.7	Muddy	1.8
Kari (P4)	Non-feeding	P4 F4	Square	1.42	Muddy	1.8
Umra (P5)	Non-feeding	P5 F5	Square	1.0	Muddy	1.5
Tilaidih (P6)	Non-feeding	P6 F6	Rectangular	1.0	Muddy	1.5

F1 - F6: Code number of different fish farmers these ponds varied due to the different sizes of the pond. Mixture of mustard oil cake and wheat flour (1:1) was applied as fish feed along with pelleted feed in feeding ponds (P1, P2 &P3) as and when required. Lime @ 100 kg $ha^{-1}year^{-1}$ was applied in feeding ponds. Pelleted feed was applied to the fish ponds @ 4% of the fish biomass (Falaye et al., 1999). Fish seed were collected from local fish seed hatchery in Gumla. The culture period was 350 days. Partial fish harvesting was done in all ponds after a period of 120-150 days of culture. No fertilizers were applied in the ponds.

To determine initial and final carbon levels in water, samples were collected prior to fish stocking and at the time of harvesting. Different physico-chemical parameters were determined according to the American Public Health Association [APHA] (2022). The water and sediment samples were refluxed with potassium dichromate ($K_2Cr_2O_7$) for organic carbon (OC). After air drying, these sediment samples were pulverized to pass by 0.25 mm screen and then analyzed for organic carbon (OC). For the measurements of OC from the fish feed (Pelleted feed, mustard oil cake, and wheat flour) and carcasses of harvested fish were freeze-dried and pulverized to pass by a 0.85-mm screen. Total OC was determined by the rapid titration method after oxidation using Potassium permanganate ($KMnO_4$) and concentrated sulfuric acid (Walkley & Black, 1934).

The survival rate, mean fish body weight, and total production of fish were determined. For carbon analysis, fish was sacrificed as per the ethics of the University protocol. For each pond, the inputs through water and feed and the outputs through water at harvested time, sediment and harvested fish were calculated. The nutrient content in sediment was calculated as follows:

Nutrient concentration in the sediment x Total sediment mass.

The total sediment mass was determined from the mean bulk density of the sediment.

Nutrient organic carbon (OC) input in feed was calculated as follows:

1) Nutrient concentration in feed x Total feed applied.

Nutrient (OC) output through fish was calculated as follows:

2) Nutrient concentration in fish carcasses x Total fish biomass.

Carbon recovery efficiency: Carbon recovery efficiency was calculated as carbon in feed (kg)/kg of fish produced. The recovery means the amount of feed carbon was converted into fish flesh. Feed is the only source of carbon. Rainfall, run-off, or plankton was not considered in the recovery efficiency.

The collected data of the water sample was grouped into three categories, i.e., summer, monsoon and winter seasons.

Data analysis: Correlation analysis (r) was performed to estimate the degree of association among multiple variables involved in the study with C use efficiency. ANNOVA was performed for the significant differences of the physico-chemical parameters, if any among the ponds, and also for the differences of carbon recovery efficiency among the ponds.

RESULTS

The results of different water quality parameters of the fish ponds are as follows:

Temperature: The mean value of water temperature ranged from 12 to 29°C. The maximum value was (24.0±4.59) in P2 in summer season and minimum value (14.3±2.51) was observed in P6 in winter season (Table 2, Fig. 1). The differences of temperatures among various ponds were not significant ($P>0.05$; $F=0.02853$; $P=0.999495$).

pH: The mean pH values of the six ponds (P1-P6) were analyzed and maximum value (8.3±0.47) was recorded in P2 in the winter season and minimum value (6.8±0.57) was observed in P6 in the same season (Table 2, Fig. 2). The differences were not significant ($P>0.05$; $F=2.3298$; $P=0.10679$).

Dissolved oxygen: The mean DO value of six ponds P1-P6 was calculated and maximum value (7.32±1.30) mg/L was recorded in P6 in the monsoon season and minimum value (5.15±1.43) mg/L was observed in P3 in the summer season (Table 2, Fig. 3). The differences were not significant ($P>0.05$; $F=1.3352$; $P=0.314219$).

Transparency: The mean transparency value of six ponds P1-P6 was calculated and maximum value (28.0 cm±3.91) was recorded in P2 in the summer season and minimum value (17.3 cm±2.28) was observed in P2 & P3 in monsoon season (Table 2, Fig. 4). The differences in transparency among different ponds were not significant ($P>0.05$; $F=0.1968$; $P=0.9577$).

Alkalinity: The mean total alkalinity value of ponds was calculated, and P3 exhibited maximum value

(224.7±38.16 mg/L as $CaCO_3$) in the winter season, and minimum value (59.6±26.27 mg/L as $CaCO_3$) was recorded in P6 in winter (Table 2, Fig. 5). The differences of total alkalinity among ponds were significant (P<0.05; F=7.5295; P=0.002065).

Carbon dioxide: Both free and dissolved CO_2 are absorbed by plants to produce glucose via the carbon pathway. The mean value of CO_2 was 2.2-12.0 mg/L. The maximum value was (3.1±0.93) in P6, and minimum value (1.3±0.21) was observed in P3 in the summer season (Table 2, Fig. 6). The differences of carbon dioxide among various ponds were not significant (P>0.05; F=0.329255; P=0.329285).

Hardness: The mean hardness value of six ponds P1-P6 was calculated, and maximum value (170.0±39.85) was recorded in P3 in the summer season and minimum value (61.6±24.66) was observed in P1 in the winter season (Table 2, Fig. 7). The differences of hardness among different ponds were significant (P<0.05; F=9.3910; P=0.000782).

Conductivity: The mean value of conductivity was 0.15-0.90 µmhos. The maximum value was (0.60±0.19) in P2 in the summer season, and minimum value (0.24±0.09) was observed in P1 in the winter season (Table 2, Fig. 8). The differences of conductivity among different ponds were significant (P<0.05; F=3.252974; P=0.043672).

Table 2. Mean± SD of physico-chemical parameters of the fishponds.

Parameter ponds	Season	Summer	Monsoon	Winter
Water	P1	23.7±4.99[c]	22.4±4.03[c]	15.6±2.56[b]
Temp (°C)	P2	24.0±4.59[c]	22.5±4.41[c]	15.1±2.56[b]
	P3	23.8±4.44[c]	22.3±4.48[c]	15.0±2.24[b]
	P4	23.8±4.37[c]	21.7±4.06[c]	14.7±2.20[b]
	P5	23.2±4.03[c]	21.4±4.04[c]	14.4±2.33[b]
	P6	23.0±4.15[c]	21.2±4.27[bc]	14.3±2.51[b]
pH	P1	7.5±0[a]	8.0±0.40[a]	7.5±0[a]
	P2	7.5±0[a]	8.0±0.40[a]	8.3±0.28[a]
	P3	7.7±0.50[a]	8.3±0.47[a]	7.5±0[a]
	P4	7.7±0.50[a]	8.1±0.25[a]	8.0±0.50[a]
	P5	7.6±0.25[a]	7.7±0.28[a]	7.8±0.57[a]
	P6	7.6±0.25[a]	7.1±0.75[a]	6.8±0.57[a]
Transparency	P1	23.2±8.99[c]	17.8±0.76[b]	23.5±3.29 [c]
(cm)	P2	28.0±3.91[c]	17.3±2.30[b]	19.5±4.35[b]
	P3	27.3±2.28[c]	17.3±2.28[b]	19.0±4.83[b]
	P4	27.3±3.44[c]	17.7±2.40[b]	22.1±7.96 [c]
	P5	26.7±2.50[c]	19.3±3.61[b]	19.8±3.49[b]
	P6	19.8±2.25[bc]	18.8±1.04[b]	19.0±3.28[b]
Dissolved	P1	6.80±1.22[a]	6.20±1.24[a]	6.13±2.54[a]
oxygen (mg/L)	P2	6.03±0.95[a]	6.40±1.42[a]	6.20±1.00[a]
	P3	5.15±1.43[a]	6.65±1.43[a]	5.23±0.35[a]
	P4	6.35±0.86[a]	7.15±0.95[a]	5.60±1.05[a]
	P5	6.70±1.04[a]	7.10±1.50[a]	6.70±0.55[a]
	P6	5.70±1.14[a]	7.33±1.30[a]	7.20±0.80[a]
Alkalinity	P1	132.2±40.50[b]	86.5±33.32[a]	64.3±22.50[a]
(mg/L)	P2	187.5±32.75[b]	197.5±50.12[bc]	140.3±23.45[b]
	P3	224.7±38.16[c]	211.5±51.67[c]	175.3±10.01[b]
	P4	176.7±34.26[b]	222.5±44.97[c]	175±15[b]
	P5	122.0±8.12[b]	119.5±46.34[b]	88.6±28.02[a]
	P6	145.0±9.41[b]	109.5±71.69[b]	59.6±26.27[a]
$C0_2$ (mg/L)	P1	3.7±1.29[a]	7.2±2.99[b]	8.4±2.02[b]
	P2	3.7±1.42[a]	7.8±3.65[b]	9.6±1.13[bc]
	P3	5.0±1.54[ab]	6.8±2.12[b]	7.0±2.90[b]

Cont. Table 2.

Plankton: The total planktons varied in all six fish ponds assigned for the present study was 240-10,488 no^{-L}. The season-wise total plankton counts varied from (540.0-814.5 no/L) in P1, (658.7- 931.5 no/L) in P2, (620.0-1068.0 no/L) in P3, (923.0-5730.0 no/L) in P4, (362.0-558.0 no/L) in P5 and (312.3- 610.5 no/L) in P6 (Table 2, Fig. 9). The differences were not significant (P>0.05; F=2.875423; P=0.062138).

Dissolved organic carbon: The mean dissolved organic carbon value of six ponds P1-P6, was calculated, and the maximum value (13.2±1.50) was recorded in P1 in the summer season and minimum value (9.3±1.15) was observed in P4 in the winter season (Table 2, Fig. 10). The differences were not significant (P>0.05; F=1.45675; P=0.2740).

Carbon efficiency in fish feeding ponds

The carbon use efficiency of feeding ponds is presented in Table 3. The Kapardar fish pond, feed carbon efficiency was 0.045 kg per kg of fish production. Overall, 0.381 kg carbon was fed for each kilogram of carbon retained in fish biomass, indicating that a

Table 2., Cont. ...

Parameter ponds	Season	Summer	Monsoon	Winter
	P4	3.4±0.69^{a}	5.8±3.01^{b}	7.7±0.66^{b}
	P5	3.4±0.80^{a}	5.5±1.86^{b}	7.3±1.13^{b}
	P6	3.1±0.93^{a}	6.2±2.38^{b}	5.7±1.97^{b}
Hardness	P1	97.7±32.52^{bc}	71.0±30.30^{b}	61.6±24.66^{b}
(mg/L)	P2	155.5±29.62^{d}	125.2±14.54^{c}	117.0±7.54^{c}
	P3	170.0±39.85^{d}	146.0±26.22^{c}	132.0±8.00^{c}
	P4	163.5 ±8.88^{d}	168.2 ±8.34^{d}	166.3±25.14^{d}
	P5	120.2 ±23.09^{c}	103.7 ±48.85^{c}	106.0±45.03^{c}
	P6	129.0 ±16.85^{c}	102.2±67.60^{c}	70.0 ±34.64^{b}
Conductivity	P1	0.31±0.05^{a}	0.28±0.06^{a}	0.24±0.09^{a}
(mmhos)	P2	0.60±0.19^{b}	0.34±0.03^{a}	0.42±0.02^{a}
	P3	0.48±0.17^{a}	0.48±0.13^{a}	0.47±0.10^{a}
	P4	0.37±0.09^{a}	0.32±0.07^{a}	0.38±0.05^{a}
	P5	0.42±0.12^{a}	0.30±0.06^{a}	0.35±0.05^{a}
	P6	0.47±0.16^{a}	0.32±0.04^{a}	0.43±0.04^{a}
Plankton	P1	814.5±29.54^{b}	540±79.37^{b}	
799.5±167.59^{b}				
(No/L)	P2	864±144.99^{b}	658.66±79.4^{b}	931.5±98.75^{b}
	P3	1068±666.33^{c}	620±69.28^{b}	808.5±65.79^{b}
	P4	5730±3995.97^{f}	923±52.50^{b}	2490±276.73^{e}
	P5	558±126.61^{b}	362±57.02^{a}	486±141.39^{a}
	P6	610.5±396.40^{b}	312.33±12.50^{a}	422±304.98^{a}
Dissolve	P1	13.2±1.50	12.7±2.21	11.0±1.00
organic	P2	10.5±0.57	10.2±0.50	10.6±0.57
Carbon (ppm)	P3	11.2±0.95	10.2±0.50	12.0±1.00
	P4	12.2±1.70	10.2±2.06	9.3±1.15
	P5	12.5±1.00	10.5±1.00	10.3±0.57
	P6	10.5±0.57	11.0±0.81	10.0±0.00

P1 - P6: Code number of different fish pond

Table 3. Carbon use efficiency (kg/kg fish produced) of feeding fish ponds

C use efficiencies	Kapardar pond	Daldali pond	Suri
Feed (kg C fed/kg of fish produced) (kg/ha)	0.045	0.086	0.063
Feed (kg C fed/kg C retained in fish biomass) (kg/ha)	0.381	0.746	0.585

Table 4 . Correlation coefficient (r) of different water parameters with carbon recovery efficiency in three feeding ponds

Water quality parameters	Kapardar pond	Daldali pond	Suri pond
Temperature	0.78	0.77	0.96
pH	0.86	0.37	0.31
Transparency	0.88	0.19	0.72
Dissolved oxygen	0.09	0.50	0.03
Alkalinity	-0.32	0.93	0.98
CO_2	0.24	0.29	0.87
Hardness	0.25	0.20	0.97
Conductivity	0.56	0.30	0.90
Dissolved organic	0.73	0.96	0.51
carbon plankton	0.84	0.95	0.50

Values more than 0.50 were significantly (P<0.05) correlated

considerable amount of carbon was wasted through feeding; in Daldali fish pond, feed carbon efficiency was 0.086 kg per kg of fish production. Overall, 0.746 kg carbon was fed for each kilogram of carbon retained in fish biomass, indicating that a good amount of carbon was utilized by the fish through feeding in the Daldali fish pond. In Suri fish pond, feed carbon efficiency was 0.063 kg per kg of fish production. Overall, 0.585 kg carbon was fed for each kilogram of carbon retained in fish biomass, indicating that a considerable amount of carbon was utilized by the fish through feeding in the Suri pond. The carbon use efficiency per kilogram of fish production among the ponds is highly significant ($P<0.01$; $F=104.9052$; $P=2.15E-05$). The carbon use efficiency per kilogram carbon retained in fish biomass among the ponds is also highly significant ($P<0.01$; $F=483.4$; $P=2.35E-07$).

Relationship of Carbon use efficiency with different water quality parameters: Carbon use efficiency (C recovery efficiency) with different water quality parameters for the fish ponds was estimated using the correlation coefficient (r) and is presented in Table 4. It is evident from the table that water temperature, dissolved organic Carbon, and plankton were strongly correlated with C use efficiency for all three feeding ponds. For other water quality parameters, no definite association was observed with the C use efficiency. For example, pH was strongly correlated with C use efficiency in Kapardar pond, while the same was not significantly correlated in the other two ponds. Alkalinity was strongly correlated with C use efficiency in Daldali and Suri ponds. Dissolved oxygen was

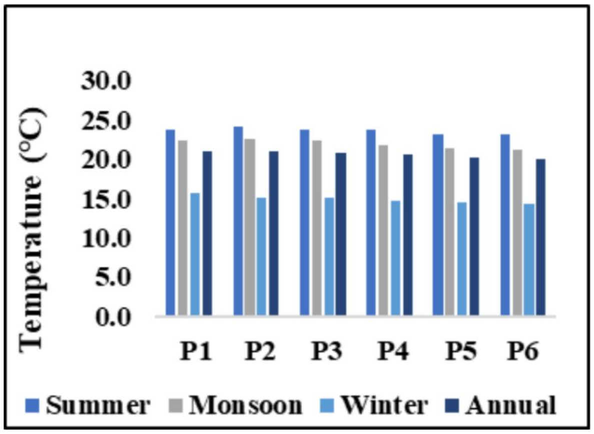

Fig. 1. Temperature (°C)

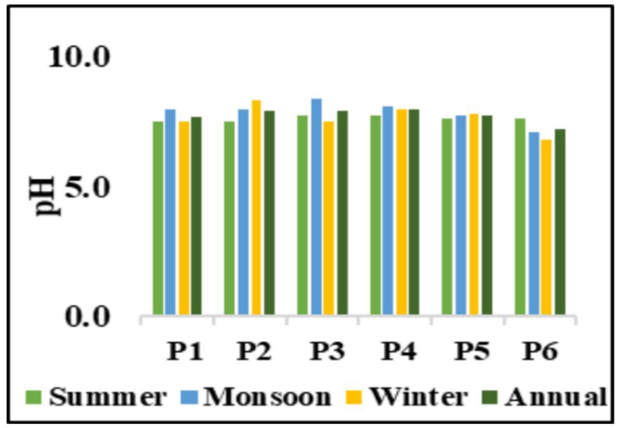

Fig. 2. pH

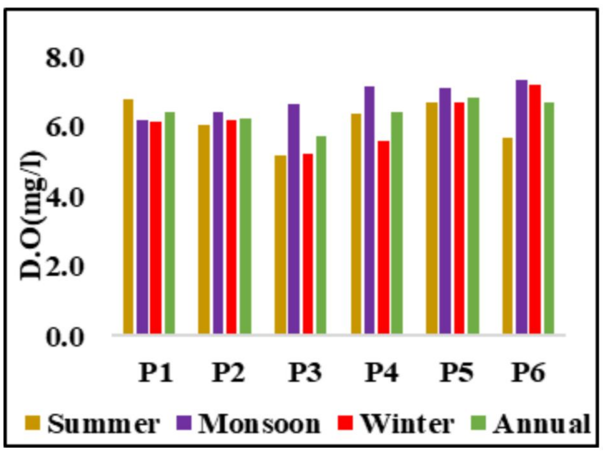

Fig. 3. Transparency

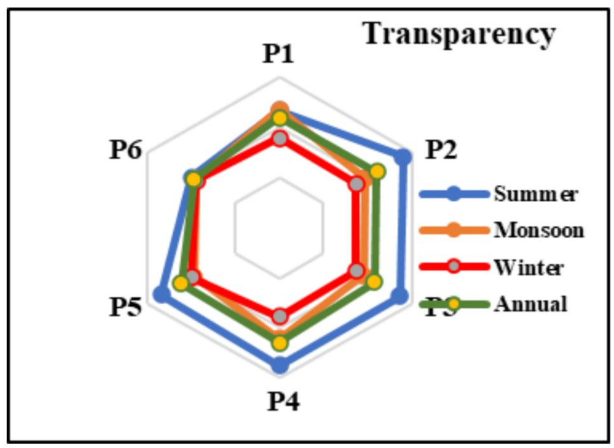

Fig. 4. Dissolve oxygen (mg/L)

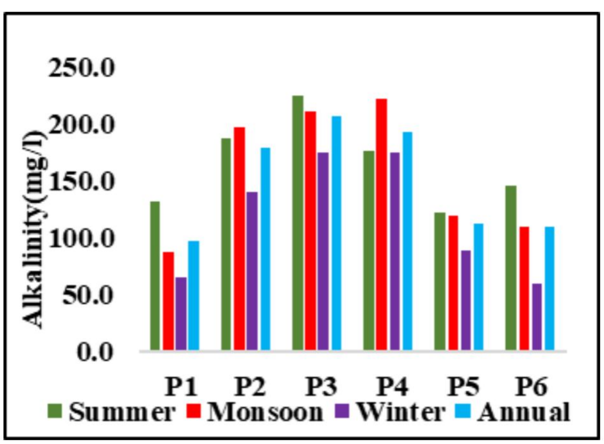

Fig. 5. Alkalinity (mg/L)

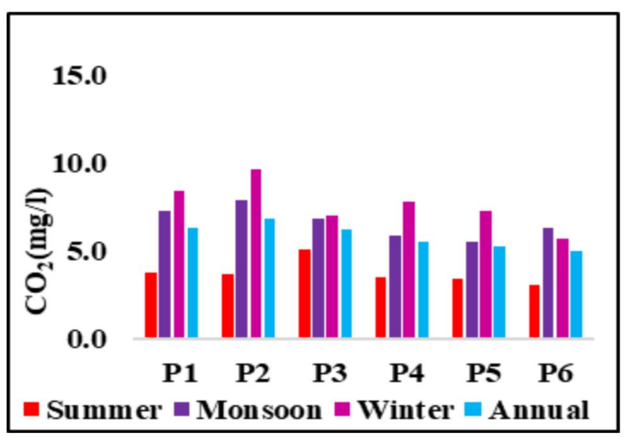

Fig. 6. CO_2 (mg/L)

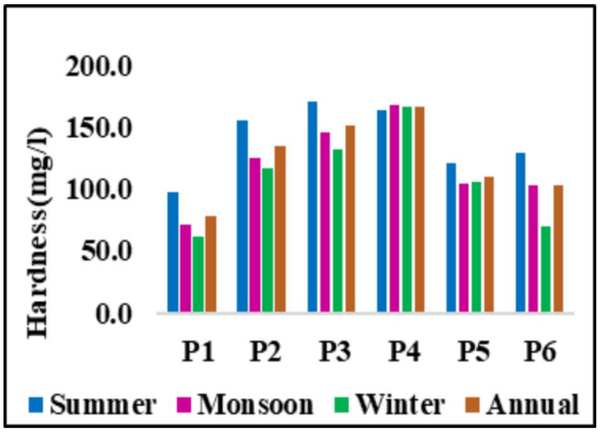

Fig. 7. Hardness (mg/L)

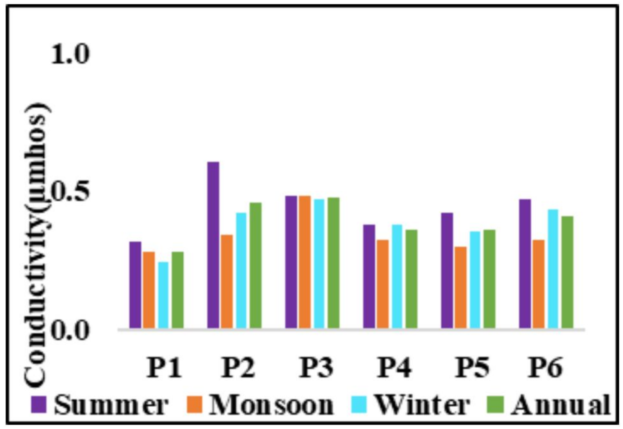

Fig. 8. Conductivity (mhos)

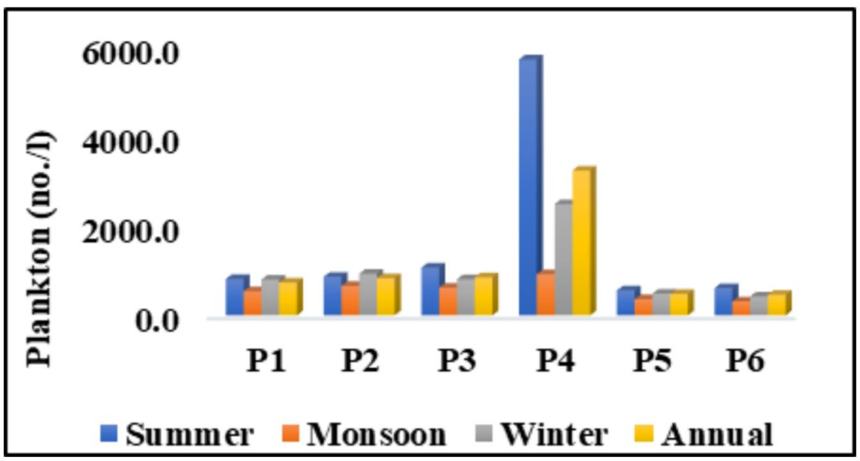

Fig. 9. Planktons (no/L)

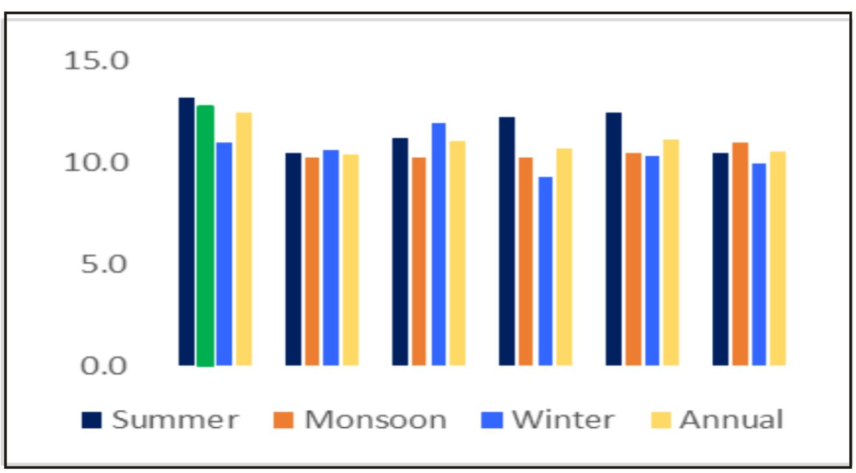

Fig. 10. Dissolve organic Carbon (ppm)

only positively correlated with C use efficiency in the Daldali pond.

DISCUSSION

Temperature is an important factor that imparts a significant impact on pond dynamics (Wooten, 1996), affecting aquaculture production by regulating various physiological activities of cultured animals. It has a direct impact on important factors *viz* growth, oxygen demand, food requirement and food conversation efficiency (Adhikari, 2011), as well as aquatic animals' overall health. Kannan and Job (1980), and Jhingran (1982) recorded the similar water temperature range (18.3-37.8°C) as observed in the present study considered suitable for fish farming. In the present study, temperature was strongly correlated with carbon recovery in feed in all three feeding ponds. Thus, it is evident that the water temperature had a significant impact on the feed carbon recovery. Temperature had a great role in feed metabolism in the fish, and thus it had an impact of fish feed carbon recovery.

Warmer water generally holds less dissolved oxygen and can potentially hold more dissolved CO_2. Changes in water chemistry can affect the equilibrium between different forms of carbon in the water column, thereby influencing carbon retention dynamics (Yvon-Durocher et al., 2011). In the present study, carbon dioxide had a strong association in the carbon recovery in the Suri pond. In the other two ponds, no association was observed. Thus, it has no specific role in carbon recovery in fish pond.

The changes in pH are the result of photosynthesis and respiration by plants and animals. Valladolid et al. (1954) determined that, among the physicochemical factors, a pH range between 7.3 and 8.4 is optimal for fish growth. The pH was higher where the clothes are washed and lower where the cattle wastes are disposed. In the present study, pH was significantly correlated with C recovery efficiency in Kapardar pond. In other two ponds, no correlation was observed. Thus, it is evident that pH had no significant role in carbon recovery in the fish ponds.

Dissolved oxygen has a considerable effect on the chemical and biological processes of aquatic organisms. However, in the present study, it was significantly correlated with C recovery in Daldali ponds. For the other two ponds, no association was observed with C recovery efficiency. Jena and Das (2011), suggested that the ideal D.O concentration for the culture of carps will be greater than 4 mg/L. Indirectly or directly, oxygen depletion in water causes poor feeding, starvation, stunted growth, and increased fish mortality (Bhatnagar & Garg, 2000). Dissolved oxygen affects the expansion, survival, distribution, behavior, and physiology of shrimps and other aquatic organisms (Solis, 1988).

The relationship of D.O on carbon sequestration in fish ponds is complex and depends on various factors. One aspect to consider is the role of aquatic plants in both oxygen production and carbon sequestration. However, under low-oxygen conditions, organic matter decomposition shifts to anaerobic processes, which produce methane- a potent greenhouse gas- instead of CO_2. Thus, maintaining adequate D.O levels in fish ponds can indirectly influence carbon sequestration by promoting aerobic decomposition pathways and minimizing methane production.

Warmer water has a lower capacity to hold dissolved oxygen, which can lead to lower oxygen levels in the pond. This can cause fish to respire anaerobically, which can lead to the production of carbon dioxide and a decrease in pH. Overall, 0.585 kg carbon was fed for each kilogram of carbon retained in fish biomass, indicating that a good amount of carbon was utilized by the fish through feeding. Adhikari et al. (2018) reported that only 8% carbon was retained in the Indian major carps in some carp polyculture ponds of Andhra Pradesh. In the present study, carbon retained in Indian major carps was less and varied from 2.07 to 6.49%, good amount of carbon was retained in the water at the time of fish harvest.

The relationship between fish production and carbon sequestration in fish ponds is influenced by various factors, including pond management practices, species composition, nutrient cycling, and environmental conditions (Karak et al., 2018; Yi et al., 2018).

pH is a significant limiting factor in aquaculture also affects the survival and development of fish. When carbon dioxide (CO_2) dissolves in water, it forms carbonic acid (H_2CO_3). According to Hönisch et al. (2012), the presence of carbonic acid can lower the pH of the pond water, making it more acidic. Optimal pH conditions are essential for photosynthesis, which fixes atmospheric CO_2 into organic carbon compounds, contributing to carbon retention in aquatic ecosystems. Changes in pH can affect the precipitation and dissolution of calcium carbonate minerals, influencing sedimentation rates and carbon burial processes.

According to Bhatnagar et al. (2004), 5-8 ppm CO_2 is required for photosynthetic activity. Free CO_2 concentration up to 6 mg^{-1} is congenial for fish culture, and a good fishery is always correlated with low free carbon dioxide content (Sinha et al., 1990). Carbon sequestration refers to the capture and long-term storage of carbon dioxide to mitigate its accumulation in the atmosphere, thus helping to combat climate change (Cole et al., 2007). Fish ponds can act as carbon sinks through the sequestration of organic carbon in sediment and aquatic vegetation. Sedimentation of organic matter, including uneaten fish feed and fish feces, contributes to the accumulation of carbon in pond sediments (Boyd, 2015).

Factors influencing carbon sequestration in fish ponds are influenced by aquatic plant species composition and density, fish stocking density and feeding practices and pond management practices such as aeration, water exchange, and sediment management (Sarker et al., 2018).

In fish ponds, alkalinity plays a crucial role in buffering pH fluctuations, which is important for maintaining optimal conditions for fish health, growth of fish and productivity. In an ideal aquaculture pond, the alkalinity should range from 75 to 200 mg^{-L} with a minimum of 20 mg^{-L}. Increase in alkalinity levels on manure applications is perceptible as seen from the values of manure applied ponds and the control units (Wurts & Durborow, 1992). Increases in total alkalinity during the rainy season have been attributed to the addition of water and the dissolution of calcium carbonate ion in the water column (Padma & Periakali, 1999). According to Bhatnagar and Devi (2013), the optimal alkalinity for fish productivity varied between 25 and 100 mg^{-L}

The correlation coefficient between alkalinity, hardness of fish pond water and carbon sequestration is influenced by various factors such as the composition of the soil, the type of vegetation around the pond, and the management practices employed. Higher concentration of total hardness is indicative of high value of Calcium (Ca) and Magnesium (Mg) salts in pond water, expressed as equivalent to calcium carbonate ($CaCO_3$) (Boyd, 1982; Boyd, 2010). According to Stone and Thomforde (2004), the optimal range for $CaCO_3$ is between 50 and 150 mg^{-L}. Alkalinity and hardness can affect the growth of aquatic plants, which play a significant role in carbon sequestration through photosynthesis. Higher alkalinity and hardness levels may support robust plant growth, leading to increased carbon uptake from the atmosphere. Hardness can influence the precipitation of carbonate minerals in pond sediments, which can sequester carbon over geological timescales. Additionally, alkalinity levels can influence the pH of the water, which in turn affects the solubility of carbon dioxide and the precipitation of carbonates (Hargreaves, 2006). Alkalinity and hardness can influence the activity of microbial communities in pond sediments, which also play a vital role in organic matter decomposition and carbon cycling that enhance carbon sequestration. In the present study, alkalinity was strongly correlated with carbon recovery in Daldali and Suri ponds, except Kapardar ponds. Water hardness is only correlated with carbon recovery in Suri ponds. So, alkalinity and hardness had no definite association with carbon recovery in the ponds. Whatever association was observed could be due to the reaction between calcium and magnesium ions with carbon.

The ability of water to conduct an electric current depends on the nature and concentration of ionized salts. The conductivity of a fish pond can vary depending on factors such as dissolved solids, temperature, pH and presence of pollutants (Sikoki & Veen, 2004). The same results were obtained by researchers (Hulyal & Kaliwal, 2011; Ramulu & Benarjee, 2013) during their study. In the present study, conductivity was strongly correlated with carbon recovery in Kapardar and Suri ponds, except Daldali ponds. Thus, conductivity may play an active role in carbon recovery of fish ponds. This may be due to the presence of different ions in the water. These ions can react with carbon and could play a role in carbon recovery.

Transparency is a physical variable significant to primary production. The water was more transparent in the summer season in comparison to the winter and rainy season may be due to a combination of factors such as rainfall, sunlight, and temperature. According to Santhosh and Singh (2007), a pond's optimal productivity for fish culture occurs when its transparency is between 30 and 40 cm. Transparency of the water body was greatly influenced by plankton abundance (Sukumaran & Das, 2002). In the present study, transparency was strongly correlated with carbon recovery in Kapardar and Suri ponds, except Daldali ponds. Thus, transparency may play an active role in carbon recovery of fish ponds. This may be either due to the presence of planktons or due to the presence of sediment in the water. These planktons and sediments can react with carbon and could play a role in carbon recovery.

Plankton plays a crucial role in the ecology of tribal fish ponds. These tiny organisms are the base of the aquatic food chain and provide a source of nutrition for many fish species. There is a close relationship between plankton abundance and fish production (Smith & Swingle, 1938). Bhatnagar and Garg (2000) suggested the optimum plankton population (3000-4500 no^{-L}) in fish culture pond. Among the

3 non-feeding ponds, plankton population was higher in P4 both in summer and winter months (5730±3995.97). P4 is a non-feeding pond showed higher plankton value, similar to its rich carbon sequestration value. In the present study, planktons were strongly correlated with carbon recovery in all three feeding ponds. Thus, planktons had an active role in carbon recovery of feeds in the fish ponds. Thus, maintenance of planktons in the fish ponds could have a significant role in carbon recovery. Thus, in addition to feed application in the fish ponds, healthy planktons should also be maintained for the better utilization of feed carbon by the fish.

Dissolved organic matters are near to related term used of dissolved organic carbon. While Dissolved Organic Carbon refers specifically to the mass of carbon in the dissolved organic material. So Dissolved Organic Matter also includes the mass of other elements present in the organic material, such as nitrogen, oxygen and hydrogen. It is typically about twice as much Dissolved Organic Matter as Dissolved Organic Carbon. Mohanty et al. (1994) have also opined that the rate of decomposition of organic matter is rapid, moderately rapid and slow in the C/N ratio ranging from 5-10, 10-20 and >20, respectively. In the present study, dissolved organic carbon was strongly correlated with carbon recovery in all three feeding ponds. Thus, it had an active role in carbon recovery of feeds in the fish ponds. It may be due to the close association of carbon present in the organic matter and the feed carbon. Thus, maintenance of dissolved organic carbon in the fish ponds could have a significant role in carbon recovery. Thus, in addition to feed application in the fish ponds, cattle dung should also be applied in the fish ponds for the better utilization of feed carbon by the fish.

In the present study, overall, 0.585 kg carbon was fed for each kilogram of carbon retained in fish biomass, indicating that a good amount of carbon was utilized by the fish through feeding. Adhikari et al. (2018) reported that only 8% carbon was retained in the Indian major carps in some carp polyculture ponds of Andhra Pradesh. In the present study, carbon retained in Indian major carps was less and varied from 2.07 to 6.49%, good amount of carbon was retained in the water at the time of fish harvest. The relationship between fish production and carbon sequestration in fish ponds is influenced by various factors, including pond management practices, species composition, nutrient cycling, and environmental conditions (Yi et al., 2018; Karak et al., 2018).

Carbon recovery from fish ponds typically involves the utilization of organic waste like uneaten feed, feces, and decaying organic matter. Observations of the various parameters revealed that the physicochemical parameters of all six ponds are within the permissible range for fish culture, with the exception of plankton concentration. It may be due to overpopulation or an increase in plankton-feeding organisms. The carbon flow in fish ponds is closely linked to productivity and understanding this relationship can help us develop strategies for improving fish pond yields and enhancing food security. Water quality is an integral component of environmental monitoring which is essential for maintaining the health and sustainability of the planet. Findings from this work, it is concluded that the physio-chemical parameters of all the feeding and non-feeding ponds are within the permissible limit for fish culture. Water temperature, dissolved organic carbon, and planktons were strongly correlated with the carbon recovery. Other water quality parameters were also more or less associated in feed carbon recovery at least in one feeding pond in the present study. Thus, it is evident from the present study that water quality parameters had a positive role in carbon recovery from the feeds in fish ponds.

Conflict of interest: There is no conflict of interest among the authors.

Author's contribution: KB: Involved in investigation, data generation, preparing original draft; TKG, SA, AKS: Engaged in conceptualization, data curation, supervision; VS, PB, SB: Engaged in analytical help, editing the manuscript.

Data availability statement: Data set generated during the research will be available from the corresponding author upon reasonable request.

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