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Performance analysis of composite carp culture policies in drought prone district Purulia in West Bengal, India

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ABSTRACT

The development of composite culture of carps in Purulia, an economically underdeveloped district of India, is confronted with several socio-economic, topographic, and climatic challenges. West Bengal Accelerated Development of Minor Irrigation Project (WBADMIP), an innovative integrated program of irrigation, agriculture, horticulture, and fisheries interventions through community institutions, was implemented in Purulia by the Government of West Bengal and was supported by the World Bank. Performances of the composite culture of carps in 172 water bodies by fisheries interest groups under the initiatives of WBADMIP were evaluated based on 18 different parameters using the k-mean algorithm. The results indicated that the water bodies could be categorized into three Clusters, based on inputs, expenditure, production, and income. Cluster 1, consisting of 85 water bodies, exhibited moderate performance with an average production of 2351 kg/ha, followed by Cluster 2 of 49 water bodies exhibiting poor performance with an average production of 1463 kg/ha, and Cluster 3 of 38 water bodies exhibiting best performance with an average production of 2488 kg/ha. Euclidean distance between Cluster centers 1 and 2 was 4.511 as compared to 3.737 and 5.102 between the Cluster centers 1 and 3 and 2 and 3, respectively. The water bodies with higher productivity were primarily associated with the WBADMIP policy that mobilized trained farmers who could adequately manage the application of feed, lime, inorganic fertilizers, and organic fertilizers. Using decision tree analysis, we predicted that the maintenance of water pH above 6.9 is crucial in obtaining optimum carps production from these water bodies. In contrast, the use of lime, inorganic fertilizers, organic fertilizers, and an adequate amount of feed need to be adjusted to maintain an economically viable production system. It is concluded that the farmers' motivation and professional training along with project support can substantially improve the productivity of the water bodies, support the nutrition of the farmers' community, and boost the local economy.

1. Introduction

The organized culture of carps in small water bodies is globally recognized as a possible means for stimulating fish production. It can support a viable livelihood option for rural farmers and benefit the rural economy through an interlinked socio-economic-environmental production system (Pant et al., 2014; Krause et al., 2015; Genschick et al., 2018; Wijenayake et al., 2016; Mosepele and Kolawole, 2017; Filipski and Belton, 2018; Farquhar et al., 2019; Lasner et al., 2020; FAO, 2020). It can also provide a dependable and easily assessable source of quality protein, the necessity of which is always crucial in the developing countries to fight malnutrition (El-Gayar and Leung, 2001; Arthur et al., 2010; Beveridge et al., 2013; Béné et al., 2015, 2016; Fiedler et al., 2016; Alam et al., 2019; Duarah and Mall, 2020). Yet, aquaculture has not been able to achieve its full potentiality to eradicate malnutrition, ensure food security, and support a stable income of rural people due to a gap in communication between the policymakers who implement aquaculture and the farmers who depend on aquaculture for their livelihood (Toufique and Belton, 2014; Krause et al., 2015). While policymakers are mainly concerned with selecting water bodies, managing inputs, and income distribution, social and political constraints from local communities often compel them to adopt socio-economically non-

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viable strategies (Pascoe et al., 2009). This is a common problem in developing countries. Unequal share of income from floodplain water bodies in Bangladesh is a socio-economic problem that affects the livelihood of small and marginal farmers (Toufique and Gregory, 2008). Selection of wrong water bodies and adoption of an unscientific method of culture affected production from inland water bodies in India (Sugunan and Katiha, 2004), Vietnam (Nguyen et al., 2005), Cambodia (Limsong et al., 2013), and Sri Lanka (Wijenayake et al., 2016). Paul et al. (2020) observed that several uncertainties affect the production of the reservoir fisheries in India and the livelihood of the associated fishers, which need to be addressed through socio-economic considerations.

Purulia is a backward district of West Bengal, India, in terms of socio-economic development and exhibits the highest incidence (26%) of poverty in the state (Chandra, 2021). Poverty is determined not only by the lack of income and resources to ensure a stable livelihood, but also by social discrimination, limited access to safe drinking water, fuel, education, sanitation, health facilities, and malnutrition. The socially backward groups constituting about 38% of the population in the district, as per Census Report, 2011 (https://www.census2011.co.in/), are the worst sufferer of poverty, followed by the daily wage and agricultural laborers (Guchhait and Sengupta, 2020).Usage of groundwater in many district blocks is significantly less, and a significant portion of the population has to depend on surface water or dams for their water requirements (Bera and Das, 2021). A sample survey of 698 households spread over four community development blocks and three municipalities in Purulia was conducted by Bagli and Tewari (2019). The authors reported that only 15% of the households had access to formal health facilities, 27% had primary education, 22% had improved sanitation, and only 31% enjoyed banking facilities. The multidimensional poverty index of Purulia (0.21) measured by the authors was almost double that of India (0.121) in 2018. More than 70% of district households belong to rural areas (Government of India, 2015; Daripa, 2018). The economy of the farming communities depends mainly on single-crop agriculture production. A substantial portion of this population belongs to below poverty level and suffers from malnutrition (Arora et al., 2014; Mishra and Chatterjee, 2018). The development of a viable composite carp culture system in Purulia is a tough challenge not only for the poverty of the people, which refrain most of them to buy necessary inputs to start a culture of fish, but also for the extreme climatic condition characterized by seasonal drought, undulated topography, and dependency on monsoon for the supply of water (Haldar and Saha, 2015). Efficient management of groundwater and surface water is thus critical to alleviating the sufferings of people of this district, particularly during the summer months, when water shortage is acute. During the last ten years, the Government of West Bengal implemented several socio-economic development schemes for sustainable water resource management of the district. These include: (1) "USHARMUKTI"– a micro-watershed scheme under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), supported by the Government of India to conserve soil and water in Purulia and to benefit about 500,000 households (Bera and Das, 2021) (2) The Jal Dharo-Jal Bharo (JDJB) scheme for the construction of small check dams and re-digging and reclamation of small and large water bodies (http://wbwridd.gov.in/wrdd/jal_dharo_jal_bharo .html) (3) The "Jalatirtha" scheme (Bera and Das, 2021) with an objective of construction of 500 check dams in the districts to provide water for irrigation in the Rabi season as well as for supplying water to the cattle, fishery activities and other various domestic uses (http://wbwridd.gov.in/wrdd/jalathirtha .html). Besides, Watershed Management Programme (http://www.wbswda.gov.in/dprs/index /s: 90), "Anandadhara" (http://wbprd.gov.in/anandadhara/index.aspx), etc. were implemented by different departments of the Government of West Bengal for micro watershed development and capacity building of the rural farmers. These schemes substantially promoted water conservation and opened up opportunities for agriculture, horticulture, and fisheries in vast areas of the district. Yet, the farmers could not be motivated to successfully develop any culture system due to a lack of scientific knowledge, training, and financial capacity. Then the West Bengal Accelerated Development of Minor Irrigation Project (WBADMIP), a flagship project of the Government of West Bengal, started in 2012 in Purulia intending to identify socially and economically backward section of people and train them to start profitable agriculture, horticulture, and fisheries in potentially viable areas. This project was partially funded by the World Bank and was implemented through the water resources investigation and development department (WRIDD) of the Government of West Bengal (wbadmip.org). Parallelly, World Bank supported the institutional and financial capacities of the gram panchayats, the rural local government, through the West Bengal Institutional Strengthening of Gram Panchayats Program (https://projects.worldbank.org/en/projects-operations/project-detail/P159427) and Japan International Cooperation Agency (https://www.adb.org/sites/default/files/linked-docu ments/49107–006-dc.pdf) supported West Bengal piped water supply project to provide safe and adequate piped water supply to people living in nine blocks of the Purulia. These projects improved the livelihood conditions of the people of Purulia and indirectly helped the implementation of WBADMIP programs in this district.

Lack of proper scientific knowledge largely impeded the success of the culture of the commercially viable species of fish and turned the farmers more interested in crop production. As a result, baseline production of fish, especially Indian major carps, which have a high demand in the local markets, remained unsatisfactory at an average level of 554 kg/ha until the intervention of WBADMIP, a joint initiative of the World Bank and the Government of West Bengal, India. WBADMIP provided incentives to small and marginal farmers, especially those belonging to socially and economically backward sections of the society of this district, and introduced an extensive orientation program to motivate and organize composite culture of carps as a means of food fish production. It could provide an alternative income source to these farmers parallel to agriculture and meet the demand for an easily accessible protein source to fight malnutrition.

In rural areas, small water bodies, which otherwise do not receive fish seeds from natural resources, have been found ideal to culture commercially viable fish for short periods (De Silva, 2016). Rural farmers can manage culture in such water bodies with little institutional support and create employment opportunities for themselves through increased production and fish marketing (World Bank, 2013; FAO, 2020). Approximately 44% of the water bodies in which fish culture is practiced in Purulia are small in size (<1 ha) followed by about 30% of moderately larger (1–2 ha,) and 25% big (>2 ha,) water bodies. While 56.7% of these water bodies belong to the farmers, the rest are used for fish culture on a leasehold basis (Biswas et al., 2019). Plenty of water bodies, particularly those in tribal villages still remain unutilized. The small water bodies are primarily seasonal in nature and dry up during the summer season (Das et al., 2019). Groundwater availability is a critical criterion for the successful implementation of carp culture (Knapp and Franklin, 2019). Average pre-monsoon groundwater depth in most of the area ranges between 5.03 and 8.05 m (16.5 to 26.4 ft) (Das et al., 2019) with Kashipur block, one of the project areas under WBADMIP, showing an average pre-monsoon groundwater depth at 1.97 to 7.55 m (6.46 to 24.77 ft) below ground level (Kundu and Nag, 2018).

The use of these water bodies for the culture of fish requires appropriate environmental planning and scientific method of culture. Most of the farmers (81.23%) in Purulia practice a traditional extensive system of fish culture (Biswas et al., 2019) and hardly have any knowledge of the modern method of the semi-intensive culture system. As a result, the production of fish and per capita income from these water bodies are poor. Therefore, multiple criteria, including environment, resources, inputs, training on scientific culture, institutional support, the participation of the farmers, their socio-economic conditions, and finally a profitable output, which influence the production of fish, need to be addressed properly for successful management of composite culture of carps in the under-utilized and unutilized water bodies in Purulia.

WBADMIP used a multidisciplinary team consisting of departmental engineers, fisheries experts, project-based contractual staff, and NGOs with the overall guidance and support of World Bank experts to start its activities in Northeast Purulia in 2012 to reach out to the small and marginal farmers. The project focussed on building an institutional framework to coordinate closely with the community and provide a single-window platform to weave agricultural support services and ensure an outcome-based result. This is a major improvement over the existing sectoral structure of governance wherein different departments operate in silos. Potential areas were identified based on the necessity of socio-economic development and started various irrigation schemes to develop agriculture, horticulture, and fisheries activities for the farmers. Thus, Water Users Associations (WUAs) were formed at the village level and were empowered to operate and maintain these irrigation schemes and sustainably manage the available water resources.WUAs acted as a single window for the delivery of all the project interventions for potential farmers. Continuous capacity building and hand-holding support were provided to all WUAs, facilitating their evolution. In 2015, the Fisheries Interest Group (FIG) was formed as a subset under each WUA to start the composite culture of fish in a selected water body. WBADMIP provided three different management policies from 2015 to 2018 in 172 small water bodies spread across different villages of Northeast Purulia to develop an economically viable composite culture of carps and augment the production of fish in this part of the district. The management policy I (MP-I) started in 2015–2016 with the selection of FIG, comprising of unskilled farmers in different villages and providing intensive training to all FIG members on the scientific culture of carps. One FIG was selected for one water body in each village to start the composite culture of carps. The culture started with the support of critical inputs from the project in the form of fingerlings, supplementary feed, lime, inorganic fertilizers, tools and gears, and a limited share of inputs from the farmers in the form of lime and organic fertilizers. The culture was continuously monitored from the project, and the farmers were motivated and guided to take appropriate measures during the culture. MP-I was continued in 2016–17 along with a new management policy, MP-II, to propagate a composite culture of carps in other existing water bodies of the village where MP-I was implemented and to produce marketable fish with limited support from the project. For each selected water body, one FIG was formed comprising of WBADMIP trained farmers. The critical inputs from the project were adjusted to supply only fingerlings and a limited quantity of feeds, while the farmers were encouraged to provide feed, lime, and organic fertilizers for the culture. However, farmers continued to receive periodic training along with exposure visits to established farms, continuous monitoring of the culture, motivation, and guidance to become self-reliant towards producing marketable fish. In 2017–2018, both MP-I and MP-II were stopped, and MP-III was introduced, intending to augment carp fishes' production. It covered more water bodies in the same villages where MP-I and MP-II were implemented and extended the facility of the composite culture of carps in hitherto unutilized or underutilized water bodies in nearby villages. FIGs were formed for each water body with WBADMIP trained farmers or farmers with previous fish culture involvement. All critical inputs, as in MP-I, but in different quantities, were provided to the farmers (Table 1). The farmers were encouraged to share lime, feed, and organic fertilizers required to increase production. Limited training, exposure visits, continuous monitoring, and guidance as in MP-II were continued. Water bodies used for MP-I, MP-II, and MP-III during 2015–2018 were 27, 59, and 86, respectively. Total production of carps in all the water bodies, except 4 out of 172, increased substantially under these policies as compared to the baseline production existing in Northeast Purulia. But the production fluctuated widely between the water bodies. In this study, we analyzed the cause of this fluctuation in depth by using Principal Component Analysis (PCA) based on 18 parameters associated with the culture. The k-mean algorithm was then employed to segregate the water bodies into different clusters on a performance scale. Finally, decision trees were used to predict the value of parameters that satisfy both production and economic measures.

The PCA is used to evaluate several aspects of fisheries, such as classification of fish farms based on environmental impacts (Chen et al., 2015); evaluation of effluents in fish ponds (Coldebella et al., 2017); analysis of water temperature variation in reservoir fisheries (Ren et al., 2020); and evaluation of environmental parameters affecting fish production (Silva et al., 2021). On the other hand, the k-mean algorithm is also a reliable tool in fisheries research that helps to identify the variability in the catch (Castro-Ortiz and Lluch-Belda, 2007), analyze the fish image for fish diseases prediction (Yao et al., 2013), fishing surveillance (Correia et al., 2020), etc. The decision tree algorithm concept is frequently used in biological research to predict the key parameters

Table 1
Nature of training, the share of resources, average inputs, and expenditure under three different policies of WBADMIP

		Policy		
		MP-I	MP-II	MP-III
Training		Scheme started with orientation training of the unskilled farmers and intensive training provided during culture.	Only trained farmers of MP-I selected for culture. Additional limited training provided during culture	Trained and untrained farmers were randomly selected for culture. Additional limited training provided during culture
Water bodies covered		27	59	86
Inputs	Share*			
Stocking density (No /ha) [1]	P	8902	10000	9945
	F	0	0	0
Inorganic fertilizers (kg/ha)	P	232	11	308
	F	0	0	0
Feed (kg/ha)	P	3043	1455	1552
	F	42	566	416
Lime (kg/ha)	P	257	0	498
	F	89	360	127
Organic fertilizers (kg/ha)	P	0	0	0
	F	847	893	740
Total expenditure (INR/ha)	P	187577	115306	133840
	F	19003	29481	27785

*P = Project; F = Farmers
[1] Fingerlings of 1 inch size

that affect specific targets. Zarkamia et al. (2012) applied it to predict habitat variables that affect the distribution of fish. Ali et al. (2020) used this technique to identify that the critical factor behind the utilization of fermented mulberry leaf meal as fishmeal replacer in the feed by the catfish *Heteropneustes fossilis* was the activity of amylase, which helped the fish to utilize carbohydrate. Therefore, the main objective of this study was to critically evaluate the performance of the policies and identify the criteria, which contribute maximum to develop a viable system of the composite culture of carps and make a road map for the augmentation of production of fish in Northeast Purulia.

2. Materials and methods

This study was based on the composite culture of carps in 172 water bodies spread in three community development block (Raghunathpur I: 23°32′20″N 86°40′41″E; Kashipur: 23°26′N 86°40′E; Santuri: 23°31′44″N 86°51′50″E) of Northeast Purulia during 2015–2018. FIGs utilized only impounded water bodies either on lease from the owners or as vested/community ponds. The water bodies varied in area, depth, and water retention capacity. The range of area and depth of these water bodies have been presented in Fig. 1.The water retention capacity directly influenced the duration of culture. WBADMIP implemented three different management policies (Table 1) to explore criteria for ideal management of composite culture of carps that can maximize carps production in this part of the district.

During the study, the project staffs of WBADMIP regularly collected data on resources and their environment used for the culture, such as WA (water area, ha), WD (water depth, feet), CD (culture duration, months), and pH (of water) directly from the water bodies. Qualitative and quantitative information on culture were collected either through FIG/WUA level participatory rural appraisals (PRAs) or through focus group discussions (FGDs) organized by an NGO named Hijli INSPIRATION (http://inspiration-india.org/).

This information, which included SDF (stocking density of fingerlings, No/ha), LP (lime supplied from the project, kg/ha), LF (lime provided by farmers, kg/ha), IFP (inorganic fertilizers supplied from the project, kg/ha), OF (organic fertilizers provided by the farmers, kg/ha), SFP (supplementary feed supplied from the project, kg/ha), SFF (supplementary feed provided by the farmers, kg/ha), BW (average body weight of fish harvested, g), PROD (production of fish, kg/ha), NoB (number of beneficiaries), CON (amount of fish consumed by the farmers, kg/ha), EP (expenditure incurred from the project, INR/ha), EF (expenditure incurred by FIG, INR/ha), INC (income generated by selling fish, INR/ha), were verified by WBADMIP staffs during the culture. Altogether, we used 18 parameters to analyze the WBADMIP policies' performance in implementing the composite culture of carps.

2.1. Principal component analysis (PCA)

Principal Component Analysis (PCA) is a statistical tool frequently used in diverse research areas because it can retain the maximum informative value of the input parameters intact while trying to reduce its dimensions (Kawabe et al., 2019). The method can identify the variance within a large dataset of correlated variables in terms of a small number of new pseudo-variable called Principal Components (PCs) (Jolliffe, 1972; Abdi and Williams, 2010). We employed PCA on the 18 parameters for factor reduction by using SPSS25 (Morgan et al., 2019). The Principal components are uncorrelated, and each component represents the information of different "statistical dimensions" inherited in the considered data set. Kaiser–Meyer–Olkin (KMO) and Bartlett's Sphericity tests were performed to find the suitability of the dataset for PCA. The KMO measure indicates the proportion of variance, which is caused by underlying Principal Components. We found that KMO = 0.734(>0.5), indicating the acceptability of PCA for the present data set. Similarly, Bartlett's test of sphericity was conducted to examine whether the correlation matrix was an identity matrix. In the current data set, the

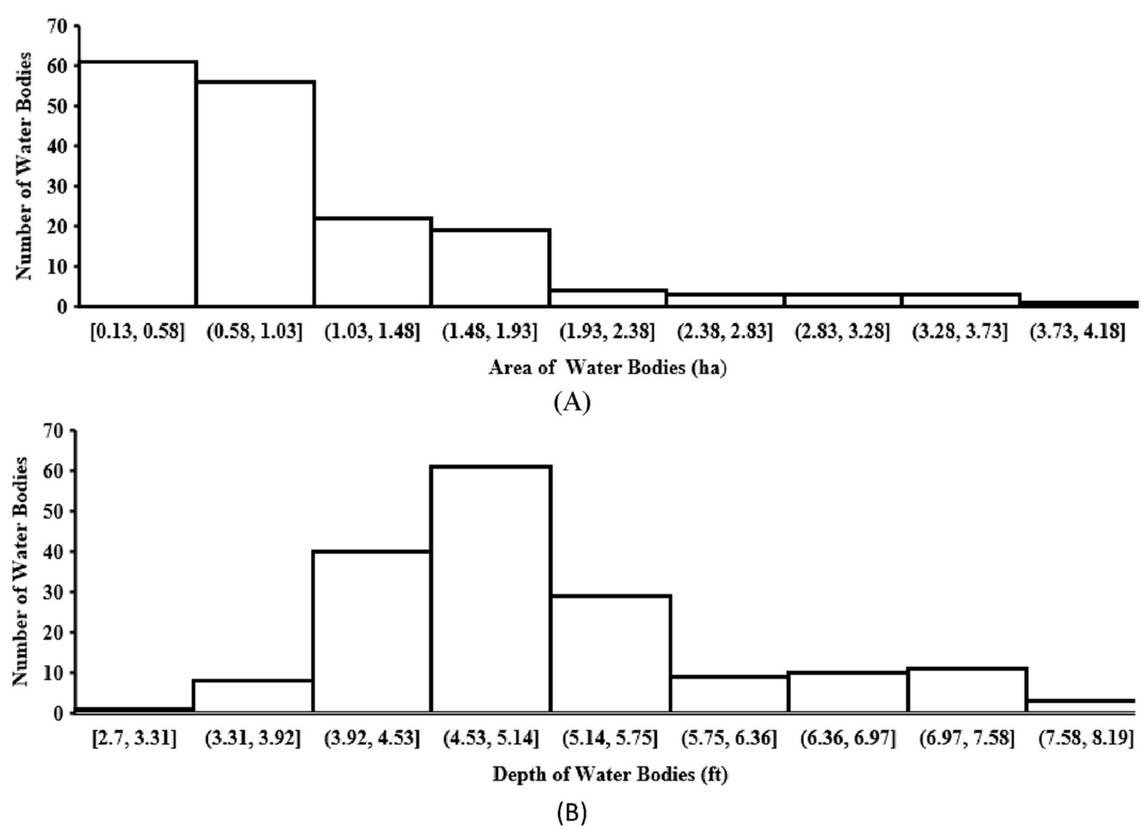

Fig. 1. Range of water area (A) and depth of the water bodies (B) under this study.

significance level was found as 0.000 (< 0.05), which rejected the null hypothesis and indicated significant relationships between the parameters. PCA was carried out using Varimax rotation with Kaiser Normalization.

2.2. k-mean algorithm

Each data series was standardized based on the mean (m) and standard deviation (s), where the standardized variable was $z = (x - m)/s$. This permits comparison between parameters by eliminating the scale factor. Series were then classified according to their variation pattern, using k-mean clustering analysis. The k-value was determined based on the normalized data and was expressed as the number of clusters. It was found that clustering into three categories (k = 3) had the best effect by comparison. The clustering of performances in fisheries and aquaculture is rare. In this study, we adopted the non-hierarchical clustering method as presented below:

Step 1: Specify the number of clusters that the procedure needs to retain (k = 3).

Step 2: Arbitrarily select the initial centers of k clusters based on the input data, i.e., z_k, k = 1, 2, 3;

Step 3: Compute the distance or norm of the certain ponds, A_i ($i = 1, \ldots, n$) to the *k*th cluster center. We used the Euclidean distance measure. Assigned the corresponding pond to a closest cluster based on the criterion $||A_i - Z_p|| \leq ||A_i - Z_k||$, ($p = 1, \ldots, k, k \neq p$);

Step 4: If the above relation is invalid, the average of A_i for each cluster is computed, and formulate a new cluster center.

Step 5: Repeat the steps 3–5 until the squared error function (SEF) defined below converges to a minimum.

$$Min\ SEF = \sum_{k=1}^{K} \sum_{A_i \epsilon A} ||A - Z_k||^2 \quad (1)$$

2.3. Decision tree

A decision tree predicts the value of a discrete dependent variable with a finite set of values (class) from the values of a group of independent attributes (Quinlan, 1986; Edwards Jr. et al., 2006). Tree construction proceeds recursively, starting with the entire set of training samples. At each step, the most informative attribute is selected as the root of the tree, and the current training set is split into subsets according to the values of the selected attributes. For the subsets of training examples in each branch, the tree construction algorithm is executed recursively. Tree construction stops when all examples in a node are of the same class or if some other stopping criterion is satisfied. Due to transparency and flexibility, classification trees (CTs) have recently gained popularity in various decision-making contexts. CTs are attractive since they are relatively straightforward to construct, and their transparency allows for easy integration into an environmental decision support system (Edwards Jr. et al., 2006). In this study, we used CTs to predict the value of the parameters that affect the efficiency of production in the water bodies and the efficiency of income by the farmers. The efficiency of production or investment can be expressed in several ways. This measure is commonly defined as the ratio of aggregate output to aggregate input used in a process (Del Gatto et al., 2011). For simplicity, we used the ratios to measure efficiencies. It was calculated as:

$$\text{Efficiency of production} = \frac{\text{Total fish production (kg/ha)}}{\text{Total feed (kg/ha) supplied from the project and by farmers}} \quad (2)$$

$$\text{Efficiency of income} = \frac{\text{Income generated by selling fish (INR/ha)}}{\text{Total expend expenditure(INR/ha) from the project and by farmers}} \quad (3)$$

Accordingly, 172 water bodies were classified into two groups and labeled as binary classification *Yes* or *No.* Note that the label against a water body is assigned as *Yes* if the "*Efficiency*" is >1, and *No* otherwise. This transformation can help us identify the water bodies that ensure profits or a higher food conversion rate. Then, according to the supervised data set, we used the J48 algorithm, a Java re-implementation of C4.5 (Quinlan, 1986), and is a part of the machine learning package Weka to draw decision trees. The percentage of correctly classified instances (% CCI) and Cohen's kappa (k) served as criteria for testing the models' fit are considered as criteria for fitting the model. Decision trees with % CCI greater or equal to 70% and kappa exceeding 0.4 were considered to be sufficiently reliable (Goethals et al., 2007). The results of decision tree analysis can assist the decision-maker in pinpointing the parameter responsible for performance differentiation.

3. Results

Percent change in the production of carps in the 172 water bodies covered in this study as compared to the baseline production has been presented in Fig. 2. The result showed wide fluctuation in the production rate between these water bodies. PCA results based on 18 parameters associated with the composite culture of carps in these water bodies have been summarized in Appendix-I, Fig. A1, and Appendix-II, Table A1. Appendix-I, Fig. A1 represents a Scree plot showing the percent variance and cumulative variance. Appendix-II, Table A1 shows the eigenvalues, individual variance, and cumulative variance of principal components (PCs). Out of those PCs, only the first four PCs were selected as they accounted for 70.62% of the total variance, including 31.32% variance by the first component itself and each eigenvalue>1. The rotated factor loadings of these four PCs have been presented in Table 2. Each component exhibits one or more parameters that influence

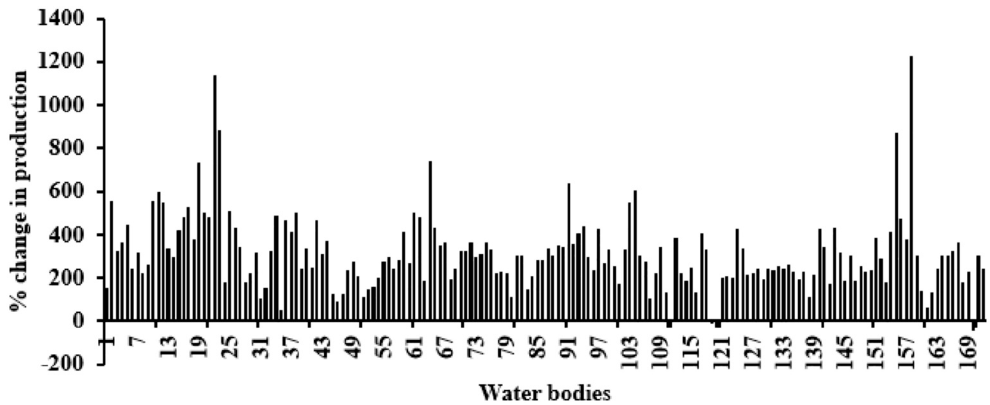

Fig. 2. Percent change in the production of carps from the baseline production.

Table 2
Rotated factor loadings of the data from 172 water bodies

	PC1	PC2	PC3	PC4
Water area (ha)		0.375	0.609	-0.560
Water depth (feet)	0.348	0.290	0.390	-0.423
Culture period (Months)	0.678	0.390	0.248	
Stocking density (No/ha)	0.264		0.428	0.350
Lime from project (kg/ha)	0.119	0.821		0.355
Lime by farmers (kg/ha)	0.556	-0.584		-0.141
Water pH	0.756	0.207	-0.134	0.134
Inorganic fertilizers from project (kg/ha)		0.783		0.315
Organic fertilizers by farmers (kg/ha)	0.589	-0.159	-0.214	-0.330
Supplementary feed from project (kg/ha)	-0.134	0.439	-0.674	-0.417
Supplementary feed by farmers (kg/ha)	0.733	-0.364		0.163
Average body weight (g)	0.931	0.141		
Fish production (kg/ha)	0.921		-0.197	
Number of beneficiaries		0.489	0.634	
Fish consumed by farmers (kg/ha)			-0.162	0.717
Expenditure from project (INR/ha)	-0.133	0.581	-0.655	-0.169
Expenditure by farmers (INR/ha)	0.795	-0.193		
Income generated by selling fish (INR/ha)	0.901	0.120	-0.145	-0.186

the performance of the composite culture of carps. For example, PC1 demonstrates the importance of the parameters associated with growth (average body weight) and production of fish; PC2 reflects the importance of lime and inorganic fertilizers, PC3 demonstrates the importance of water area and the number of beneficiaries, and PC4 demonstrates the consumption of fish by the farmers as an essential parameter.

Since PCA exhibited that all the parameters contributed to the variation in performance of the culture, we carried out the k-mean algorithm using all the parameters. The results have been presented in Appendix-II, Table A2. Based on the effects of these parameters, the water bodies could be segregated into three main clusters. Water bodies in Cluster 1 exhibited moderate performance in terms of inputs, expenditure, production, and income, followed by Cluster 2 water bodies with poor performance and Cluster 3 water bodies with the best performance in the perspective of productivity (Appendix- II, Table A3). Note that the Euclidean distances between the final cluster centers among Clusters 1 and 2, Clusters 1 and 3, and Clusters 2 and 3 are 4.511, 3.737, and 5.105, respectively. Therefore, Clusters 2 and 3 are the

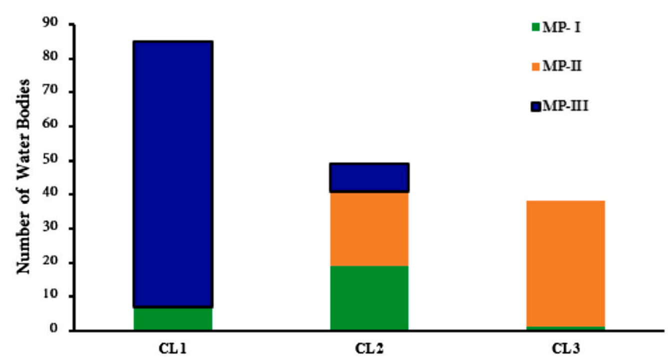

Fig. 4. Number of water bodies covered by different policies in each cluster.

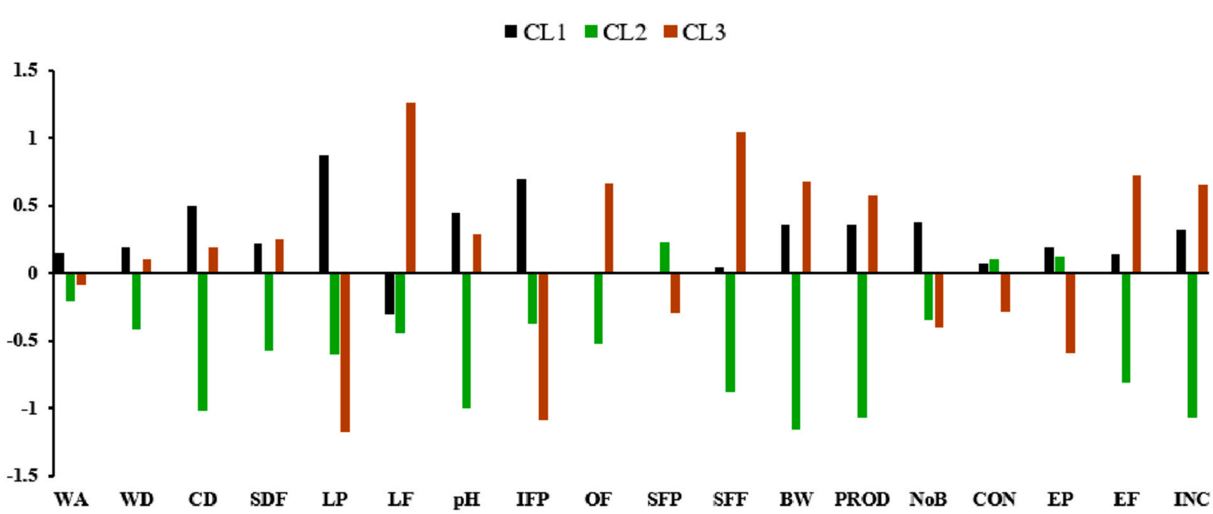

Fig. 3. Clustering (CL) of the water bodies based on the k-mean algorithm. Legends of the parameters have been explained in the text.

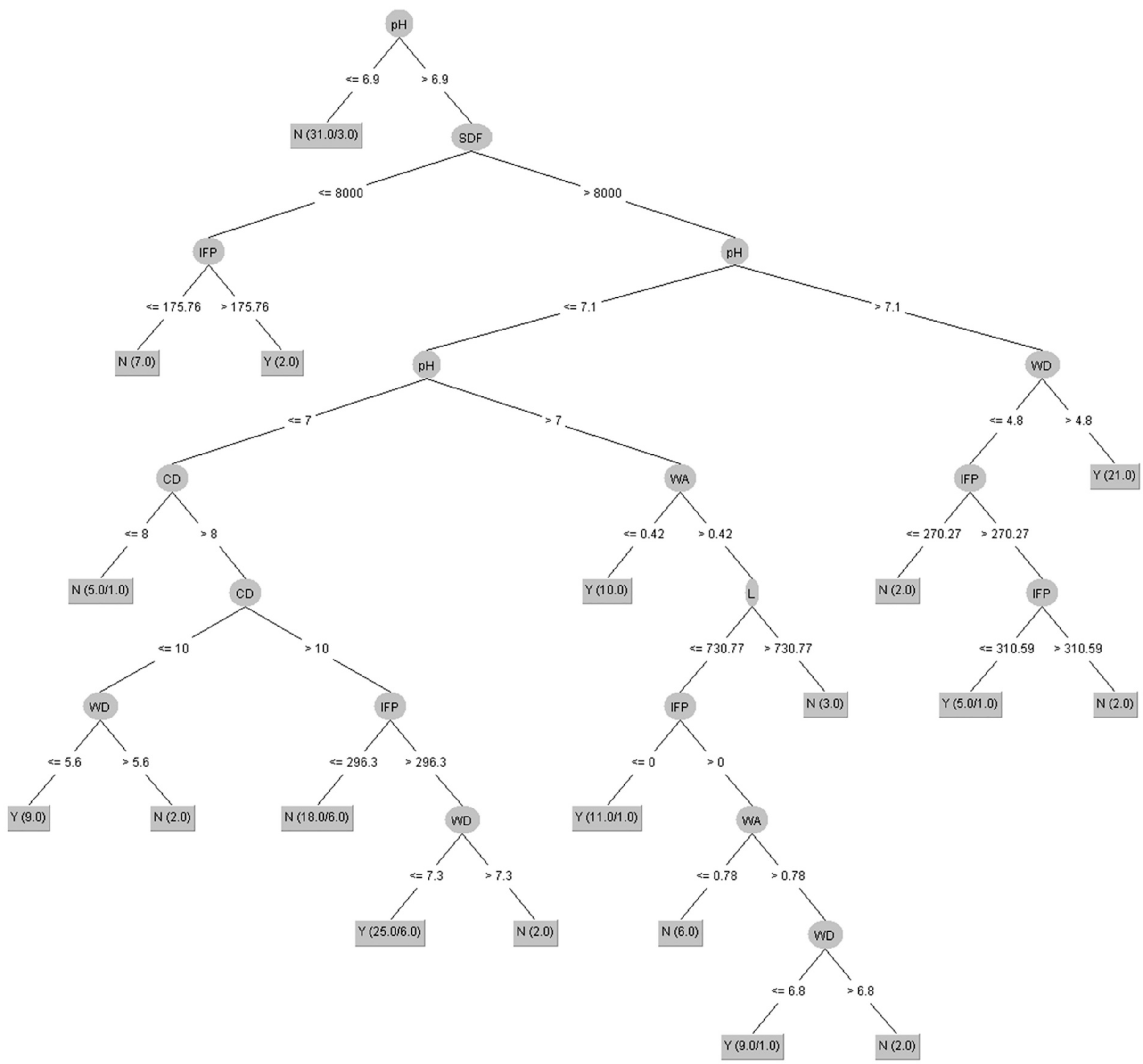

Fig. 5. Prediction of the value of different parameters that affect the efficiency of production (%CCI-73.62 and Kappa statistics- 0.426ction) (See the detail of parameters in Table 1).

utmost difference.

Average production in Cluster 1 water bodies was 2351 kg/ha followed by 1463 and 2488 kg/h in Cluster 2 and Cluster 3 water bodies. Fig. 3 presents clustering of the water bodies based on all 18 parameters. Altogether 85 water bodies were grouped under Cluster 1, out of which 78 were managed under MP-III policy and 7 under MP-I policy. Cluster 2 contained 49 water bodies, with 19, 22, and 8 waterbodies under MP-I, MP-II, and MP-III, respectively. Cluster 3 had 38 water bodies, out of which 37 were managed under MP-II policy and only one under policy MP-I (Fig. 4). It was revealed that the production of carps in Northeast Purulia could be substantially increased from the baseline production existing in the district through a proper combination of farmer selection, training, and resource distribution as implemented in different policies of WBADMIP.

To evaluate different parameters in terms of the efficiency of production (Eq. (2)) and efficiency of income (Eq. (3)), we first measured the efficiencies of each water body. Then based on the level data (yes/no), we employed C4.5 algorithm. It was observed that 129 water bodies were efficient in production, and 93 water bodies were efficient in income. The results demonstrate that maintenance of water pH at a level higher than 6.9 is a crucial factor for the success of the composite culture of carps in Northeast Purulia. When water pH was higher than 7.0 but less than 7.3, the efficiency of production defined in Eq. (2) increased in the water bodies subject to water depth restriction at 1.46 m (4.8 ft), water area 0.42 ha, and culture duration minimum up to 10 months (Fig. 5). When water pH was more than 7.0, inorganic fertilizers may not be necessary, but the lime application (L- representing total lime) should be restricted to 730 kg/ha to get optimum production. The efficiency of income defined in Eq. (3) increased in water bodies where fish grew to an average size of more than 564 g, and the number of farmers was restricted to 22 (Fig. 6). Keeping these two conditions constant observed the efficiency of income to increase in 124 water bodies where water depth was more than 1.34 m (4.4 ft), which is also crucial for optimum carps production.

4. Discussion

Results of the present study indicate that the motivation of the small and marginal farmers by WBADMIP to start a composite culture of carps as an alternative source of income in Northeast Purulia yielded encouraging results. The productivity of the water bodies covered by WBADMIP increased substantially from the baseline production, and the

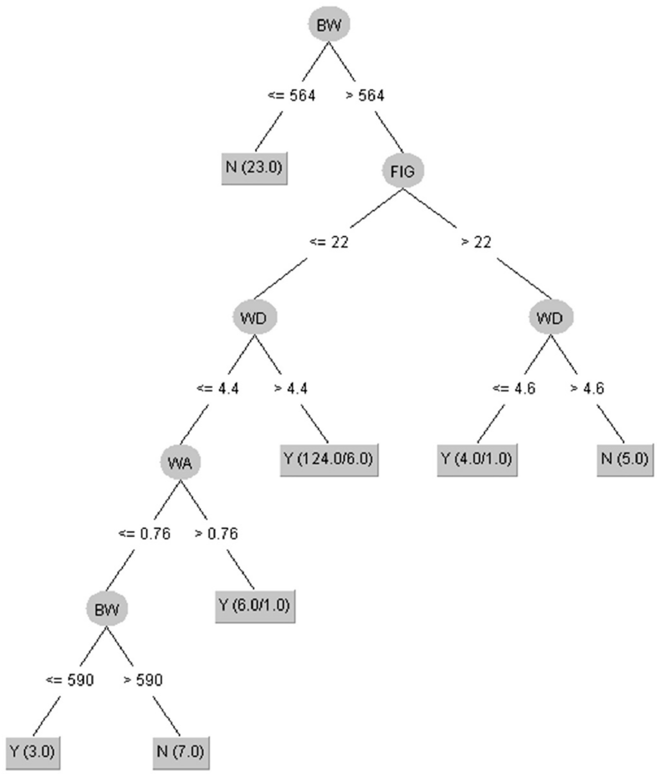

Fig. 6. Prediction of the value of different parameters that affect the efficiency of income (%CCI-86.62 and Kappa statistics- 0.623) (See the detail of parameters in Table 1).

marginal farmers were benefitted despite climatic and socio-economic constraints. Institutional support is crucial to develop a composite culture of fish in economically backward areas. In India, government and non-government projects, private and academic institutions, extension agencies, and financial institutions have played important roles in augmenting fish production in rural areas during the last decade (Pandey and Dewan, 2008; Kumaran et al., 2012; Sundaray et al., 2020). A similar increase in fish production through institutional support has also been observed in adjoining countries like Bangladesh (Ali et al., 2016) and Nepal (Farquhar et al., 2019). However, failure or success in fisheries and aquaculture, hence the benefits from this sector, particularly in developing countries, depend largely on the management of the policy (Mosepele and Kolawole, 2017).We analyzed the three policies implemented by WBADMIP in Northeast Purulia and observed that the policies yielded different results. MP-I was designed to motivate and train unskilled farmers. Share of the farmers was also minimum. Out of the 27 water bodies covered under this policy only seven were grouped under Cluster 1 with moderate performance and one under Cluster 3 with excellent performance. The rest 19 were grouped under Cluster 2, showing poor performance. Despite the unsatisfactory performance, MP-I motivated more farmers in the same village and the adjoining villages to start the composite culture of carps as their livelihood. Moreover, MP-II started with farmers trained under MP-I. Out of the 59 water bodies covered under MP-II policy, 37 water bodies (62.71%) were grouped under Cluster 3, showing excellent performance, indicating that proper training of the farmers is a decisive factor to increase production and income. Production of mola carplet (*Amblypharyngodon mola*), a small indigenous fish rich in vitamin-A and other micronutrients, could be increased through polyculture with major carps in Bangladesh only after motivation and training of the village households for long periods and dissemination of the culture technology (Roos et al., 2007; Karim et al., 2017). Although a maximum number of water bodies (86) were covered under MP-III of WBADMIP in Northeast Purulia to augment carps production, 78 of these water bodies (91.76%) were grouped under Cluster 1, showing moderate performance, and eight water bodies were grouped under Cluster 2 showing poor performance. Farmers under MP-III comprised a heterogeneous group of trained and non-trained farmers, which resulted in moderate performance in most water bodies. Training and continuous monitoring increase the skill of the farmers to utilize the resources properly and judiciously manage the inputs for the culture. However, the climatic condition also affected the performance of the composite culture of carps in these water bodies. Purulia is a drought-prone district, and aquaculture and agriculture depend on monsoon rain (Das et al., 2019). The performance of the 19 water bodies under MP-I was poor due to the farmers' lack of experience and due to poor annual rainfall (1116 mm) during 2015–16. Annual rainfall improved during 2016–17 (1441 mm) and 2017–18 (1546 mm), but was uneven and affected the performance in some water bodies. Even in MP-II, which was largely successful, 37.29% of the water bodies exhibited poor performance, including four water bodies in which production declined below the baseline production (Fig. 2). This was mostly due to conflict of interest between aquaculture and agriculture during dry periods and lack of knowledge of the farmers to compromise between the two farming options to get maximum benefits from both. Water bodies used for fish culture are the primary sites for water retention after heavy rain. Rational exploitation of this water is required for optimum production of fish and agricultural crops. While retaining the maximum amount of water in the water bodies for a long period and depriving irrigation of the adjacent agricultural lands harm crop production, excessive use of water from the aquaculture ponds for irrigation purposes can lead the water level to fall below the threshold level necessary to maintain productive fish culture. From the classification tree, we determined that subject to water availability, the culture of carps for a minimum period of 10 months could yield maximum growth of the fish and thus maximum production and income from the water bodies. It was possible only when there was sufficient monsoon rain, and the size of the water body was sufficiently large to hold the water. Farmers are encouraged by WBADMIP not to extend culture beyond one year because culture for a longer duration increases production risk and reduces the benefit-cost ratio (Huang et al., 2016). Interestingly, it was further determined by the CTs that the ideal size and minimum depth of a water body for optimum production of carps should be 0.42 ha and 1.46 m (4.8 ft), respectively. Most of the small water bodies in Purulia dry up during the summer months, and water levels fall below 1.46 m (4.8 ft), rendering these water bodies unsuitable for carp culture. Monosex culture of tilapia or calture of air-breathing fishes in these water bodies during summer months is a viable option to maintain a sustainable production of fish throughout the year. Small and marginal farmers in Bangladesh obtained maximum return by introducing small indigenous fishes like *Amblypharyngodon mola* or *Gudusia chapra* along with carps in small-scale composite culture ponds (Roos et al., 2007; Karim et al., 2017). Results of the present study indicate that the number of farmers should also be restricted to less than 22 for each water body. Size of the water body and the number of farmers involved in fish culture significantly determine output from the water bodies (Adewuvi et al., 2010). Farmers in Northeast Purulia require the knowledge to manage these parameters to obtain maximum carps production from the available water bodies. While maintaining water depth too high can prevent irrigation of the agricultural lands, it can also hamper the productivity of the water body. A higher quantity of lime, fertilizers, and supplementary feed are required to maintain the fish's growth when water depth increases. The four water bodies under MP-II, which exhibited carps production below the baseline production, were managed by FIGs, who lacked the confidence to trust aquaculture as their livelihood compared to agriculture. Due to a lack of skill and proper training, the marginal farmers in rural areas are often scared to adopt fish farming as their livelihood (Mulokozi et al., 2020) and rely more on agriculture for a secured income. This is also why the poor participation of young age group farmers in fish culture in their livelihood (Biswas et al., 2019). The farmers associated with the four water bodies under question unwisely used water from their carp culture ponds to agricultural lands, resulting in water level in the fish ponds falling below the threshold level 1.46 m (4.8 ft), which irrevocably reduced productivity of the water bodies. Community-based management of fish culture through sharing of resources, inputs, and experiences would reduce the risk of the culture and increase the income of the farmers. In Bangladesh, the resource-poor 'Adivasi' (ethnic) communities were found to increase their income substantially and ensure food and nutrition security through sharing of resources in community-based management of aquaculture and related livelihoods (Pant et al., 2014). The scheduled cast and scheduled tribes, the resource-poor social groups of Purulia, were the predominant FIGs under all policies of WBADMIP. They exhibit community sharing in their festivals and ceremonies but do not know to apply it appropriately in their livelihoods.This area needs to be addressed in the future.

Strategic maintenance of water quality and management of inputs is crucial to optimize the production of fish under extreme climatic conditions of Purulia. The CT indicates that maintenance of pH of water above 6.9 and preferably above 7.1 is a crucial factor for increasing the production of fish in Northeast Purulia. Since groundwater in this part of the district is generally acidic (Kundu and Nag, 2018) appropriate quantity of lime is required to maintain an optimum pH of water. The farmers under MP-III often mismanaged lime application, thereby rendering most water bodies either acidic or excessively alkaline. Lime controls the water pH and influences the growth of fish. But the higher application of lime may be counter-productive because it may reduce the availability of carbon dioxide and limit primary production in a water body (Boyd, 1997). The typical dose of lime in a water body with neutral bottom soil is 200–250 kg/ha annually. When the pH of the base soil is 5.1 to 6.5, the dose of lime can be increased to 1000 kg/ha (Jhingran, 1991). The water bodies which exhibited poor performance and were grouped under Cluster 2 received an average combined dose (both from the project and the farmers) of only 247 kg/ha of lime as compared to the average dose of 638 kg/ha in Cluster 1 water bodies and 451 kg/ha in Cluster 2 water bodies. Since groundwater of North-eastern Purulia is acidic in nature, the water bodies require excess lime. But it is necessary to manage the application of lime based on water pH. The decision tree indicates that in a water body of 0.42 ha, the lime application should not exceed 730 kg/ha. The application of inorganic and organic fertilizers is also essential inputs in the composite culture of carps, and the success of the culture depends on the proper management of these inputs. Inorganic fertilizers, especially phosphorus, increase phytoplankton growth, which increases the growth of the fish (Boyd, 1997).

On the other hand, organic fertilizers influence zooplankton growth, which serves as a food source for the planktophagus carp fish. However, the reduction of water levels in the seasonal water bodies requires immediate intervention of the farmers to stop applying inorganic fertilizer. Accumulation of excess nitrogen may cause algal bloom and water quality deterioration in the water body (Zhao et al., 2018). In many water bodies due to lack of proper knowledge, the farmers could not take timely measures, which hampered the productivity of the water bodies. An appropriate quantity of supplementary feed and organic fertilizers together quantitatively increases the production of the composite culture of carps (Yadava and Garg, 1992). In the present study, a significant portion of the supplementary feed required for the culture was provided from the project. Average supplemental feed and the ratio of feed supplied from the project and the farmers to water bodies were 2177 kg/ha and 80:20, 1979 kg/ha; 97:03, 2365 kg/ha; and 65:35 in Clusters 1, 2, and 3, respectively (Appendix-II, Table A3). It indicates that the performance of the water bodies increases when the farmers judiciously share the inputs for the culture. The farmers provided the organic fertilizers as per their financial capacity, which was too little to support a good production (Yadava and Garg, 1992). The average production of 2488 kg/ha of fish with maximum production reaching 3394 kg/ha observed in Cluster 3 ponds (Appendix-II, Table A3) could be further increased if farmers could afford more organic fertilizers from their end.

Performances of the water bodies were affected by the inputs and production and by consumption of fish by the farmers and income from selling of the fish. Per capita consumption of fish and market price are good indicators of the success of exploitation of the natural resources for fish (Samy-Kamal, 2021). It is a fact that fish consumption by the rural farmers increases when the production of fish is increased (Roos et al., 2007; Wahab et al., 2011). It supports the nutrition of the fish farmers (Thompson et al., 2002: Roos et al., 2003; Sukumaran et al., 2016; Barik, 2017), even if income from the water bodies is reduced. Average fish consumption in the present study was found at 341 kg/ha with an average number of 14 farmers involved in the culture (Appendix-II, Table A3). Taking into consideration of 5 family members of a farmer, the average per capita fish consumption would come around 4.87 kg per year, which is close to the average annual per capita consumption of all population (5–6 kg) in India, but about 50% of the 8–9 kg annual per capita consumption of the fish-eating population of the country (Salim, 2016). The average per capita consumption of fish under MP-II was less than MP-I and MP-III, which increased the farmers' income under MP-II and, hence, this policy's overall performance. The efficiency of income depended mainly on the growth of the fish. Maximum income was obtained only when the fish grew up to an average body weight above 0.5 kg, which substantially increases the market price of the fish. However, growing fish up to this weight required appropriate management of the resources, inputs, and pH of water, as discussed above. These were exhibited well by the farmers under WBADMIP policy, MP-II.

5. Conclusions

It is concluded from this study that WBADMIP is by and large successful in developing the confidence of a large section of the small and marginal farmers in Northeast Purulia to undertake composite culture of carps as a source of livelihood among all other integrated efforts in the project area. With the intervention of WBADMIP production of carp fishes substantially increased from the baseline production existing in this part of the district. As a result, the availability of fish increased in the area, which provided food security and nutrition to households and increased fish supply to the local markets boosting the local economy. However, to further improve the effectiveness of the composite culture of carps, farmers require proper training to increase their skill in managing the resources available and the inputs needed to grow the fish. Since Purulia is a drought-prone area and single-crop agriculture is the main livelihood of most farmers, it is necessary to develop proper water resource management so that there is no conflict between utilizing water resources for agriculture and aquaculture. Small water bodies, which cannot hold water up to 10 months and depth of water frequently fall below 1.22 m (4.0 ft), are unsuitable for carps culture. There is a scope to explore if these water bodies can be used for fast-growing species like tilapia or air-breathing fish. In the large water bodies, which are suitable for growing Indian major carps and the exotic carps, management of inputs like supplementary feed, lime, inorganic fertilizers, and organic fertilizers is crucial to maintain maximum productivity of the water bodies. While excessive use of these inputs either deteriorated the quality of water or incurred an unnecessary expenditure of the culture, underuse of the inputs hampered the growth of the fish and hence productivity of the water bodies. Further research is necessary to determine the critical threshold value of these inputs based on the resources available and guide the farmers to use these inputs with minimum wastage and maximum outcome optimally.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aquaculture.2021.737018.

References

Abdi, H., Williams, L.J., 2010. Principal component analysis. Wiley. Interdiscip. Rev. Comput. Stat. 2 (4), 433–459.
Adewuvi, S.A., Phillip, B.B., Avinde, I.A., Akerele, D., 2010. Analysis of profitability of fish farming in Ogun state, Nigeria. J. Hum. Ecol. 31 (3), 179–184.
Alam, M.M., Haque, M.M., Aziz, M.S.B., Mondol, M.M.R., 2019. Development of pangasius–carp polyculture in Bangladesh: understanding farm characteristics by, and association between, socio-economic and biological variables. Aquaculture 505, 431–440.
Ali, H., Murshed-e-Jahan, K., Belton, B., Dhar, G.C., Rashid, H.O., 2016. Factors determining the productivity of mola carplet (*Amblypharyngodon mola*, Hamilton, 1822) in carp polyculture systems in Barisal district of Bangladesh. Aquaculture. 465, 198–208.
Ali, S., Saha, S., Kaviraj, A., 2020. Fermented mulberry leaf meal as fishmeal replacer in the formulation of feed for carp *Labeo rohita* and catfish *Heteropneustes fossilis* —optimization by mathematical programming. Trop. Anim. Health. Pro. 52, 839–849.
Arora, D., Datta, S., Sau, S.K., 2014. An assessment of socio-economic factors on nutritional status in primary school - a cross sectional study in Purulia of West Bengal. Int. J. Occup. Safety. Health. 4 (2), 15–18.
Arthur, R.I., Lorenzen, K., Homekingkeo, P., Sidavong, K., Sengvilaikham, B., Garaway, C.J., 2010. Assessing impacts of introduced aquaculture species on native fish communities: Nile tilapia and major carps in SE Asian freshwaters. Aquaculture 299 (1–4), 81–88.
Bagli, S., Tewari, G., 2019. Multidimensional poverty: an exploratory study in Purulia district, West Bengal. Econ. Aff. 64 (3), 517–527.
Barik, N.K., 2017. Freshwater fish for nutrition security in India: evidence from FAO data. Aquacult. Rep. 7, 1–6.
Béné, C., Barange, M., Subasinghe, R., Pinstrup-Andersen, P., Merino, G., Hemre, G., Williams, M., 2015. Feeding 9 billion by 2050 – putting fish back on the menu. Food. Secur. 7, 261–274.
Béné, C., Arthur, R., Norbury, H., Allison, E.H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D., Thilsted, S.H., Troell, M., Williams, M., 2016. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. World Dev. 99, 177–196.
Bera, A., Das, S., 2021. Water Resource Management in Semi-Arid Purulia District of West Bengal, in the Context of Sustainable Development Goals. Groundwater and Society, Applications of Geospatial Technology, pp. 501–519.
Beveridge, M.C.M., Thilsted, S.H., Phill, M.J., 2013. Meeting the food and nutrition needs of the poor: the role of fish and the opportunities and challenges emerging from the rise of aquaculture. J. Fish Biol. 83, 1067–1084.
Biswas, A., Patra, P.P., Dubey, S.K., Roy, M., 2019. Prevailing aquaculture practices in a drought-prone landscape: a case of Purulia district of West Bengal, India. J. Entomol. Zool. Stud. 7 (1), 129–136.
Boyd, C.E., 1997. Practical aspects of chemistry in pond aquaculture. Prog.Fish-Cult. 59 (2), 85–93.
Castro-Ortiz, J.L., Lluch-Belda, D., 2007. Low frequency variability of fishing resources, climate, and ocean. Fish. Res. 85 (1–2), 186–196.
Chandra, H., 2021. District-level estimates of poverty incidence for the state of West Bengal in India: application of small area estimation technique combining NSSO survey and census data. J. Quant. Econ. 1–17.
Chen, X., Samson, E., Tocqueville, A., Aubin, J., 2015. Environmental assessment of trout farming in France by life cycle assessment: using bootstrapped principal component analysis to better define system classification. J. Clean. Prod. 87, 87–95.
Coldebella, A., Gentelini, A.L., Piana, P.A., Coldebella, P.F., Boscolo, W.R., Feiden, A., 2017. Effluents from fish farming ponds: a view from the perspective of its main components. Sustainability. 10 (1), 1–16.
Correia, A., Moura, R., Agua, P., Lobo, V., 2020. K-means clustering for information dissemination of fishing surveillance. In: Rocha, Á., Ferrás, C., Marin, C. Montenegro, García, V. Medina (Eds.), ICITS 2020: Information Technology and Systems, 84-93. Advances in Intelligent Systems and Computing, vol 1137. Springer, Cham.
Daripa, S.K., 2018. Socio economic status of the tribals of Purulia district in the post colonial period. *Int. J.* Soc. Sci. Res. 8 (2), 727–738.
Das, B., Pal, S.C., Malik, S., Chakrabortty, R., 2019. Modeling groundwater potential zones of Purulia district, West Bengal, India using remote sensing and GIS techniques. Geo. Ecol. Landscapes. 3 (3), 223–237.
De Silva, S.S., 2016. Culture based fisheries in Asia are a strategy to augment food security. Food. Secur. 8, 585–596.
Del Gatto, M., Di Liberto, A., Petraglia, C., 2011. Measuring productivity. J. Econ. Surv. 25 (5), 952–1008.
Duarah, J.P., Mall, M., 2020. Diversified fish farming for sustainable livelihood: a case-based study on small and marginal fish farmers in Cachar district of Assam, India. Aquaculture 529, 735569.
Edwards Jr., T.C., Cutler, D.R., Zimmermann, N.E., Geiser, L., Moisen, G.G., 2006. Effects of sample survey design on the accuracy of classification tree models in species distribution models. Ecol. Model. 199 (2), 132–141.
El-Gayar, O.F., Leung, P.S., 2001. A multiple criteria decision making framework for regional aquaculture development. Eur. J. Oper. Res. 133, 462–482.
Farquhar, S.D., Khanal, N., Shrestha, M., Farthing, M., Bhujel, R.C., 2019. Socio-economic impacts of the women in aquaculture (WiA) project in Nepal. Kasetsart. J. Soc. Sci. 40.
Fiedler, J.L., Lividini, K., Drummond, E., Thilsted, S.H., 2016. Strengthening the contribution of aquaculture to food and nutrition security: the potential of a vitamin A-rich, small fish in Bangladesh. Aquaculture, 452, 291–303.
Filipski, M., Belton, B., 2018. Give a man a fishpond: modeling the impacts of aquaculture in the rural economy. World Dev. 110, 205–223.
Food and Agriculture Organization of the United Nations, 2020. The State of World Fisheries and Aquaculture 2020*,* Sustainability in Action. FAO, Rome. www.fao.org/.
Genschick, S., Marinda, P., Tembo, G., Kaminski, A.M., Thilsted, S.H., 2018. Fish consumption in urban Lusaka: the need for aquaculture to improve targeting of the poor. Aquaculture 492, 280–289.
Goethals, P.L.M., Dedecker, A.P., Gabriels, W., Lek, S., De Pauw, N., 2007. Applications of artificial neural networks predicting macroinvertebrates in freshwaters. Aquat. Ecol. 41 (3), 491–508.
Government of India, 2015. National family health survey-4, 2015–16. District fact sheet Puruliya, West Bengal. Retrieved from http://rchiips.org/nfhs.FCTS/WB/WB_ Fact Sheet_340_Puruliya.pdf. Accessed December 24, 2020.
Guchhait, S.K., Sengupta, S., 2020. Determinants and decomposition of poverty of rural India: Glimpses from the Purulia district of West Bengal. J. Asian Afr. Stud. https://doi.org/10.1177/0021909620960155 p.0021909620960155.
Haldar, S., Saha, P., 2015. Identifying the causes of water scarcity in Purulia, West Bengal, India - a geographical perspective. J. Environ. Sci. Toxicol. Food. Technol. 9 (8), 41–51.
Huang, C.T., Chiou, J.T., Khac, H.T., Hsiao, Y.J., Chen, S.C., 2016. Improving the management of commercial giant mottled eel *Anguilla marmorata* aquaculture in Taiwan for improved productivity: a bioeconomic analysis. Fish. Sci. 82, 95–111.
Jhingran, V.G., 1991. Fish and Fisheries of India. Hindusthan Publishing Corporation, New Delhi.
Jolliffe, I.T., 1972. Discarding variables in a principal component analysis. I: artificial data. J. R. Stat. Soc.: Ser. C: Appl. Stat. 21 (2), 160–173.
Karim, M., Ullah, H., Castine, S., Islam, M.M., Kunda, M., Thilsted, S.H., Phillips, M., 2017. Carp–mola productivity and fish consumption in small-scale homestead aquaculture in Bangladesh. Aquac. Int. 25, 867–879.
Kawabe, S., Murakami, H., Usui, M., Miyasaki, T., 2019. Changes in volatile compounds of living Pacific oyster *Crassostrea gigas* during air-exposed storage. Fish. Sci. 85 (4), 747–755.
Knapp, K.C., Franklin, B., 2019. Groundwater usage and management: common property, efficiency, and sustainability. Water Res. Econ. 27, 100135.
Krause, G., Brugere, C., Diedrich, A., Ebeling, M.W., Ferse, S.C., Mikkelsen, E., Troell, M., 2015. A revolution without people? Closing the people–policy gap in aquaculture development. Aquaculture, 447, 44–55.
Kumaran, M., Deboral, V.D., Chandrasekharan, V.S., Alagappan, M., Raj.S., 2012. Extension approach for an effective fisheries and aquaculture extension service in India. J. Agric. Educ. Ext. 18 (3), 247–267.
Kundu, A., Nag, S.K., 2018. Assessment of groundwater quality in Kashipur Block, Purulia district, West Bengal. Appl Water Sci 8 (1). Article 33.
Lasner, T., Mytlewski, A., Nourry, M., Rakowski, M., Oberle, M., 2020. Carp land: economics of fish farms and the impact of region-marketing in the Aischgrund (DEU) and Barycz Valley (POL). Aquaculture 519, 734731.
Limsong, S., Sitha, H., Sary, O., Vutha, O., Mohan, C.V., De Silva, S.S., 2013. Introduction of culture based fishery practices in small water bodies in Cambodia: issues and strategies. Aquacult. Asia. 18 (4), 12–17.
Mishra, M., Chatterjee, S., 2018. Application of analytical hierarchy process (AHP) algorithm to income insecurity susceptibility mapping – a study in the district of Purulia, India. Socio-Econ. Plan. Sci. 62, 56–74.
Morgan, G.A., Barrett, K.C., Leech, N.L., Gloeckner, G.W., 2019. IBM SPSS for Introductory Statistics: Use and Interpretation. Routledge.
Mosepele, K., Kolawole, O.D., 2017. Fisheries governance, management and marginalisation in developing countries: insights from Botswana. Cogent. Food. Agric. 3 (1), 1338637.
Mulokozi, D.P., Mmanda, F.P., Onyango, P., Lundh, T., Tamatamah, R., Berg, H., 2020. Rural aquaculture: Assessment of its contribution to household income and farmers' perception in selected districts, Tanzania. Aquac. Econ. Manag. 24 (4), 387–405. https://doi.org/10.1080/13657305.2020.1725687.
Nguyen, H.S., Bui, A.T., Nguyen, D.Q., Truong, D.Q., Le, L.T., Abery, N.W., De Silva, S.S., 2005. Culture-based fisheries in small reservoirs in northern Vietnam: effect of stocking density and species combinations. Aquac. Res. 36, 1037–1048.
Pandey, S.K., Dewan, R., 2008. Institutional support for freshwater aquaculture development-a study of Mirzapur district of Uttar Pradesh, India. J. Indian. Fish. Assoc. 35, 51–73.

Pant, J., Barman, B.K., Murshed-E-Jahan, K., Belton, B., Beveridge, M., 2014. Can aquaculture benefit the extreme poor? A case study of landless and socially marginalized Adivasi (ethnic) communities in Bangladesh. Aquaculture. 418, 1–10.

Pascoe, S., Rodrigo Bustamante, R., Wilcox, C., Gibbs, M., 2009. Spatial fisheries management: a framework for multi-objective qualitative assessment. Ocean Coast. Manag. 52, 130–138.

Paul, T.T., Salim, S.S., Manoharan, S., Sarkar, U.K., Das, B.K., 2020. Understanding variations in socio-economic vulnerabilities and the strategies adopted by small scale fishing communities of tropical reservoirs. Fish.Res. 226, 105523.

Quinlan, J.R., 1986. Induction of decision trees. Mach. Learn. 1 (1), 81–106.

Ren, L., Song, C., Wu, W., Guo, M., Zhou, X., 2020. Reservoir effects on the variations of the water temperature in the upper Yellow River, China, using principal component analysis. J. Environ. Manag. 262, 110339.

Roos, N., Islam, M.M., Thilsted, S.H., 2003. Small indigenous fish species in Bangladesh: contribution to vitamin a, calcium and iron intakes. J. Nutr. 133 (11), 4021–4026.

Roos, N., Wahab, M.A., Hossain, M.A.R., Thilsted, S.H., 2007. Linking human nutrition and fisheries: incorporating micronutrient-dense, small indigenous fish species in carp polyculture production in Bangladesh. Food Nutr. Bull. 28 (2), 280–293.

Salim, S., 2016. Fish consumption pattern in India and exports-overview. In: Food and Beverage News, 8. Foodex, pp. 25–28.

Samy-Kamal, M., 2021. Prices in the Egyptian seafood market: insights for fisheries management and food security. Fish. Res. 233, 105764.

Silva, L.C.B., Lopesb, B., Pontesa, M.J., Blanquetc, I., Segattoa, M.E.V., Marquesb, C., 2021. Fast decision-making tool for monitoring recirculation aquaculture systems based on a multivariate statistical analysis. Aquaculture. 530, 1–6.

Sugunan, V.V., Katiha, P.K., 2004. Impact of stocking on yield in small reservoirs in Andhra Pradesh, India. Fish. Manag. Ecol. 11 (2), 65–69.

Sukumaran, V., Park, S.C., Giri, S.S., 2016. Role of dietary ginger *Zingiber officinale* in improving growth performances and immune functions of *Labeo rohita* fingerlings. Fish. Shellfish. Immunol. 57, 362–370.

Sundaray, J.K., Ananth, P.N., Barik, N.K., Sahoo, P.R., Pal, P.P., Dash, A.K., 2020. Institutional perspective for doubling fish farmers' income: a case study. Indian J. Fish. 67 (2), 102–109.

Thompson, P., Roos, N., Sultana, P., Thilsted, S.H., 2002. Changing significance of inland fisheries for livelihoods and nutrition in Bangladesh. In: Kataki, P.K. (Ed.), Food Systems for Improved Human Nutrition: Linking Agriculture, Nutrition and Productivity, pp. 249–314. Haworth, Binghamton.

Toufique, K.A., Belton, B., 2014. Is aquaculture pro poor? Emperical evidence of impacts on fish consumption in Bangladesh. World Dev. 64, 609–620.

Toufique, K.A., Gregory, R., 2008. Common waters and private lands: distributional impacts of floodplain aquaculture in Bangladesh. Food Policy 33 (6), 587–594.

Wahab, M.A., Kadir, A., Milstein, A., Kunda, M., 2011. Manipulation of species combination for enhancing fish production in polyculture systems involving major carps and small indigenous fish species. Aquaculture, 321 (3–4), 289–297.

Wijenayake, W.M.H.K., Amarasinghe, U.S., De Silva, S.S., 2016. Application of a multiple-criteria decision making approach for selecting non-perennial reservoirs for culture-based fishery development: case study from Sri Lanka. Aquaculture. 459, 26–35.

World Bank, 2013. Fish to 2030 Prospects for Fisheries and Aquaculture. World bank report number 83177-GLB.

Yadava, N.K., Garg, S.K., 1992. Relative efficacy of different doses of organic fertilizer and supplement feed utilization under intensive fish farming. Bioresour. Technol. 42 (1), 61–65.

Yao, H., Duan, Q., Li, D., Wang, J., 2013. An improved K-means clustering algorithm for fish image segmentation. Math. Comput. Model. 58, 790–798.

Zarkamia, R., Sadeghib, R., Goethalsc, P., 2012. Use of fish distribution modelling for river management. Ecol. Model. 230, 44–49.

Zhao, Z., Luo, L., Wang, C., Li, J., Wang, L., Du, X., Xu, Q., 2018. Effects of organic carbon addition on water quality and growth performance of bottom- and filter-feeding carp in a minimum-water-exchange pond polyculture system. Fish. Sci. 84, 681–689.