

Effect of combined shrimp and rice farming on water and soil quality in Bangladesh

Md. Arif Chowdhury · Yahya Khairun · Md. Salequzzaman ·
Md. Mizanur Rahman

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Abstract This study analyzed water and soil quality and environmental impacts of shrimp farming in the southwestern coastal region of Bangladesh. Shrimp farming in the region is very traditional in nature where two culture systems viz. shrimp–rice and shrimp-only are being practiced, which are characterized by lower production, repeated stocking, irregular feeding, and fertilizing. Water quality in both farming systems was found suitable for optimum growth and survival of shrimp (*Penaeus* spp.). The level of 5-day biological oxygen demand (BOD₅) in both systems even in canal water was within the recommended level provided by the Government of Bangladesh which is less than 5 mg/l. Therefore, effluents of shrimp farms in the study area did not show any nutrient pollution on the surrounding environment. However, saltwater intrusion has caused many problems like loss of agricultural production, reduced availability of fodder for livestock, and fresh water for domestic uses in the coastal region. The findings of this study confirmed that shrimp farming using saline water have long-term effect of soil salinization. As a result, it poses a real threat toward sustainability of coastal shrimp farming as well as coastal development in Bangladesh.

Md. A. Chowdhury (✉)
Centre for Marine and Coastal Studies (CEMACS), Universiti Sains Malaysia (USM),
11800 Pulau Pinang, Malaysia
e-mail: arifait@yahoo.com

Y. Khairun
Centre for Marine and Coastal Studies & School of Biological Sciences,
Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia
e-mail: khairun@usm.my

Md. Salequzzaman
Environmental Science Discipline, Khulna University, Khulna, Bangladesh
e-mail: salek_uz@yahoo.com

Md. M. Rahman
Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University,
Salna, Gazipur 1706, Bangladesh
e-mail: rmizanur@yahoo.com

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Introduction

In last decades, coastal aquaculture has become a profitable industry in many south-east Asian countries like China, Thailand, Indonesia, Bangladesh, and many other countries, and its effluents can be a major source of environmental pollution (Boyd and Green 2002; Naylor et al. 2000). Environmental studies into the effects of shrimp aquaculture have focused on in-pond and receiving water quality. The monitoring of water and soil quality is essential to identify the impacts of shrimp farming. In shrimp aquaculture, water quality management is of primary consideration particularly in farms those are involved with higher stocking density. Presently, the shrimp production system evolved from extensive toward intensive with increasing inputs of high-quality feed and water supply (Thakur and Lin 2003; Hambrey 1996). Uneaten feeds and metabolic wastes are responsible for deterioration of the quality of water (Phillips 1998). In traditional farming system, farmers need to exchange pond water to maintain the suitable water quality and standard salinity ranges for optimum growth of shrimp. To mitigate the environmental impacts of effluent discharge and to reduce the risk of disease contamination from externally polluted water supply, shrimp culture in recent years has been attempted to evolve from “open system” with frequent water discharge to “closed system” with little or “zero” water discharge (Thakur and Lin 2003). Now-a-days effluent treatment is routinely done in intensive culture systems to reduce the nutrient and organic loads for the protection of surrounding environment. The impacts of effluents depend on mass flow of the water and capacity of receiving water to assimilate waste materials. If receiving water bodies have the ability to dilute and assimilate nutrients and organic matters, and if that capacity is not exceeded, the discharge effluents will not cause eutrophication (Boyd et al. 1998).

Shrimp farming in Bangladesh is characterized by small-scale operation and marginal management with irregular application of feed and fertilizers with an average production of $146 \text{ kg ha}^{-1}\text{year}^{-1}$ in different category of farming systems (Alam et al. 2007), which indicates lower production. Even with this lower production, Bangladesh ranked eighth among the shrimp producing countries in the world yielding 67,197 metric tons shrimp during 2008 by volume (FAO 2010). According to the level of intensification, Bangladesh shrimp farming can be categorized into extensive to improve extensive in nature of management where farmers do not follow proper feeding, fertilizing, and water quality monitoring (Barg 1992). Repeated stocking and harvesting are observed round the year. Based on cropping pattern, the most commonly employed systems in the region are the shrimp–rice and shrimp-only farming. The shrimp–rice farming system is an integrated process of shrimp farming, coexisting with salt tolerant rice cultivation, thereby maximizing the benefits of the same land area. This system is very common and popular in southwestern Bangladesh (Azad et al. 2009). In traditional system, farming lands are enclosed by embankments with narrow inlet and outlet channels, controlled by sluice gates or wooden plates. Sometimes trenches and dykes are constructed in paddy fields to shelter the shrimps from shallow waters. Shrimp excreta increase the availability of many nutrients in the field and directly contribute to increase production. Rice is transplanted to grow between September and December when monsoon rains flush the salts out from the system, which can coincide with shrimp cultivation or after shrimp cultivation. The shrimp-only

farming pattern takes place where the salinity of 3–15 ppt exists year-round in nearby rivers, a common method of farming in the extreme southwestern zone close to the *Sundarbans* mangrove forest. In this method, the shrimps are cultured for 9–10 months starting from January or February to the end of October. Nearly all farmers use improved extensive management with less usage of feed and fertilizers.

Considering the high demand of shrimp product in international market, Bangladesh government has overlooked the unplanned expansion of shrimp farming in coastal areas over the last decades, which has created many problems such as, salinization of agricultural lands, reduced fodder for livestock, loss of freshwater sources for drinking water, and other natural resources (Azad et al. 2009; Chowdhury et al. 2006). This study thus attempts to analyze water and soil quality of shrimp farms and impacts of such farming on soil quality and surrounding environment in South-western coastal region of Bangladesh.

Materials and methods

Study area

Three subdistricts (Rampal, Mongla, and Shayamnagar) under southwestern Khulna region of Bangladesh were selected for this study to get a good average. The area is situated in the southwestern coastal Bangladesh between 22°11' and 22°41' latitude and 89°0' and 89°84' longitudes (Fig. 1). The area is under Ganges tidal floodplains agro-ecological zone where most of the lands are being used for shrimp–rice and shrimp-only farming. The world's largest mangrove forest, the *Sundarbans* is situated in this region.

Water samples collection and analysis

For water quality analysis, 5 (five) shrimp–rice farms, 7 (seven) shrimp-only farms, and 4 (four) canals were selected for monthly water sample collection from February to October 2008. The canals were selected from the close vicinity of the shrimp ponds that were used for water source and effluent discharge of the farms. Water samples were collected monthly using a crescent-shaped hollow plastic tube to have water from surface to 30 cm depth from three points of each farm at the same time to make the sample average, and the samples were preserved in plastic black bottles at room temperature (25°C) for laboratory analysis. Water depth was measured by using a centimeter marking scale. Water parameters such as temperature, transparency, salinity, and total dissolved solids (TDS) were measured immediately after sample collection in the field by using mercury-filled Celsius thermometer, *Secchi* disk, refractometer, and TDS meter (model no. HI 9635), respectively. Rest of the parameters like pH, dissolved oxygen (DO), and 5-day biological oxygen demands (BOD₅) were analyzed in the water quality laboratory of Environmental Science Discipline of Khulna University. The pH was measured by using the bench pH meter (model no. pH 211) in the laboratory on the day of collection at the earliest possible time. Winkler's method (APHA 1980) was applied for analyzing DO and BOD₅.

Soil samples collection and analysis

First batch soil samples were collected from 26 spots (13 spots for shrimp-only, 8 for shrimp–rice and 5 for rice-only) at the beginning of the culture period to compare with the

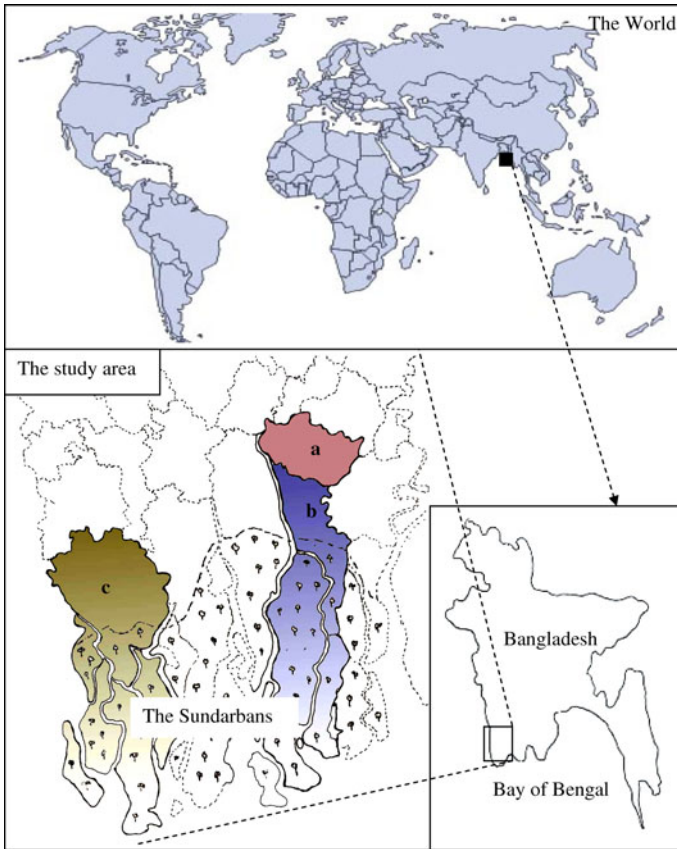


Fig. 1 The study area (*a* = Rampal, *b* = Mongla, *c* = Shayamnagar)

soil data reported by Soil Resource Development Institute (SRDI), Bangladesh in 1991. Soil samples were collected by the assistance of SRDI technicians. Final soil samples were collected from the same ponds those were being used for water quality analysis (5 shrimp-rice and 7 shrimp-only) to compare soil quality between two culture systems. Soil samples were collected from the depth of 30 cm at three different locations from the same plot to get an average. Transparent polyethylene bags were used to preserve the samples with proper labeling. The soil samples were dried under shade at room temperature (25°C) for 2 weeks and then ground and sieved using a 2-mm sieve to make sample suitable for laboratory analysis (Hesse 1971; James and Wells 1990; Petersen 2002). After drying, samples were sent to the laboratory and kept at room temperature until completion of chemical analysis. Soil pH was measured using soil water ratio 1:2.5 (McLean 1982) and electric conductivity using conductivity meter (Rhoades 1982). Organic matter (OM) and total nitrogen (TN) were determined by wet oxidation and Kjeldhal method, respectively (Bremner and Mulvaney 1982). The soil phosphorus (P) was analyzed using Bray and Kurtz method for acid soils (Bray and Kurtz 1945) and Olsen's method for neutral/alkaline soil (Olsen and Sommers 1982). Potassium (K) was analyzed using ammonium acetate extraction method (Knudsen et al. 1982).

Table 1 Suitability ranges of some water quality parameters of shrimp aquaculture

Suitability class (scoring value)	Depth (cm)	Tem. (°C)	Trans. (cm)	pH	DO (mg/l)	BOD ₅ (mg/l)	TDS (mg/l)	Salinity (ppt)
Highly suitable (4)	>100	25–30	25–30	7.5–8.5	>5	<2	<5.0	>12
Suitable (3)	80–<100	>30–33 20–<30	>30–40 20–<25	6.5–7.4 8.6–9.0	4–5	2–<3	5.0–15.0	8–12
Moderately suitable (2)	60–<80	18–<20 >33–35	15–<20 >40–50	5.5–6.4 9.1–9.5	2–3.9	3–5	15.0–30	3–<8
Not suitable (1)	<60	<18 or >35	<15 or >50	<5.5 or >9.5	<2	>5	>30.0	<3

Adopted from Boyd (2003), Hossain (2001)

Table 2 Suitability ranges of soil quality (fertility status)

Range/fertility status	EC (dS/m)	OM (%)	P (µg/gm soil)	K (meq/100 gm soil)	TN (%)
High (3)	>15	>5.5	26–75	0.41–1.5	>0.450
Medium (2)	8.0–12.0	1.0–3.5	13–25	0.21–0.40	0.181–0.450
Low (1)	2.0–4.0	<1.00	≤12	≤0.20	<0.180

Source: SRDI (2003)

Data analysis

All the data were analyzed using SPSS statistical package version 11.0. Mean water and soil quality parameters were compared using analysis of variance (ANOVA) and least significance difference (LSD) test. Differences were considered significant when $P < 0.05$. Correlations between different water parameters were found out using Pearson’s correlation coefficient ($P < 0.01$). It ranges between 1 for highly positive correlation to -1 for highly negative correlation and 0 indicating a purely random relationship.

Water and soil quality index values were also calculated by using Eq. 1 to compare between shrimp–rice and shrimp-only culture system (Chowdhury 2006). This concept was used by Samantray et al. (2009) to identify the deterioration of water quality of rivers and canals with different parameters like pH, turbidity, TDS, NO₃, BOD, and DO due to industrialization and human activities.

$$QI = \sum S_n / N * h \tag{1}$$

where, QI = quality index, S = suitability score (Tables 1, 2), $n = 1, 2, 3 \dots nth$ data, N = total number of data, h = highest score value (e.g. “4” for water quality and “3” for soil quality).

Results

Water quality

Summary statistics of the measured parameters are presented in Table 3. The highest temperature of water was found as 32.7°C in April and the lowest was 23.2°C in October,

Table 3 Summary statistics of water quality parameters in different type of water bodies

Parameters	Water bodies	Ranges (N)	Mean	Std.	Index value
Temperature (°C)	Shrimp–rice	23.2–32.6 (27)	29.00 ^a	2.456	0.870
	Shrimp-only	23.3–32.4 (40)	28.68 ^a	2.594	0.875
	Canal	23.3–32.7 (21)	28.58 ^a	2.968	0.869
Depth (cm)	Shrimp–rice	38–128 (27)	74.33 ^a	23.368	0.546
	Shrimp-only	35–122 (40)	86.78 ^b	22.950	0.716
	Canal	43–250 (21)	138.19 ^{ab}	60.92	0.952
Transparency (cm)	Shrimp–rice	38–46 (27)	41.74 ^a	7.445	0.583
	Shrimp-only	25–61 (40)	35.70 ^b	9.648	0.744
	Canal	20–73 (21)	36.86 ^{ab}	13.82	Turbid
pH	Shrimp–rice	6.8–9.3 (27)	8.06 ^a	0.829	0.824
	Shrimp-only	6.8–9.12 (40)	7.83 ^a	0.625	0.869
	Canal	6.9–8.3 (21)	7.49 ^b	0.408	0.881
DO (mg/l)	Shrimp–rice	2.8–9.6 (27)	6.27 ^a	1.793	0.917
	Shrimp-only	2.2–10.8 (40)	5.64 ^a	2.416	0.800
	Canal	2.5–7.8 (21)	5.35 ^b	1.429	0.857
BOD ₅ (mg/l)	Shrimp–rice	1.5–5.2 (27)	3.28 ^a	1.019	0.718
	Shrimp-only	1.2–5.2 (40)	3.31 ^a	0.995	0.769
	Canal	1.9–4.5 (21)	3.53 ^a	0.788	0.761
TDS (gm/l)	Shrimp–rice	0.96–18.4 (27)	9.28 ^a	6.045	0.642
	Shrimp-only	1.03–36.3 (40)	9.45 ^a	6.961	0.567
	Canal	0.70–31.4 (21)	8.82 ^a	8.083	0.540
Salinity (ppt)	Shrimp–rice	0.88–16.7 (27)	8.18 ^a	5.28	0.648
	Shrimp-only	0.94–34.05 (40)	8.24 ^a	6.373	0.625
	Canal	0.64–27.26 (21)	8.00 ^a	7.148	0.557

Data Source: Field survey 2008; Mean values followed by different superscript letters (a, b, ab) within column of same parameters are significantly different at 95% level of confidence

which is related to the atmospheric temperature. No significant difference ($P > 0.05$) was found in temperature between waters of both culture methods and canal system. The water temperature was found positively correlated ($P < 0.01$) with salinity, pH, and TDS and negatively correlated with water depth (Table 4). During the sampling period, water depth was found to vary from 35 to 128 cm in different shrimp farms (Table 3). The highest mean depth (138.19 ± 60.92 cm) was found in canal, which ranged from 43 to 250 cm.

The mean water depth in shrimp-only pond (index value = 0.716) was found significantly higher than that of shrimp–rice system (index value = 0.546), and both farming systems were lower than that of canal (Table 3). The water depth in the shrimp pond was found negatively correlated ($P < 0.01$) with water temperature, pH, TDS, and salinity (Table 4). The mean transparency (*secchi* depth) value in shrimp-only farming was significantly lower than that of shrimp–rice farming. The mean pH values were 8.06 ± 0.829 , 7.83 ± 0.625 , and 7.49 ± 0.408 in shrimp–rice, shrimp-only, and canal water, respectively (Table 3). The pH value in canal was significantly lower than that of shrimp–rice and shrimp-only system. However, there was no significant difference in mean pH values

Table 4 Pearson correlation matrix of water quality parameters in the study area

	Depth	Transparency	Salinity	PH	DO	BOD	TDS	Temperature
Water depth	1	-.140	-.370(**)	-.399(**)	-.080	.016	-.345(**)	-.470(**)
Secchi depth	-.140	1	.120	.108	.037	-.051	.141	.188
Salinity	-.370(**)	.120	1	.392(**)	.019	.064	.976(**)	.623(**)
pH	-.399(**)	.108	.392(**)	1	.276(**)	.161	.406(**)	.500(**)
DO	-.080	.037	.019	.276(**)	1	.106	.037	.139
BOD	.016	-.051	.064	.161	.106	1	.070	.045
TDS	-.345(**)	.141	.976(**)	.406(**)	.037	.070	1	.628(**)
Temperature	-.470(**)	.188	.623(**)	.500(**)	.139	.045	.628(**)	1

** Correlation is significant at the 0.01 level (2-tailed)

between shrimp–rice and shrimp-only system. The pH value in shrimp ponds was found positively correlated ($P < 0.01$) with water temperature, DO, TDS, and salinity and negatively correlated with water depth (Table 4). The mean DO values were found as 6.27 ± 1.793 mg/l, 5.64 ± 2.416 mg/l, and 5.35 ± 1.429 mg/l in shrimp–rice, shrimp-only, and canal water, respectively (Table 3). The DO in canal water was significantly lower ($P < 0.05$) than that of shrimp–rice and shrimp-only systems, but no significant difference between shrimp–rice and shrimp-only systems. The DO was found positively correlated ($P < 0.01$) with water pH. Higher index values of DO (shrimp–rice = 0.917; shrimp-only = 0.800) indicate optimum condition for shrimp growth in both culture systems. The mean BOD₅ was found 3.28 ± 1.019 mg/l, 3.31 ± 0.995 mg/l, and 3.53 ± 0.788 mg/l in shrimp–rice, shrimp-only, and canal systems, respectively (Table 3). There was no significant difference ($P > 0.05$) between the canal water with both shrimp farming systems. TDS level in water samples ranged from 0.702 to 36.3 gm/l (Table 3). No significant difference ($P > 0.05$) was found in TDS of water in different farming systems. The TDS value was found positively correlated ($P < 0.01$) with salinity, pH, and water temperature and negatively correlated with water depth (Table 4). The salinity ranges in all systems were very wider (0.64–34.04 ppt). No significant difference was found in salinity between the shrimp farming systems and the canal water. It was found positively correlated ($P < 0.01$) with water temperature, TDS, pH and negatively correlated with water depth (Table 4).

Soil quality

Soil quality status among the farming systems

Results of soil quality of 12 shrimp ponds (5 shrimp–rice and 7 shrimp-only systems) are summarized in Table 5. No significant differences ($P > 0.05$) were observed in soil pH, EC, OM, and TN between the farming systems. Soils in the shrimp farms in the study area were neutral to moderately alkaline (6.9–8.3). Soil P in shrimp-only farms (13.2 ± 4.756 µg/gm soil) was found significantly ($P < 0.05$) higher than that of shrimp–rice system (9.7 ± 2.845 µg/gm soil). Similarly, K content (0.92 ± 0.271 mµ/100 g soil) in shrimp-only farming system was found significantly ($P < 0.05$) higher than that of shrimp–rice farming system (0.83 ± 0.275 mµ/100 g soil), because shrimp-only farms hold saline water for prolonged period than shrimp–rice system.

Table 5 Comparative statistics of soil parameters (in 2008)

Parameters	Shrimp–rice				Shrimp-only			
	Range (<i>N</i> = 5×2)	Mean	SD	Index value	Range (<i>N</i> = 7×2)	Mean	SD	Index value
pH	7.7–8.3	8.0 ^a	0.168	0.750	6.9–8.3	7.9 ^a	0.395	0.786
EC(dS/m)	4.08–15.84	7.8 ^a	2.780	0.593	3.93–29.79	9.2 ^a	2.980	0.571
OM(%)	0.78–2.64	1.56 ^a	0.531	0.722	1.15–5.52	2.10 ^b	0.542	0.810
TN(%)	0.057–0.265	0.11 ^a	0.051	0.417	0.06–0.226	0.11 ^a	0.051	0.446
P(μg/gm soil)	5.6–15.91	9.7 ^a	2.845	0.407	3.8–21.09	13.2 ^b	4.756	0.524
K(mμ/100 g soil)	0.52–1.60	0.83 ^a	0.275	1.000	0.64–1.34	0.92 ^b	0.271	1.000

Data Source: Field survey 2008

Mean values followed by different superscript letters (a, b) within row of same parameter are significantly different at 95% level of confidence

Sampling points: Same ponds (5 shrimp–rice and 7 shrimp-only) were used for water quality

Table 6 Mean and standard deviation of different soil parameters in selected plots in the study area (in 1991 and 2008)

Parameters	1991			2008		
	Range (<i>N</i> = 26)	Mean	SD	Range (<i>N</i> = 26)	Mean	SD
pH	3.8–8.2	7.02 ^a	1.210	3.8–8.4	7.45 ^b	1.158
EC(dS/m)	2.52–23.5	6.50 ^a	4.972	1.78–29.79	9.76 ^b	5.795
OM(%)	1.3–6.25	2.61 ^a	1.212	0.69–7.45	2.44 ^a	1.939
TN(%)	0.025–0.201	0.11 ^a	0.049	0.045–0.28	0.12 ^a	0.059
P(μg/gm soil)	2.25–48.10	17.43 ^a	14.118	1.14–17.61	9.01 ^b	5.085
K(mμ/100g soil)	0.48–1.5	0.85 ^a	0.244	0.37–1.6	0.92 ^a	0.313

Data source: data of 1991 from SRDI (2003) and same sampling points were used in 2008

Sampling points: Among 26 spots 13 from shrimp-only, 8 from shrimp–rice, and 5 from only rice farming systems nearby shrimp ponds

Mean values followed by different superscript letters within same parameters are significantly different at 95% level of confidence

Soil quality changes during 1991–2008

Results of different soil parameters during the period 1991–2008 are presented in Table 6, and the quality changes at different sampling spots over the period are presented in Fig. 3(a–f). The pH value has increased significantly ($P < 0.05$) during the period 1991–2008. The average EC was recorded as 9.76 ± 5.795 dS/m in 2008, while it was 6.5 ± 4.972 dS/m in 1991. This increment was statistically significant ($P < 0.05$). Content of P was 17.43 ± 14.118 μg/gm soil in 1991 and 9.01 ± 5.085 μg/gm soil in 2008. This decline was statistically significant ($P < 0.05$). Statistically no significant changes ($P > 0.05$) in OM, TN, and K content were found between the year 1991 and 2008 (Table 6).

Discussion

Seasonal variation and rainfalls affect the diurnal fluctuation of temperature (Lertpai-toonpan 2000). The level of water temperature for better growth and development of shrimp in pond is between 25 and 30°C (Liu 1989); however, it depends on water depth of the pond. Temperature is the only parameter beyond the control of farmers or aquaculturists in natural earthen pond. According to Table 3, higher index value (0.870 in shrimp–rice and 0.875 in shrimp-only system) of temperature in both farming systems indicates favorable condition for shrimp growth in Bangladesh like other Southeast Asian countries. The water depth of canal varies depending on regular tidal water that affects 4 (four) times daily—2 (two) times high tides and 2 (two) times low tides. Water depth of shrimp pond might be a critical factor for shrimp when water temperature is more than 35°C and vice versa. The water depth shows increasing trend and reached at the highest in October due to high rainfall, continuous tidal fluctuation and low evaporation in the month of August–October (Fig. 2b). Transparency (*secchi* depth) is a measure of turbidity and natural productivity of the pond which means presence of phytoplankton and zooplankton in water body. Higher index value (0.744) in shrimp-only farming indicates favorable transparency that means presence of natural feeds in optimum growth of shrimp. Canal water in most cases was turbid because of diurnal tidal inundation and strong existing current in the system. The pH value within 7.5–8.5 is the best for the shrimp growth (Liu 1989). However, Boyd and Green (2002) reported that a pH value within 6.0–9.00 is the best for shrimp growth, while a value between 4.0 to 6.0 and 9.0 to 11.0 may cause slow growth (Boyd 2003; Hossain 2001). Brackish waters are well buffered against pH changing, where pH seldom falls below 6.5 or rises above 9.0. According to Fig. 2d, the mean pH values were found decreasing trend which was mainly due to decreased salinity trend in the later months. Dissolve oxygen is the most critical water quality variable that has a great influence on growth of shrimp. The suitable range of DO for optimum growth of shrimp is 5.0–7.5 mg/l (Boyd 2003; Liu 1989; Chanratchakool et al. 1994). In both system, DO was in good condition because of lower density of shrimp and use of less food and fertilizer. The effluent of shrimp farms is primarily responsible for eutrophication of natural waters, where BOD₅ is considered as a good indicator to determine the effluent quality (Boyd and Green 2002). The government of Bangladesh has recommended BOD₅ range at less than 5 mg/l for natural water systems (DoE 1999). Therefore, in all survey farms, BOD₅ values were within the recommended levels. It means shrimp farms effluents in the study area have no impact on surrounding environment. This result almost similar to McIntosh and Fitzsimmons (2003) estimated BOD₅ value of 6.40 mg/l in low-salinity shrimp farms effluents. A shrimp farm effluent under intensive culture method is a great concern for deterioration of the quality of natural waters in many countries like Thailand, Indonesia, and the Philippines. Tanavud et al. (2001) has reported the mean BOD₅ value of 26.33 mg/l in intensive shrimp culture in Thailand.

Total dissolved solids include various types of mineral present in water in dissolved form and also include organic substances, as in the case of polluted waters. In natural waters, dissolved solids are composed of mainly carbonates, bicarbonates, chlorides, sulfate, phosphate, silica, calcium, magnesium, sodium, and potassium. Highest TDS values were recorded in the months of April and May, and lowest values were obtained in the month of October (Fig. 2g). It was highly positively correlated with water salinity (Table 4). The dissolved solids in the investigated shrimp farms did not show any indication of the nutrient pollution. Penaeid shrimp generally exhibits ideal growth at salinity values between 10 and 30 ppt., but can tolerate even salinity less than 1 (one) if salt level

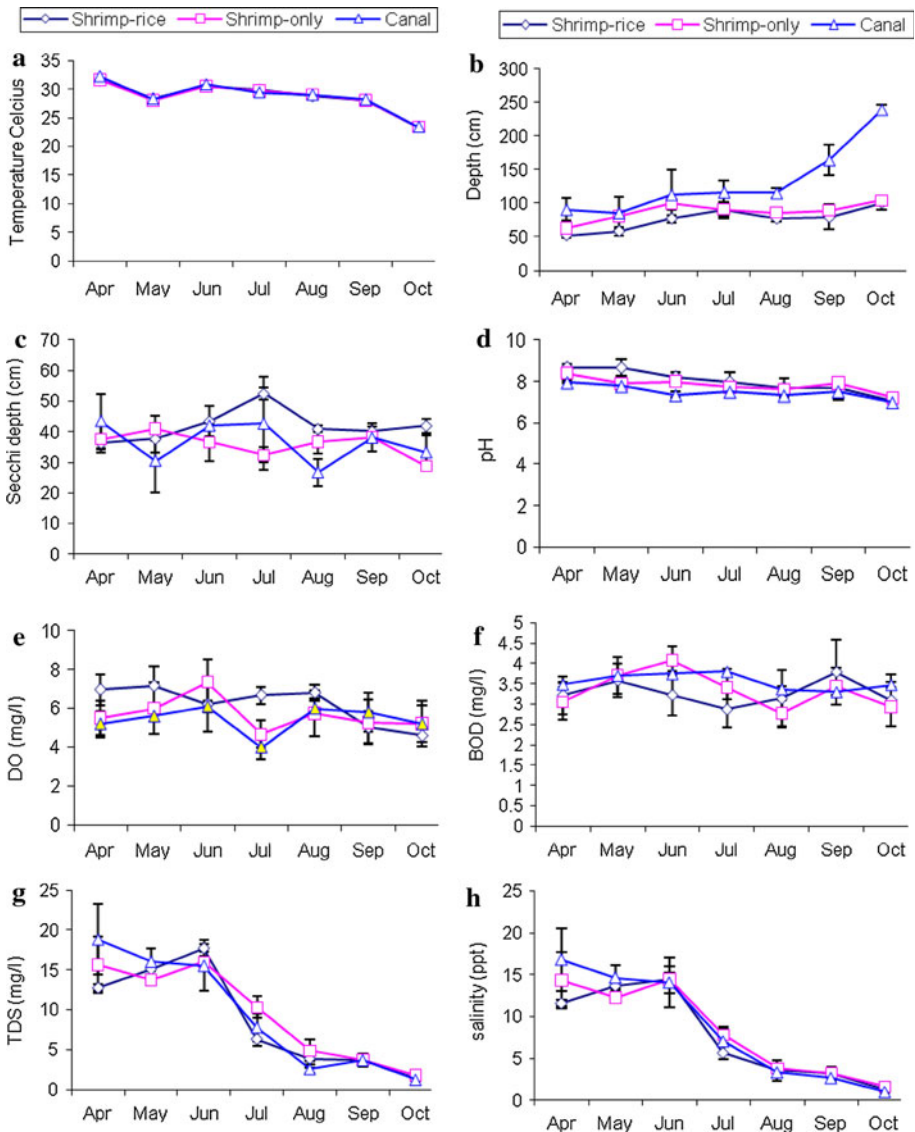


Fig. 2 a–h Monthly variations of water quality parameters in different type of water bodies

falls gradually (Chanratchakool et al. 1994). In that sense, average salinity in the shrimp ponds (8.18 ± 5.28 ppt in shrimp–rice and 8.24 ± 6.373 ppt in shrimp-only) is not a problem in the study area for shrimp growth. Higher salinity in all systems was recorded in April–June, and lowest value was recorded in October (Fig. 2h). It was mainly due to rainfall and upstream fresh water inflow during the month of July to October.

The degree of acidity or alkalinity of a soil that is usually presented in pH scale is considered one of the most useful indicators of pond fertility. Though the alkaline ($\text{pH} > 7.0$) soils in both systems (Table 5) are suitable for shrimp aquaculture, but these are not good in terms of soil fertility status for agricultural production (SRDI 2003). The

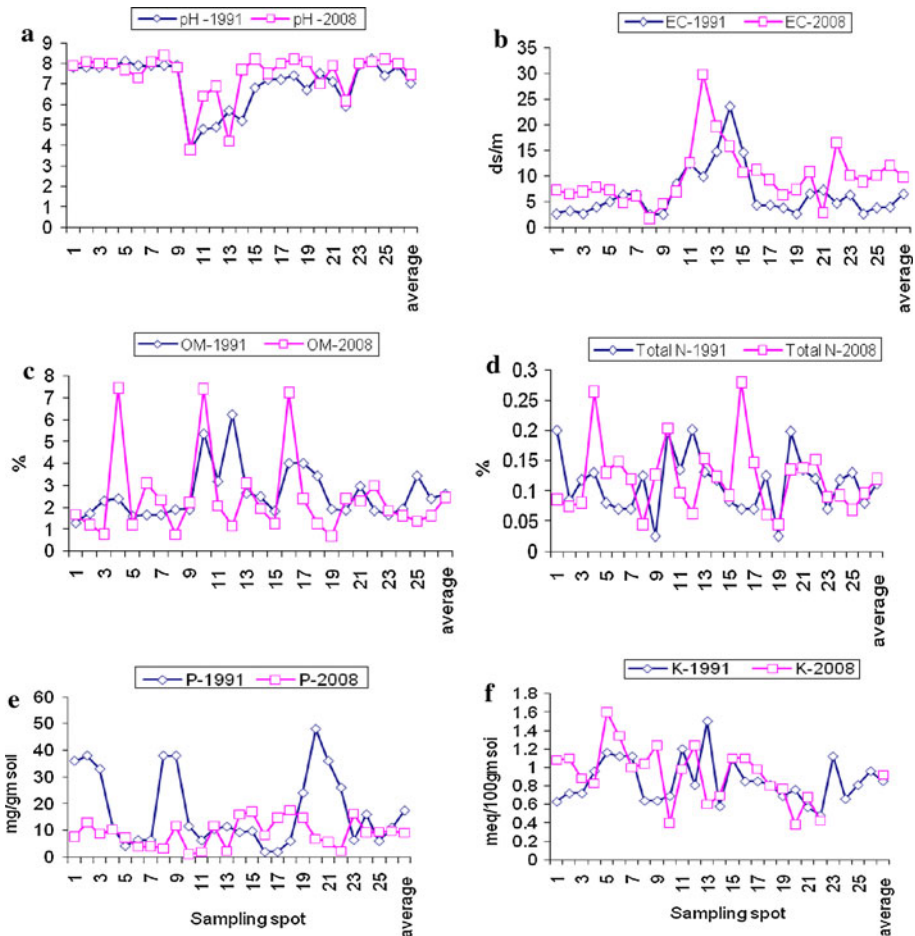


Fig. 3 a–f Comparative analyses of different soil parameters during 1991–2008

high pH level in both systems may subsequently increase the water pH of the pond, which ultimately increases natural food production within the culture ponds (Tanavud et al. 2001). Very little increment was observed in soil pH in average during the period 1991–2008 as shown in Fig. 3a. High organic matter of the surface horizon might be attributed by decaying feedstuff and organic fertilizer in case of shrimp-only farming and by rice straw in case of shrimp–rice farming. According to SRDI (2003) guideline, in both cases the mean OM was found at optimum level of soil fertility from agricultural point of view. Organic matter improves the soil structure (Rasul and Thapa 2004) that helps to reduce nutrient losses, increases water-holding capacity of a soil, and supports the activities of microorganisms. The poor nitrogen status of salt-affected soil is due to high rates of decomposition of organic matter (Bandyopadhyay 1998), high volatilization of ammonium nitrogen, and inadequate amount of organic fertilizer in terms of cow dung, compost etc. Index values of phosphorus in both systems (0.407 in shrimp–rice and 0.524 in shrimp-only system) are not at satisfactory levels according to soil fertility status. The potassium

content in both systems was in very good condition (Index value is 1.00 in both cases) for shrimp growth as well as for agricultural production (SRDI (2003).

The study has identified soil salinization problem in the area and it has been increased significantly in shrimp farming area during the period of 1991–2008 (Fig. 3b). Azad et al. (2009) has reported that soil salinization by shrimp farming is an important environmental impact of shrimp farming in Bangladesh. Long-term inundation of saline water for every year causes higher salinity in all the horizons. Farmers try to maintain higher salinity in shrimp ponds for better shrimp growth during culture period, which leaches and sometimes they discharge saline effluent into nearby waterways and thus may increase the salinity of surface and ground water. This might be the reason of increased salinity in soil, which may have harmful effect on agricultural production (Ali 2006; Wahab 2003; Tanavud et al. 2001). Braaten and Flaherty (2001) has estimated that seepage and external discharge contributed 38 and 33% of salt losses, respectively, while 6% of total salt deposited in sediment and the rest 23% remained as dissolved salt in the pond water. Due to leaching of saline water, horizontal dispersion of salt can go as far as 600–800 meters in nearby soils (Nissapa et al. 2002). These effects are reported in a number of countries and regions, including Taiwan, China, Thailand, Indonesia, Bangladesh, the Philippines, and Ecuador (Primavera 2006; Dierberg and Kiattisimkul 1996; Primavera 1994). The saltwater intrusion has caused many problems in coastal region like loss of crop production, reduced availability of fodder for livestock, fresh water for drinking, and bathing etc. (Chowdhury 2006; Salequzzaman 2001). Long-term inundation of land by saltwater prevents free nitrogen fixation, and thus, mineralization is halted and fertility of land is reduced rapidly within 1–2 years (Ham and Nandy 1990). Rice yields have decreased substantially by shrimp farms salinity, thereby threatening their staple food supply (Islam 2003). The area even could not produce vegetables in and around the homestead in some places. Saline soil does not support plant growth, primarily for excessive salt in the soil, as it prevents absorption of moisture and nutrients in adequate amounts due to higher osmotic pressure of the system (Salequzzaman 2001). Therefore, the sustainability of present shrimp–rice farming is under threat because of increased salinization in coastal lands and decreased agricultural production.

Conclusion

Shrimp farming in Bangladesh is very extensive in nature utilizing less feed and fertilizers. As a result, discharged effluents from shrimp farms did not show any nutrient pollution in the surrounding environment of the coastal area of Bangladesh. The average BOD₅ was below 5 mg/l which is under the recommended level by the Government of Bangladesh. However, salinity intrusion was found as a major problem in the coastal area for agricultural crop production. Unplanned construction of shrimp farms, inflow of saline water in shrimp ponds, and discharge of farm effluents to surrounding areas changed the local hydrology and boosted up salinity intrusion. Prolonged retention of saline water leads to deposition of salt in soil and increases seepage of saline water into nearby ponds and paddy plots and other water bodies. Most importantly, once excavated and converted a land into shrimp ponds, the coastal environments can not be easily restored to their natural state or function. Though shrimp farming is a more profitable industry over agriculture in coastal areas of Bangladesh in present times, but disease outbreaks and presence of hazardous chemical in shrimp may make the industry unsustainable in the long run. Continued storage of saltwater in shrimp ponds alters the chemical properties of the soil which is unsuitable

for agricultural production, and it might be a difficult task to switchback to traditional agriculture in future with these high saline soils resulted from shrimp farming.

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