Bangladesh J. Fish. (2023) **35**(1): 83-97

Impact of aquaculture on crop productivity in greater Noakhali, Bangladesh

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Abstract. Aquaculture expanded to a great extent in Bangladesh through the conversion of agricultural lands due to high profitability resulting in land-use conflicts. The present study is the first initiative to elucidate the impacts of aquaculture on agricultural farms of greater Noakhali (Noakhali, Feni, and Lakshmipur), Bangladesh. Soil and water samples were drawn from 240 selected farms from fish farms (FF), near land (NL), distance land (DL), and control sites. Soil and water quality parameters were analysed following standard methods. A pre-coded structured questionnaire-based interview of farmers was performed from July 2017 to March 2018. Organic matter, organic carbon, total nitrogen, and pH (soil and water) of FF showed significant influence on its surrounding agricultural lands but sulfur, boron, and potassium did not show such kind of influence in all three districts. Total fish production and gross profit were found higher in large fish farms (32.19 MT/year and 238.24%) compared to medium and small fish farms. NL's total crop production and gross profits also showed the same pattern but DL's showed the opposite pattern. Aqua farms negatively impacted agriculture in terms of cropping patterns but showed an increasing rate for HYVs (High Yield Variety) of rice in greater Noakhali.
Keywords: Aquaculture, Agriculture, Soil and water quality, Socio-economic status

Introduction

Aquaculture poses threats compared to other stressors, mainly agriculture, and thus it should be taken into consideration (Diana 2012). Establishment of aquafarms owing to business potential is on march and requires extensive use of agricultural land (Growing *et al.* 2006). Aquaculture activities cause land degradation due to pond construction, may cause eutrophication by receiving pond effluents, and spread diseases into natural communities by releasing drugs into the surrounding environment (Diana 2012). Furthermore, during aquaculture, farmers need to exchange pond water to maintain suitable water quality (Chowdhury *et al.* 2011) creates water sharing between aquaculture-agriculture and finally hampers agriculture production of surrounding lands.

The impacts of aquaculture, mainly shrimp culture, have acquired much interest in Bangladesh (Abdullah *et al.* 2017). However, shrimp is not the most common cultured species in Bangladesh, i.e., about 60% of aquaculture production, mainly fish, is produced in the ponds of aquafarms (Diana 2012). Generally, aquaculture ponds constructed on agricultural lands, convert multiple agricultural croplands to mono-crop production (Hossain *et al.* 2013) which has a direct impact on lower-class family's income. Traditionally, smallholder farming in the coastal region was mainly subsistence-oriented, involving wet-season rice, livestock, and vegetable crops that altered the construction of coastal embankments in the 1960s (Kabir *et al.* 2016). Due to the high

https://doi.org/10.52168/bjf.2023.35.08

profitability of aquaculture, particularly shrimp culture, i.e. 12 times higher than that of high-yielding variety rice (Shang *et al.* 1998), on livelihoods in coastal people Bangladesh expanded to an excellent context in the coastal areas (Abdullah *et al.* 2017) which is acknowledged by the six times more total fish production of Bangladesh in last three decades (FRSS 2019).

Sometimes outlets or drainage systems of aquaculture farms may overflow, and the waste materials spread throughout the surrounding agricultural land resulting in severe damage to agricultural lands and crops. Usually, most farmers do not understand the extent of damage in human health hazards, food quality, safety, land pollution, and water pollution. However, they watch lower crop production. Therefore, the present study aimed to evaluate the impacts of aquaculture on crop productivity in the greater Noakhali district of Bangladesh.

Materials and Methods

Study area: The study was conducted in the greater Noakhali district (Noakhali, Luxmipur, and Feni). Soil-water samples and socio-economic data from 240 farms under different upazillas in Greater Noakhali district (Fig. 1) were considered in the present study. The duration of the study was from May 2017 to September 2018. Two types of activities were performed in the study. One was laboratory analysis through the collection of soil and water samples for physical verification of FF, NL, DL, and control sites and another activity was a detailed survey among the aquafarmers and non-aqua farmers' livelihood and agricultural production adjacent to the aquafarms.

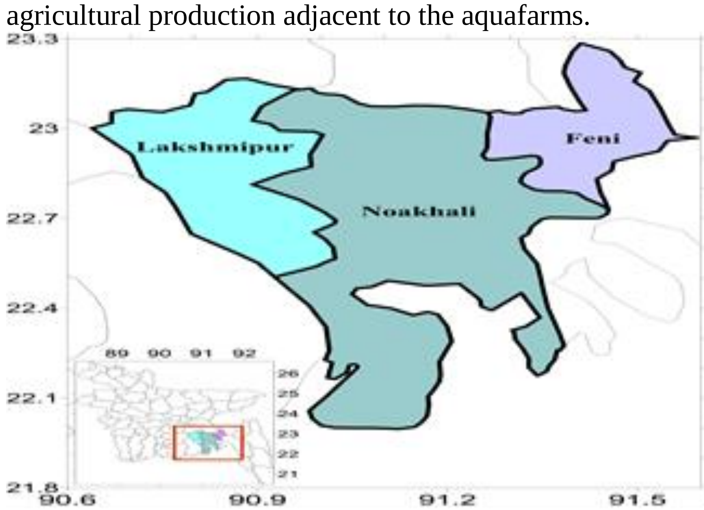

Fig. 1. Map of the greater Noakhali District (Study area)

Sampling techniques and sample size: A total of 240 farms (about 16% of the total sample) were selected for the study. Two hundred forty farms were then divided by 4 (fish farm, FF; near land agriculture farms, NL; distant land agriculture farms, DL; and control sides), and equal numbers of samples (60) from each district were collected. The selected farms were categorized as small (< 5 acres), medium (5 - 15 acres), and large (> 15 acres). Based on farm size, the stratified random sampling technique was followed to select farm households.

Soil sample collection and analysis: Soil samples (30cm deep) were collected from 4 categorized sites (FF, NL, DL, CL) from five places forming Z-shape and were mixed. Soil samples were collected in transparent polyethylene bags with proper labeling and carried to the Soil Resource Development Institute's (SRDI) regional laboratory, Noakhali. Organic matter (OM), organic carbon (OC), total nitrogen (TN), available phosphorus (P), potassium (K), sulfur (S), and boron (B) were measured in the SRDI laboratory. The soil samples were grounded after drying at room temperature under a shade and then filtrated using a 2-mm sieve for laboratory analysis (Petersen 2002).

Soil pH was measured using a glass electrode pH meter by maintaining the soil-water ratio of 1: 2.5 (McLean 1983). Calculating the electrical resistance by a conductivity cell maintaining a soil-water ratio of 1:5, soil salinity was calculated indirectly from electrical conductivity (EC) (Petersen 2002). Organic carbon was detected volumetrically by the process of wet oxidation (Walkley and Black 1934), which was used by multiplying the Van Bemmelen factor to measure organic matter (Piper 1950), and total nitrogen was calculated using the Kjeldahl method (Bremner 1982). The Bray and Kurtz method for acid soils (Bray and Krutz 1945) and the Olsen method for neutral/alkaline soil were used to assess soil phosphorus (Olsen 1982). Potassium was examined using a flame photometer by extracting ammonium acetate (Black 1965). Sulfur content was determined by the process of sulfur extraction solution (Fox ***et al.*** 1964), and boron was measured by a spectrophotometer calculated using a standard curve at a wavelength of 420 nm (Petersen 2002).

Water sample collection and analysis: Water samples were collected from the fish farm (FF) and adjacent water bodies of near land (NL), distance land (DL), and control sites. The ecological parameters such as temperature (℃), dissolved oxygen (mg/L), pH, and salinity (ppt) were measured *in situ* using Hannah multi-parameters (Model: H198194, Romania). Water samples were collected in prewashed plastic bottles and carried to the Soil Resource Development Institute (SRDI) regional laboratory, Noakhali, to estimate OM, OC, TN, P, K, S, and B contents using the standard method described in SRDI manual. Before analysis, water samples were filtered using dry Whatman (GF/F) filter paper into a dry screw cap bottle and stored in the refrigerator.

Data collection of livelihood and crop production : The study was based on primary data collection done directly from the farm owner. Before collecting primary data, a detailed questionnaire was developed and was tested in some nearby fish farms. In this test, much endeavour was placed in order to reach the objectives of the study. The selected farms were categorized as small (0-5 acre, medium (5-15 acre), and large (> 15 acres) to observe the agricultural impact on farm sizes. Based on farm size, the stratified random sampling technique was followed to select farm households. The farmers of selected farms (FF, NL, DL, and control sides) were the same as to soil and water quality sampling farms through field surveys.

Data analysis: Normality and homoscedasticity tests were checked before being analyzed data. The one-way analysis of variance (ANOVA) was carried out in the case of normal and homoscedastic data. Multiple comparisons (Tukey's HSD post hoc test) were performed to find out the site and district wise variation in the mean values of soil quality parameters. Pearson's correlation was carried out to find out the relationships among soil quality parameters. Multiple regression model (ANOVA) was accomplished using soil samples in the present study.

Results and Discussions

Soil and water quality parameters

pH: The soil pH levels in Feni and Lakshmipur indicated acidic across all sites, with the exception of the FF site in Lakshmipur. Conversely, in Noakhali, all sites displayed alkaline conditions except for the control sites (Table I). The influence of aquaculture on agriculture became evident through the soil pH levels in NL and DL of Noakhali and Lakshmipur, as most plant nutrients are typically available within the pH range of 6.0 to 6.5 (Vossen 2006). Furthermore, according to CIBA (2001), the recommended optimal soil pH for aquaculture falls within the range of 6.5 to 7.5.The pH of Noakhali and Lakshmipur water at all sites exhibited alkaline conditions, except Lakshmipur control sites, while all Feni sites exhibited acidic conditions (Table II). The water pH ranged from 6.49±0.51 to 7.86±0.32 in the current analysis, consistent with others (Chowdhury *et al.* 2011).

Table I. Soil quality parameters observed in greater Noakhali

	Sites	pH	OM (%)	OC (%)	TN (%)	P (µg/g)	S (µg/g)	B (µg/g)	K (meq/100g)
Noakhali	FF	7.09±0.7	2.13±1.13	1.21±0.63	0.10±0.05	12.77 ± 9.26	42.05 ± 13.81	0.40 ± 0.29	0.28 ± 0.08
	NL	7.09±0.8	2.04±1.45	1.18±0.84	0.10±0.07	15.80 ± 9.96	50.12 ± 19.16	0.38 ± 0.26	0.29 ± 0.08
	DL	7.00±0.6	1.96±0.73	1.14±0.42	0.10±0.04	14.02 ± 11.39	42.04 ± 16.66	0.42 ± 0.29	0.29 ± 0.11
	Control	6.49±0.6	1.17±0.44	0.71±0.15	0.15±0.29	9.79 ± 4.32	51.93 ± 18.21	0.54 ± 0.28	0.20 ± 0.07
Feni	FF	6.25±0.5	2.66±1.45	1.54±0.84	0.13±0.07	13.55 ± 0.64	1.65 ± 1.31	0.53± 0.41	.003 ± .002
	NL	5.92±0.5	2.68±1.30	1.55±0.75	0.16±0.12	12.38 ± 0.28	1.69 ± 1.15	0.51 ± 0.42	.002 ± .001
	DL	5.83±0.7	2.98±1.46	1.73±0.85	0.15±0.07	9.02 ± 0.53	1.63 ± 1.18	0.55 ± 0.42	0.02 ± .001
	Control	5.19±0.3	0.90±0.37	1.19±0.31	2.17±0.81	8.02 ± 0.21	1.83 ± 0.51	0.43 ± 0.37	0.02 ± 0.02
Lakshmipur	FF	7.33±0.5	1.91±1.25	1.11±0.72	0.09±0.06	15.69 ± 22.23	16.26 ± 19.37	0.18 ± 0.15	0.17 ± 0.10
	NL	6.83±0.6	2.53±0.99	1.47±0.58	0.13±0.05	13.10 ± 13.3	15.38 ± 13.61	0.36 ± 0.33	0.18 ± 0.08
	DL	6.96± 0.5	2.11± 0.77	1.11±0.31	0.11±0.04	8.29 ± 5.38	14.24 ± 11.49	0.35 ± 0.35	0.18 ± 0.08
	Control	5.20± 0.3	2.19± 0.75	0.93±0.36	0.10±0.06	8.24 ± 2.20	19.57 ± 4.23	0.44 ± 0.34	0.23 ± 0.12

OM = Organic matter, OC = Organic carbon, TN = Total nitrogen, P = Phosphorus, S = Sulfur, B = Boron, K = Potassium

Table II. Water quality parameters observed in greater Noakhali

	Sites	DO (mg/L)	Temp. (°C)	pH	Salinity (ppt)	OM (%)	OC (%)	TN (%)	P (µg/g)	S (µg/g)	B (µg/g)	K (meq/100g)
Noakhali	FF	6.51±0.99	32.6±1.2	7.68±0.30	0.06±0.02	1.36±0.23	0.75±0.14	0.07±0.01	2.07±2.76	2.89±0.86	0.78±1.14	0.015±0.007
	NL	6.30±1.04	32.5±1.1	7.69±0.32	0.06±0.02	1.20±0.35	0.70±0.21	0.06±0.02	2.03± 2.55	3.29± 1.07	0.73±0.51	0.017±0.008
	DL	6.68±1.09	32.5±1.2	7.71±0.33	0.08±0.06	1.18±0.21	0.74±0.18	0.07±0.01	1.95±2.18	2.79±0.98	0.75± 0.58	0.013±0.006
	C	6.74±1.09	32.4±1.0	7.86±0.32	0.06±0.02	1.17±0.23	0.6 ±0.18	0.05±0.01	2.17±2.11	2.64±0.95	0.65±0.54	0.011±0.003
Feni	FF	9.01±2.19	30.9±0.9	6.71±0.49	0.04±0.00	1.5±0.48	0.92±0.83	0.08 0.04	0.59±0.55	1.44±0.01	0.32±1.02	0.224±0.014
	NL	7.66±2.18	30.7±0.6	6.84±0.49	0.04±0.00	1.37±0.65	0.79±0.38	0.07±0.03	0.48±0.27	2.49± 2.41	0.30±0.17	0.016±0.011
	DL	8.09±2.18	30.8±0.7	6.73±0.47	0.04±0.00	1.59±0.65	0.92±0.38	0.08±0.03	0.54±0.27	1.82± 2.41	0.25±0.17	0.015±0.011
	C	7.94±2.11	30.9±0.9	6.59±0.50	.004±0.00	1.01±0.31	0.58±0.24	0.04±0.02	0.35±0.17	1.13±0.01	0.24± 0.98	0.166±0.010
Lakshmipur	FF	8.88±1.76	31.1±0.9	7.63±0.48	0.26±0.25	4.01±1.09	2.32±0.63	0.20±0.05	0.97±1.85	3.26± 3.18	0.08±0.03	0.011±0.010
	NL	8.73±1.57	31.2±1.0	7.46±0.76	0.27±0.14	3.99±0.90	2.31±0.52	0.20±0.05	0.89±1.97	3.53±3.26	0.09±0.10	0.007±0.007
	DL	8.64±1.41	31.1±0.9	7.71±0.58	0.25±0.1	4.17±0.57	2.42±0.33	0.21±0.03	0.58±0.87	2.96±1.87	0.10± 0.03	0.010±0.010
	C	8.82±1.78	30.9±0.9	6.49±0.51	0.03±0.01	0.61±0.23	1.05±0.31	0.04±0.02	0.35±0.16	0.01±0.11	1.10 0.92	0.245±0.164

OM = Organic matter, OC = Organic carbon, TN = Total nitrogen, P = Phosphorus, S = Sulfur, B = Boron, K = Potassium, C= Control

Salinity (ppt): Water salinity in the present study ranged from 0.02 ± 0.05 to 0.69 ± 0.41. (Table II). The water salinity of FF, NL, and DL was significantly higher (p<0.05) than that of the control sites for the entire study area, implying that fish farms had a potential effect on their surrounding agricultural land. Garg and Bhatnagar (1996) suggested a desirable range of up to 2 ppt for common carp to help current aquaculture findings in the selected areas.

Dissolved oxygen (mg/L): Water DO was found in optimum level in FF, NL, DL, and control sites of three districts during the current investigation (Table II) for aquaculture practices, as recommended by Cheng *et al.* (2003). The average or successful DO concentration should be above 5.0 mg/L if it is between 3.0 and 5.0 mg/L in ponds, which endorsed the present analysis findings, will be considered unproductive (BARC 2005).

Temperature (℃): The temperature in the present study ranged from 30.7 ± 0.6 ℃ to 32.6 ± 1.2 ℃ (Table 2), and the recommended temperature for tropical major carps is 28−32 ℃ (BARC, 2005), which supported the current findings.

Organic matter (%): The mean value of soil OM in FF and their surrounding agricultural lands during the current investigation (Table I) were supported by BARC (2005), Haque (2006) and (Tapader *et al.* 2017). Organic matter content both in the soil and water of FF, NL, and DL were significantly higher (p< 0.05) than the control sites in all three districts suggesting a significant influence of FF on their surrounding agricultural lands through the use of fish feed and fertilizers in fish farms that leached to the NL and DL gradually.

Organic carbon (%): In the present study mean value of soil (0.71−1.73%) and water (0.63−2.42%) organic carbon in three districts were found within the range of Banerjea (1967) findings. However, FF, NL, and DL showed significantly higher (p<0.05) values in all districts compared to control sites (Tables I and II). The mean value of soil organic carbon recorded (1.47±0.53%) in the newly constructed pond in Noakhali (Tapader et al. 2017) was almost three times lower than the present findings.

Total nitrogen (%): The total nitrogen content varied between 0.09% and 2.17% in the soil and between 0.04% and 0.21% in the water of the three districts (Tables I and II). Higher total nitrogen (TN) values in the control sites of the soil suggested elevated concentrations of NO_3-N in FF, NL, and DL across the three districts. Conversely, lower TN values in the water control sites indicated a reduced presence of NO_3-nitrogen in the three districts (Heiskary *et al.* 2013). The soil TN% in the FF, NL, and DL areas of the study exhibited a significantly higher level (p<0.05) compared to the control sites, indicating a notable impact of fish farms on the adjacent agricultural lands. However, the opposite scenario was observed for water TN%, which enters into the water in various forms, including inorganic forms such as ammonia, ammonium, nitrate, and nitrite, as well as organic forms. De-nitrification was identified as a significant pathway for nitrogen removal from ponds.

Phosphorus (µg/g): Soil and water phosphorus mean values of the present study (Table I and II) were supported by Heiskary *et al.* (2013). However, control sites in all districts for both soil and water phosphorus contents were significantly lower (p< 0.05) than the FF, NL, and DL, suggesting the application of fish feed and fertilizers might yield high phosphorus concentrations. Pond soil interacts with the water column affecting the phosphorus cycle in natural waters, a significant factor in pond aquaculture (Boyd, 1995).

Sulfur (µg/g): Soil sulfur ranged from 1.63±1.18 to 50.12±19.16, and the higher value was very near to 65.2, suggested by Rahman and Ahsan (2001) (Table I). The sulfur values in water were found remarkably lower than the reference value (Table II), and this is maybe due to the collection of samples in the peak rainy season. No influence of fish farms was found by soil and water sulfur content on the nearby agricultural lands in all three districts.

Boron (µg/g): Boron contents found in the present study (Tables I and II) was coincided with the findings of SRDI of Bangladesh (SRDI 2001). The mean concentration of boron in the soil in the present study was higher than in the water. No significant influence of fish farms from both soil and water boron content was found on its surrounding agricultural lands during the study period.

Potassium (meq/100g): The mean concentration of potassium in water was much higher than soil contents in all three districts (Tables I and II) during the current study and the values were coherent with Heiskary *et al.* (2013). Accordingly, FF, NL, and DL showed higher values of potassium compared to control sites. No significant influence of fish farms was observed on its surrounding agricultural lands through soil and water potassium. Potassium from dead phytoplankton and zooplankton due to the application of fish feed might mix with clay materials and be bound in soil but dissolve in water resulting in higher water values.

Variation in soil quality: Multiple comparisons were made to assess the district-wise difference in the mean values of soil quality parameters (Tukey's HSD post hoc test $p < 0.05$). Soil pH, OC, OM, TN, P, and salinity of Noakhali significantly varied from Feni district, and K, S, and B were significantly different in three districts (Table III).

Table III. Multiple comparisons of soil quality parameters (Tukey's HSD post hoc test) during the present study

Dependent Variable			Mean Difference(I−J)	Std. Error	Significance	95% Confidence Interval	
						Lower Bound	Upper Bound
pH	Noakhali	Feni	1.067*	0.121	0.000	0.781	1.353
		Lakshmipur	0.021	0.116	0.983	-0.254	0.295
OC%	Noakhali	Feni	-0.432*	0.129	0.003	-0.739	-0.125
		Lakshmipur	-0.217	0.125	0.194	-0.511	0.078
OM%	Noakhali	Feni	-0.728*	0.225	0.004	-1.259	-0.196
		Lakshmipur	-0.356	0.216	0.225	-0.867	0.152
TN%	Noakhali	Feni	-0.048*	0.013	0.001	-0.078	-0.018
		Lakshmipur	-0.019	0.012	0.273	-0.048	0.010
P (µg/g)	Noakhali	Feni	9.704*	2.124	0.000	4.685	14.723
		Lakshmipur	1.812	2.038	0.648	-3.003	6.627
K	Noakhali	Feni	0.055*	0.020	0.016	0.009	0.101
(meq/100g)		Lakshmipur	0.109*	0.019	0.000	0.065	0.154
S (µg/g)	Noakhali	Feni	28.140*	2.739	0.000	21.669	34.612
		Lakshmipur	29.391*	2.627	0.000	23.183	35.599
B (µg/g)	Noakhali	Feni	-0.117	0.062	0.139	-0.263	0.028
		Lakshmipur	0.102	0.059	0.200	-0.038	0.241

* Mean difference significant at $p < 0.05$

Table IV. Pearson's correlation matrix of soil quality parameters during the present study

	pH	OC	OM	TN	P	K	S	B	Salinity	District	Sites
pH	1.00										
OC	-0.388**	1.00									
OM	-0.390**	0.998**	1.00								
TN	-0.391**	0.831**	0.829**	1.00							
P	0.328**	0.017	0.013	-0.016	1.00						
K	-0.070	0.096	0.092	0.036	0.212**	1.00					
S	0.122	-0.039	-0.040	-0.061	0.241**	0.536**	1.00				
B	0.003	0.034	0.030	0.051	-0.186*	0.028	-0.026	1.00			
Salinity	0.597**	-0.150*	-0.152*	-0.179*	0.278**	0.050	0.268**	-0.072	1.00		
District	0.036	0.109	0.103	0.091	-0.036	-0.395**	-0.589**	-0.140	0.140	1.00	
Sites	-0.015	0.135	0.129	0.114	-0.066	-0.392**	-0.565**	-0.101	0.166*	0.949**	1.00

** Correlation significant at $p < 0.01$ (2-tailed), * Correlation significant at $p < 0.05$ (2-tailed), OM = Organic matter, OC = Organic carbon, TN = Total nitrogen, P = Phosphorus, S = Sulfur, B = Boron, K = Potassium

Correlation among soil quality parameters

Soil pH in three districts was found highly negatively correlated with OC, OM, TN and positively correlated with phosphorus and salinity (Table IV). On the other hand, organic carbon showed highly positively correlated with organic matter and total nitrogen (TN) while negatively correlated with salinity (Table IV). The composition of the soil bottom is related to organic matter means organic carbon and nitrogen. Organic matter of the soil releases organic carbon after the bacterial degradation showed a highly positive relationship with total nitrogen and negative relation with salinity. Phosphorus showed a highly significant positive relationship with potassium, sulfur, and salinity with a significant negative relationship with boron. Potassium was highly correlated with the concentration of sulfur and was found different in each district and location. Soil salinity in each site (FF, NL, DL, and control) was significantly different (p<0.05) from each district.

Relationship among soil OM, OC, and TN

Many studies have been conducted in different countries and different regions to elucidate the relationship between soil organic matter, organic carbon, and total nitrogen. Unfortunately, no study was conducted to determine their relationship with the vast number of samples in Bangladesh. A stepwise multiple regression model (ANOVA) with 186 soil samples data from the present study suggested that if OC% increases by 1%, OM% increases by 1.726% (Table V). On the other hand, if OC% increases by 1%, total nitrogen (%) increase by 0.083% (Table VI).

Table V. ANOVA Regression model for soil quality parameters in greater Noakhali

	Sum of Squares	Df	Mean Square	F	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
Regression	281.378	1	281.378	51947.968	0.000^b	B	Std. Error	Beta		
Residual	1.002	185	0.005			0.003	0.012		0.258	0.796
Total	282.380	186				1.726	0.008	0.998	227.921	0.000

Dependent Variable: OM%; B. Predictors: (Constant), OC%; p<0.05

Table VI. ANOVA Regression model for water quality parameters in greater Noakhali

	Sum of Squares	Df	Mean Square	F	Sig.	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
Regression	0.646	1	0.646	412.23	0.000^b	B	Std. Error	Beta		
Residual	0.290	185	0.002			0.008	0.006		1.298	0.196
Total	0.936	186				0.083	0.004	0.831	20.303	0.000

Dependent Variable: TN%; B. Predictors: (Constant), OC%; p<0.05

Agricultural productivity and profitability analysis

Fish farm productivity and income: The fish farm owners converted their agricultural cropland into fish farms for more profit in the study areas. Therefore, the total production of fish farms and crops (rice, pulses, vegetables) before and after the establishment of fish farms was studied. Results from the greater Noakhali revealed that the total fish production and gross profit were found higher in large fish farms (LFF) (32.19 MT/year and 238.24%) compared to medium fish farms (MFF) (3.76 MT/year and 160.79%) and small fish farms (SFF) (2.25 MT/year and 66.69%) (Table VII) Area of LFF, MFF, SFF is about >15 acre, 5-15 acre and <5 acre respectively.

Table VII. Total cost (Lac Taka/year), fish production (MT/year) and profitability (%) of fish farms (FF) in greater Noakhali

Farm Category	No. of FF	Fixed Cost		Temporary Cost		Fish production		Fish Sale		% of Profit
		Total	Avg	Total	Avg	Total	Avg	Total	Avg	
LFF	9	301.26	33.47	1572.41	174.71	32.19	3.58	6337.50	704.17	238.24
MFF	16	24.11	1.51	228.34	14.27	3.76	0.23	658.36	41.15	160.79
SFF	42	24.72	0.59	213.44	5.08	2.25	0.05	397.00	9.45	66.69

Avg. Average, LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms

Impact of aquaculture on agricultural productions and profitability: A comparative scenario of average crop production and the profitability of surrounding agricultural lands (NL and DL) of the study area's fish farms has presented in Table VIII. NL's total crop production change was higher (19.09%) in larger fish farms and lower (3.31%) in the small fish farms. In the case of a change in DL's, total crop production was found higher (21.62%) in small fish farms and lower (17.77%) in larger fish farms. The change of gross profit from crops in NL after the establishment of fish farms was found to be the highest (17.01%) in the large fish farms compared to medium (8.24%) and small (2.0%) fish farms in greater Noakhali. In case of a change in DL's, maximum gross profit was achieved from the small farms (43.19%) and medium farms (42.80%) while lower at large farms (17.96%) (Table VIII).

Table VIII. Changes (%) in average crop production and profit of aquaculture farms in greater Noakhali

Farm Category	FF No	Near land (NL)						Distance land (DL)					
		Crop production			Gross profit			Crop production			Gross profit		
		Before	After	% Change	Before	After	% Change	Before	After	% Change	Before	After	% Change
LFF	9	126.89	151.11	19.09	63,216.67	73,972.22	17.01	217.00	255.56	17.77	116,066.67	136,911.11	17.96
MFF	16	54.13	60.69	12.12	15,546.88	16,828.13	8.24	49.38	59.81	21.14	11,843.75	16,912.50	42.80
SFF	42	43.83	45.29	3.31	17,670.83	18,023.93	2.00	45.81	55.71	21.62	15,075.60	21,586.90	43.19

LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms

Aquaculture activities, mainly supplying vast volumes of nutrient-rich waters, might be positively impacted (large farms of NL, small and medium farms of DL) and negatively (small and medium farms of NL and large farms of DL) in the total crop production and gross profit. The focus group's statement revealed that continuous draining from nutrient-rich water to its nearby agricultural land made the area water-logged. The NL small farms area may be water-logged all of the time, but the large farms' full area may not water-logged, which causes higher production in large farms than the small farms in NL. On the other hand, continuous leaching of nutrient-rich waters gradually decreased from near land to distant land by moving from a wet area to dry land and might develop the small and medium farms of distance land suitable for more crops.

Change in crop diversity: In both NL and DL, HYV rice showed an increasing rate in every case after fish farm establishment (Table 9). The release of the vast volume of water by the large fish farms making the NL waterlogged. Therefore, 66% NL farmers were forced to cultivate HYV. Similarly, 50% (8 out of 16) and 42% (18 out of 42) of NL farmers were habituated to cultivating HYV rice owing to the effect of medium and small fish farm establishment, respectively (Table IX). Cropping diversity was greatly decreased in NL and DL after establishing small fish farms (Table IX).

Table IX. Changes in the crop diversity after the fish farms establishment in greater Noakhali

Farm Category	No of FF	Change	Near land (NL)					Distant land (DL)				
			HYV	WIF	Hybrid	Both	None	HYV	WIF	Hybrid	Both	None
LFF	9	Increase	6	1	0	0	0	5	0	0	2	0
		Decrease	0	2	2	1	4	0	0	1	0	7
MFF	16	Increase	8	0	0	0	0	11	0	0	2	0
		Decrease	0	5	5	0	8	0	0	0	1	15
SFF	42	Increase	18	0	0	1	0	33	0	0	5	0
		Decrease	2	10	6	7	18	0	2	2	1	16

LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms

Change in cropping pattern: Activities of the large-scale aquaculture farms (>15 acres) negatively impacted agricultural production in terms of cropping patterns (Table 10). Cultivation of groundnut (-100%) was disappeared entirely in the NL of fish farms in greater Noakhali, whereas Helon dal (lentil) herein pulses (-80%) and vegetable (-67%) were about to disappear in these areas. Large aquaculture farms and medium and small farms have a negative impact on the cropping patterns of agricultural land (NL and DL) in greater Noakhali (Table X).

Table X. Changes in cropping patterns (%) after the fish farms establishment in greater Noakhali

Farm	FF No.	Time	Near land (NL)					Distant land (DL)				
			Rice	Helon	Groundnut	Vegetable	Other	Rice	Helon	Groundnut	Vegetable	Other
LFF	9	Before	9	5	1	3	1	9	2	2	1	1
		After	8	1	0	1	0	9	0	1	4	0
		Change	−11	−80	−100	−67	−100	0	−100	−50	+400	−100
		TC (%)	72%					130%				
MFF	16	Before	16	3	3	6	1	16	2	2	6	1
		After	16	1	0	2	0	16	1	0	3	0
		Change	0	−67	−100	−67	−100	0	−50	−100	−50	−100
		TC (%)	67%					60%				
SFF	42	Before	39	11	4	9	1	41	3	3	14	2
		After	42	3	0	2	1	42	1	0	6	1
		Change	+108	−73	−100	−78	0	+102	−67	100	−57	−50
		TC (%)	72%					75%				

LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms, TC. Total Change

Changes in soil and water color: Water color of large fish farm showed no change, but the medium (93.75%) and small (88.10%) farms showed an increasing rate of color change in NL than DL after fish farm establishment. Percentage of soil color change showed a slightly different pattern. The highest soil color change was found in large farms (100%) of DL. Medium (93.75%) and small (92.86%) fish farms of NL showed the greater change in color than the medium (50%) and small (83.33%) farms of DL (Supplementary 1).

Supplementary 1. Changes in of soil and water color after the fish farms establishment in greater Noakhali

Farm	No. of FF	Near land (NL)		Distance land (DL)	
		Soil Color Change (%)	Water Color Change (%)	Soil Color Change (%)	Water Color Change (%)
LFF	9	88.89	88.89	100	88.89
MFF	16	93.75	93.75	50	81.25
SFF	42	92.86	88.10	83.33	80.95

LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms

Effects on socio-economic status

Changes in income: A dramatically increasing rate of income was observed for all the farm owners after the farm establishment. This change was found higher for Large fish farm (203.09%) than medium (146.22%) and small farms (122.48%) (Supplementary 2).

Supplementary 2. Changes in annual income (Lac Taka) after the fish farms establishment in greater Noakhali

Farm Category	No of Fish Farm	Previous annual income		Annual income after farm establishment		Average increase of income (%)	% of owner taken loan
		Total	Mean	Total	Mean		
LFF	9	1,117.5	124.2	3,387	376.3	203.0	55.6
MFF	16	172	10.75	423.5	26.47	146.2	25
SFF	42	120.3	2.86	267.6	6.37	122.5	30.9

LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms

Changes in educational status: In the present study, the educational facilities of the large fish farm owners were found almost the same (100%) as before, but in medium (100%) and small size farms (97.62%), a dramatically increasing rate was observed after the fish farm establishment (Supplementary 3).

Supplementary 3. Changes in education, medical and sanitation facilities after the establishment of fish farm in greater Noakhali

Farm Category	No. of Fish Farm	Education Facility			Medical Facility			Sanitation Facility		
		Before	After	% availed after	Before	After	% availed after	Before	After	% availed after
LFF	9	9	9	100	9	9	100	9	9	100
MFF	16	12	16	100	15	16	100	16	16	100
SFF	42	38	41	97.62	41	42	100	40	42	100

LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms

Changes in medical facilities*:* The increasing rate in the medical facility was observed almost identical in the large fish farm owners as before but in medium (100%) and small size farm (100%) slightly increasing rate was observed after the fish farm establishment (Supplementary 3).

Changes in sanitary facilities*:* In the present study, the sanitation facilities of large and medium fish farm owner were found almost the same (100%) as before, but in small size farms (100%) slightly increasing rate was observed after the fish farm establishment (Supplementary 3).

Changes in electrical equipment and motor vehicle usages: Dramatically increasing rate was observed in using electrical equipment and motor vehicles among the fish farm owners after the fish farm establishment in the experimental area (Supplementary 4). From the present study, the increasing rate for electrical equipment and motor vehicles used was found higher in small farms> medium farms > large farms (Supplementary 4).

Supplementary 4. Changes in electrical equipment and motor vehicle uses after the establishment of fish farm in greater Noakhali

Farm Category	No of Fish Farm	TV, Fridge and Mobile			Motor Vehicle		
		Before	After	% Change	Before	After	% Change
LFF	9	4	7	75	4	9	125
MFF	16	2	14	600	4	11	175
SFF	42	6	32	433.33	9	29	222.22

LFF. Large Fish Farms, MFF. Medium Fish Farms, SFF. Small Fish Farms

This study highlights the impact of aquaculture on agricultural farms in greater Noakhali, Bangladesh. Soil and water quality parameters from aquafarms, such as soil pH, soil and water organic matter, organic carbon, total nitrogen, and phosphorus, significantly affect nearby agricultural lands. However, there is no notable influence on soil and water sulfur, boron, and potassium contents in the study areas. Aquaculture alters soil and water color, enriching nutrients in nearby waterlogged areas of greater Noakhali. This positively affects fish farmers with increased fish production and gross profit, as well as neighboring agriculture farmers with enhanced rice production. Larger fish farms in NL and DL exhibit higher total fish production and gross profit, with varying impacts on total crop production and profits. The use of high-yielding varieties (HYVs) of rice increases in every sized fish farm in NL and DL. Fish farms lacking proper water drainage and established haphazardly pose a significant threat to nearby agriculture farms, affecting food security by altering cropping patterns and reducing diversity in greater Noakhali.

Acknowledgments: We would like to acknowledge Bangladesh Agriculture Research Council (BARC) and the World Bank for arranging the grand fund and supervising the CRGs (Comprehensive Research Grants) by BARC. All the respondents who were surveyed during the present study are also acknowledged for their kind cooperation.

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(Manuscript received 22 September 2023)