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Assessment of water and soil quality parameters in earthen ponds of Vannamei shrimp at Ankola, Uttara Kannada district, Karnataka

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Abstract

The present study was carried out assess the water, soil quality parameters and health status of selected earthen ponds of *Litopenaeus vannamei* (white leg shrimp) situated at Fisheries Research and Information Center (Marine), Bela, Ankola, Uttara Kannada district of Karnataka over a culture period. Physico-chemical parameters of water and soil were analysed by standard methods. The study was conducted during the period of March-June (P1 and P2). The results indicated that some parameters with slight deviation compared with the optimal water quality values. Soil quality and pond bottom soil processes, as well as the association between ponds soil and water, are important for fish or shrimp growth. Water and sediment quality play an important part in enhancing the pond's overall production. The water quality parameters namely temperature, pH, alkalinity, salinity, DO, BOD, TSS, TDS, NH_3-N, NO_2-N, NO_3-N, PO_4-P and SiO_3-Si were found to vary from 28.5-34.0° C, 7.8-8.2, 73-115 ppm, 14-34 PSU, 4.07-8.95 mg/l, 2.03-6.10 mg/l, 0.032-0.21 g/l, 18.23-67.04 g/l, 0.25-10.48 µg-at/l, 0.20-1.52 µg-at/l, 0.06-6.57 µg-at/l, 0.17-2.31 µg-at/l and 7.63-90.80 µg-at/l respectively. The soil parameters comprising of temperature, pH, organic carbon, texture ranged from 29.0-34.5°C, 7.4-8.4, 0.26-1.38%, Sand:59.51-86.45%; Clay:1.30-2.45%; Silt:11.55-38.04%, respectively. The results of health status analysis showed negative for commonly tested viruses namely WSSV, MBV, IHHNV, HPV and EHP due to good pre-stocking management practices. By adopting better management practices, the production could be increased. Thus, with the ideal range of water and soil parameters, there exists a great potential for brackish water shrimp farming in the Uttara Kannada district of Karnataka.

Keywords: Vannamei Shrimp Farming, Water and Soil Quality, Ankola, Uttara Kannada

Introduction

Brackish water aquaculture presents significant potential in India, which has an estimated 11.9 lakh hectares of brackish water area, of which only 1.02 lakh hectares are currently underutilization (Krishnan *et al*., 2014) [25]. In 2019, India produced 7.5 lakh tonnes of shrimp, with *Litopenaeus vannamei* contributing 7.11 lakh tonnes (CIBA, 2019) [15]. White-leg shrimp (*L. vannamei)* is the dominant farmed species and a commercially important crustacean (Ackefors, 2009) [2]. Native to the Eastern Pacific coast, it thrives in tropical marine waters where temperatures exceed 20°C year-round. Shrimp is a globally popular seafood and a rich source of protein, with 100 g of cooked shrimp providing approximately 21 g of protein (FDA, 2008; Mahmoud, 2009) [21,31].

The intensification of shrimp pond culture has necessitated the adoption of strict pond management practices to prevent disease outbreaks and maintain water quality, which are critical for consistent production. Key water quality parameters influencing shrimp behavior and growth include temperature, salinity, dissolved oxygen, pH, alkalinity, total hardness, nutrients, primary productivity, and the abundance of phytoplankton, zooplankton, and heterotrophic bacteria (Boyd and Green, 2002) [12]. A healthy aquatic environment and sufficient plankton production are essential for successful pond culture. While water is the primary medium supporting aquatic life, soil plays a critical role in water retention and nutrient cycling, releasing nutrients into the overlying water through chemical and biochemical processes to sustain biological productivity.

Shrimp culture faces multiple challenges, including viral and bacterial diseases such as White Spot Syndrome Virus (WSSV), Monodon Baculovirus (MBV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), Enterocytozoon hepatopenaei (EHP), Hepatopancreatic Parvovirus (HPV), White Feces Syndrome (WFS), Loose Shell Syndrome and Black Gill Disease (BGD). Additional constraints include limited availability of quality seeds, price fluctuations, environmental pollution, antibiotic residues, climate change, and crop failures due to poor management. To address these challenges, the adoption of Better Management Practices (BMPs) and biosecurity protocols is essential for sustainable shrimp farming (Babu *et al*., 2013) [6].Poor pond preparation and inadequate water quality management have been linked to outbreaks of diseases such as white feces and white spot disease, emphasizing the need for increased awareness and capacity-building among farmers. *L. vannamei* culture has expanded rapidly over the past three decades, significantly contributing to the aquaculture sector, with production expected to double by 2030 (FAO, 2016) [20]. Despite its economic significance, systematic studies evaluating water and soil quality in *L. vannamei* ponds are limited. Therefore, the present study was undertaken to assess the water and soil quality parameters of earthen shrimp ponds at the Fisheries Research and Information Centre (Marine), Bela, Ankola, Uttara Kannada District, Karnataka, with the aim of providing baseline data to support sustainable and productive *L. vannamei* shrimp culture.

Materials and Methods

Study area

The present study was carried out in the *Litopenaeus vannamei* culture ponds of Ankola, Uttara Kannada District, Karnataka. Two shrimp ponds belong to the Fisheries Research and Information Center (Marine), Ankola and Keni Creek1 water were studied. The water source drawn from Keni Creek for FRIC(M) ponds during high tide. The present study was carried out for one complete culture cycle, from stocking of the shrimp seed to harvesting. The stocking density of *Litopenaeus vannamei* shrimp seed in each pond was 60,000 No's/ha and the total culture period was 115 days**.** The coordinates of the locations of two shrimp culture ponds and Creek 1 are mentioned in Table 1. The satellite images and experimental shrimp ponds P_1 & P_2 at FRIC (M), Ankola are depicted in Map 1 and Photos 1&2 respectively.

Table 1: The Latitude and Longitude of selected shrimp ponds during the study period

Shrimp Ponds	Study Area	Latitude	Longitude
P1	Ponds of FRIC(M) Ankola	14°39'41.4"N	74°16'56.9"E
P2	Ponds of FRIC(M) Ankola	14°39'43.4"N	74°16'59.3"E
Creek 1 (Water Source)	Keni creek of Ankola	14°39'46.5"N	74°16'58.8"E

Map 1: Satellite image of FRIC (M), Ankola shrimp ponds during the study period

Photos 1&2: Experimental Shrimp ponds P_1 & P_2 at FRIC (M), Ankola

Sampling and analysis

Fortnightly samples were collected during morning hours. Parameters such as air temperature, water temperature, salinity, water pH and sediment temperature were measured in-situ. Water and sediment samples were collected and carried to the laboratory for further analyses. Water temperature, pH and salinity were measured using standard mercury thermometer, pocket pH meter (Hanna) and hand-held refractometer respectively. Water samples were collected from the shrimp ponds for the analysis of dissolved oxygen, ammonia-nitrogen and alkalinity were performed in the laboratory as per the standard methods (APHA, 2017) [5]. For dissolved oxygen analysis, water samples were collected in glass bottles of 125 ml capacity and fixed on the field using Winkler's reagents. For the estimation of ammonia-nitrogen, 50 ml of water sample was collected in clean amber-colored glass bottles (125ml capacity) and fixed in the field by following the phenol-hypochlorite method (Parsons *et al*., 1989) [33]. For the nutrients analysis, surface water samples were collected in clean polythene bottles and kept immediately in an icebox and transported to the laboratory and the water samples were filtered and analysed for nitrite-nitrogen, nitrate-nitrogen, phosphate-phosphorous and silicate-silicon by adopting standard procedures.

Sediment organic carbon was determined by EL-Wakeel and Riley method (1957) [19] and the values were expressed as % of organic carbon. Sediment samples were weighed and wet sieved through a 0.0625 mm sieve to separate sand from silt and clay fractions. The sand fractions were dried, weighed and percentage was determined. Further the percentage of silt and clay were determined by employing pipette analysis (Buchanan and Kain, 1971) [14]. Health status analysis namely White Spot Syndrome Virus (WSSV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), Enterocytozoon heoatopenaei (EHP), Monodon Baculovirus (MBV) and Hepatopancreatic Parvo (HPV) viruses were detected by Polymerase Chain Reaction (PCR) based diagnostic techniques (Lightner & Redman, 1998 and Karthikeyan *et al*., 2017) [29,26].

Statistical analysis

The simple correlation was determined between various water and soil parameters such as water temperature, pH, salinity, dissolved oxygen, biological oxygen demand, total alkalinity, total hardness, total suspended solids, total dissolved solids, ammonia, nutrients, sediment temperature, sediment pH, sediment organic carbon and sediment texture.

Results

Physico-chemical characteristics of water

The research stations two shrimp ponds and source water samples were analysed for selected physico-chemical parameters for every fortnight during culture period (summer crop). The variations in water quality and soil characteristics during cultured period of Vannamei shrimp ponds are given in Table 2. The health status analysis of experimental shrimp samples are shown in Table 3. The significant correlation coefficient between water quality and soil parameters in P1 and P2 shrimp ponds are presented in Table 4.

Air, water and sediment temperatures of selected earthen shrimp ponds were shown in Fig1, 2 and 3. Air and water temperature ranged from 27-33.5°C and 28.5-34.0°C respectively. Maximum water temperature of 34°C was recorded during the month of May on 60th day of culture. The sediment temperature of the selected ponds was documented between 29 ºC and 34.5 ºC. Minimum value was recorded at P2 during the month of June on 105th day of culture, while the maximum was recorded at P1 during the month of May on 60th day of culture.

Water pH of selected ponds fluctuated between 7.1 and 8.5 with a maximum during the 75th of culture (May) and a minimum during the 105th day of culture (June).Variation of water pH is represented in Fig4.

- **Salinity**: Maximum salinity was observed during the 60th day of culture (May) at P2. Minimum salinity was observed during the 105th day of culture (July) at P1 and P2. Fluctuation of salinity was observed between 14 and 35 PSU, while source water Creek 1 showed 0-31 PSU (Fig5). In the present study, salinities recorded was well suited for *L.vannamei* culture, as the most successful shrimp culture appears to be have done at salinities above 2 PSU. Culture species of *L. vannamei* can tolerate salinities of 0.50 to 45 PSU.
- **Alkalinity:** The fluctuations in alkalinity values in the shrimp ponds during the study period are graphically presented in Fig 6. The alkalinity during the study period fluctuated from 73 to 115 ppm. The maximum was during the 60th DOC (May), the lowest value during the 115th DOC (July). The source water Creek 1, varied from 25 to 118 ppm.
- **Dissolved Oxygen:** The dissolved oxygen concentration in the shrimp ponds varied between 4.07 and 8.95 mg/l. The minimum concentration was recorded at P1 during the 15th DOC (March) and the maximum was at P1 during the 105th DOC (June). Generally, the dissolved oxygen concentration was lower during the initial sampling days. The variation in dissolved oxygen in the shrimp ponds during the study are graphically depicted in Fig 7.
- **Biochemical Oxygen Demand (BOD):** BOD values varied between 2.03 and 6.1 mg/l at experimental shrimp ponds, where the maximum value was observed at P2 during the 115th DOC (July) and the minimum value was observed at P1 during the 15th DOC (March). The source water, Creek 1 varied from 1.43-5.28 mg/l. Biological oxygen demand values observed during study period are depicted graphically in Fig8.
- **Total Suspended Solids (TSS):** The concentration of TSS during the study period is graphically depicted in Fig9. The suspended solids concentration at shrimp ponds showed a maximum of 0.21 g/l during the 90th DOC (June), while the least concentration was found during the 75th DOC (May), i.e., 0.032 g/l. The source water Creek 1 ranged from 0.018 to 0.18 g/l.
- **Total Dissolved Solids (TDS):** The concentration of TDS during the study period is graphically depicted in Fig10. During the study period, the TDS concentration at P1 showed a maximum of 67.04 g/l during the 60th DOC (May) and a minimum value of 18.23 g/l was shown by P2 during the 115th DOC (July). The TDS concentration of Creek 1 water varied from 1.63 to 62.78 g/l.

Nutrients

- **Ammonia-Nitrogen:** In shrimp ponds, ammonia nitrogen values varied between 0.25 and 10.48 µg-at/l.

The minimum value was recorded at P2 during the 30th DOC (April), and the maximum was at P1 during the 60th DOC (May). The source water for the FRIC(M) experimental shrimp pond is Creek 1, which varied from 0.5 to 8.96 µg-at/l. Ammonia-Nitrogen values recorded during the study period are graphically shown in Fig11.

- **Nitrite-Nitrogen**: The variation in nitrite-nitrogen concentrations recorded is shown graphically in Fig12. Nitrite concentrations vary significantly in shrimp ponds. Nitrite values varied from 0.2 to 1.52 µg-at/l during the study. Creek 1 water nitrite varied from 0.16 to 1.52 µg-at/l.
- **Nitrate-Nitrogen:** The nitrate concentration at experimental shrimp ponds varied from 0.06 to 6.57 µg-at/l, while Creek 1 water varied from 0.1 to 8.76 µg-at/l. The variation in nitrate concentrations recorded is shown graphically in Fig13.
- **Phosphate-Phosphorus:** The phosphate concentration data is presented in graphically in Fig14. The phosphate concentration at experimental shrimp ponds varied from 0.17 to 2.31 µg-at/l, the minimum at P2 on the day of stocking (March) and the maximum at P2 during the 115th DOC (July). The source water showed 0.17-13.14 µg-at/l.
- **Silicate-Silicon:** The silicate concentration was observed to be significantly higher during the summer season. The silicate at experimental shrimp ponds varied from 7.63 to 90.8 µg-at/l, while, Creek 1 water varied between 9.29 and 77.19 µg-at/l. The highest value was found at P1 during the 30th DOC (April) and the lowest at P1 during the 60th DOC (May). The silicate data observed during the study period is graphically depicted in Fig15.
- **Sediment pH:** The pH values fluctuated between 7.4 and 8.4 at experimental shrimp ponds during the study period. The highest concentration was found at P2 during the 105th DOC (June), while the lowest concentration was found at P1 on the day of stocking (March). The pH values documented during the study period are graphically depicted in Fig16.
- **Sediment Organic Carbon**: The percentages of organic carbon recorded during the study period are presented in graphically in Fig17. Organic carbon at experimental shrimp ponds was found to be 0.26-1.38% during the study period. The minimum value was recorded at P1 during the 60th DOC (May), while the maximum value was recorded at P1 during the 30th DOC (April).
- **Sediment texture:** The experimental shrimp ponds (P1 and P2) soils were in the coarse textured group (loamy sand, sandy loam, and sand). The variation in texture of shrimp culture pond soils from different locations is presented graphically in Fig18.
- **Health status analysis:** The results of PCR analysis of shrimp samples for health status studies are presented in Table 3. The FRIC(M) experimental shrimp ponds (P1 and P2) showed negative results throughout the culture period for all the pathogens namely White Spot Syndrome Virus (WSSV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), Enterocytozoon heoatopenaei (EHP), Monodon Baculovirus (MBV) and Hepatopancreatic Parvo (HPV) viruses.

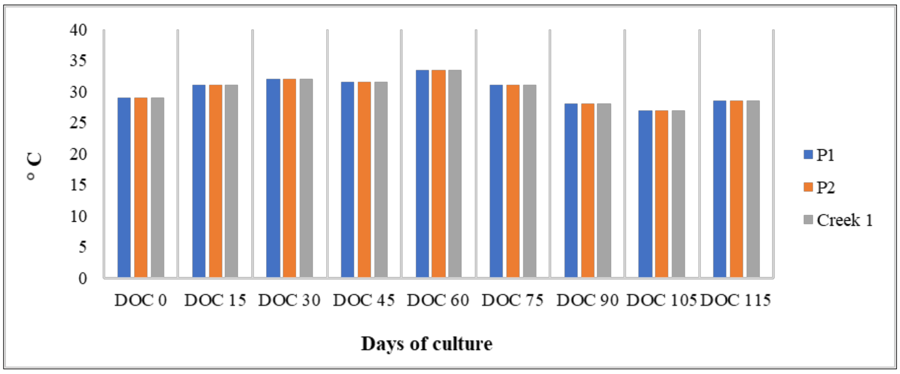

Fig 1: The variation of Air temperature (° C) at FRIC(M) experimental shrimp ponds during the study period.

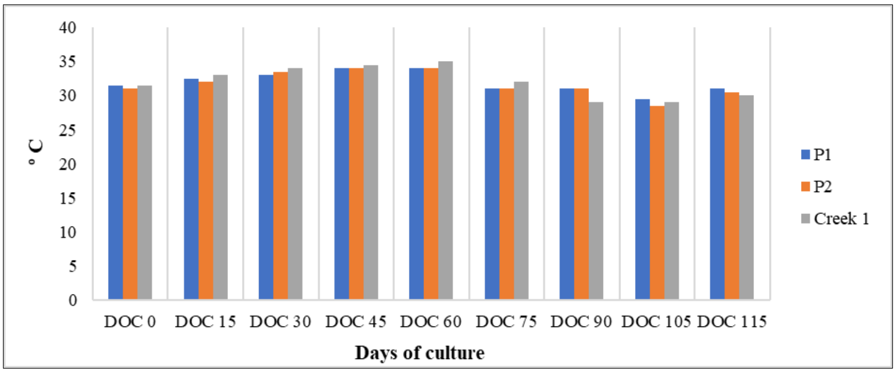

Fig 2: The variation of Water temperature (° C) at FRIC(M) experimental shrimp ponds during the study period.

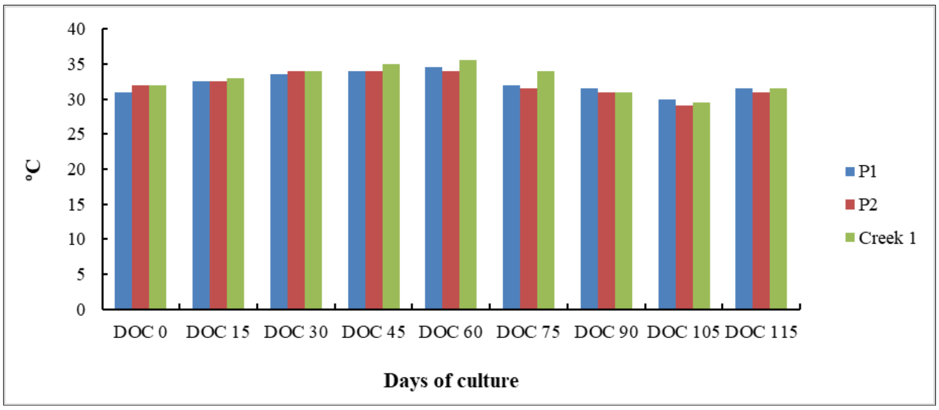

Fig 3: The variation of sediment temperature (ºC) at FRIC(M) experimental shrimp ponds during the study period.

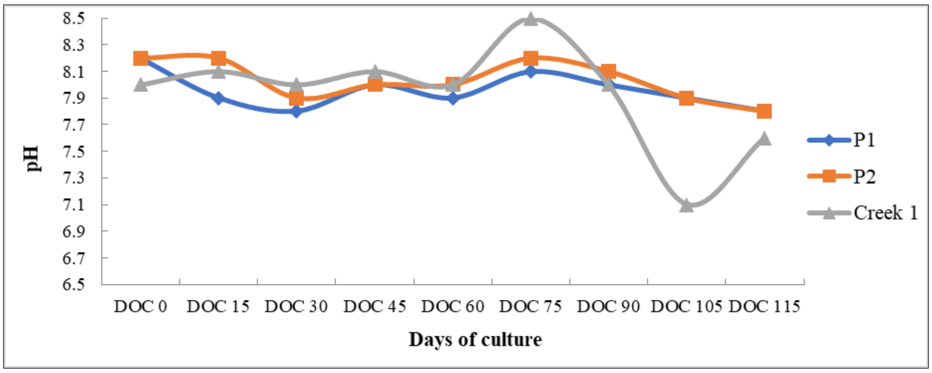

Fig 4: The variation of Water pH at FRIC(M) experimental shrimp ponds during the study period.

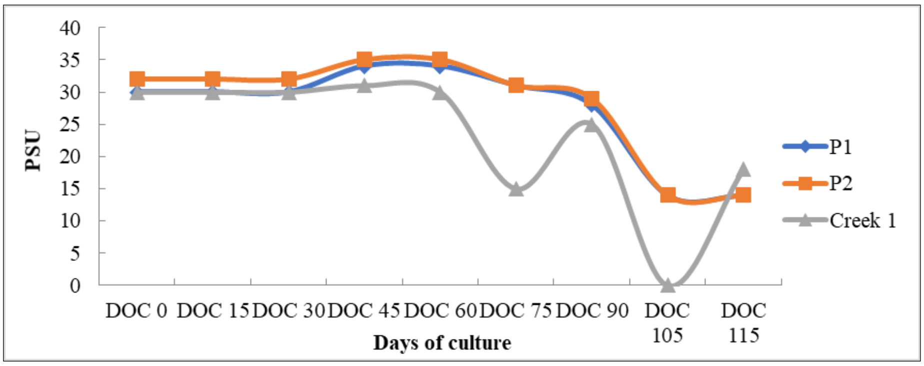

Fig 5: The variation of Salinity (PSU) at FRIC(M) experimental shrimp ponds during the study period.

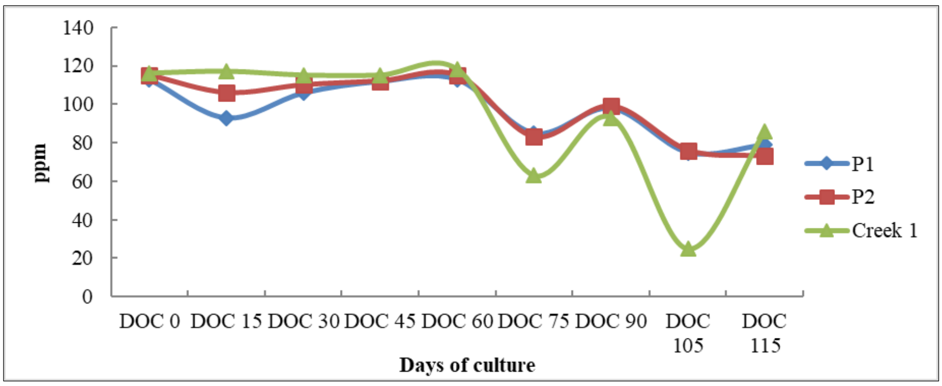

Fig 6: The variation of Total Alkalinity (ppm) at FRIC(M) experimental shrimp ponds during the study period.

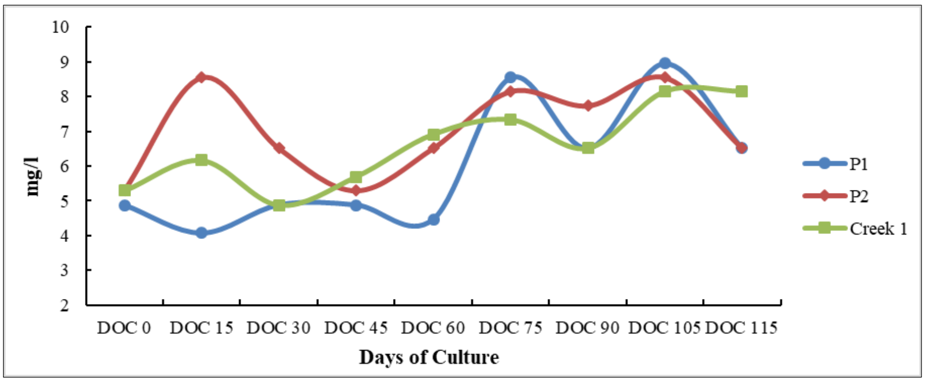

Fig 7: The variation of DO (mg/l) at FRIC(M) experimental shrimp ponds during the study period.

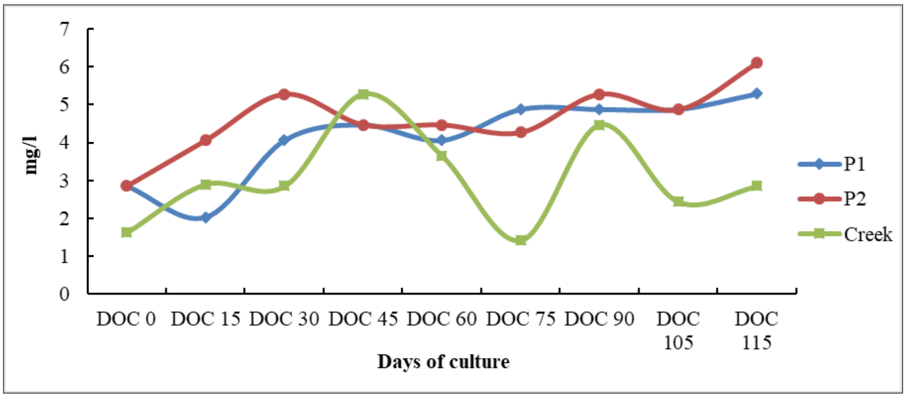

Fig 8: The variation of BOD (mg/l) at FRIC(M) experimental shrimp ponds during the study period.

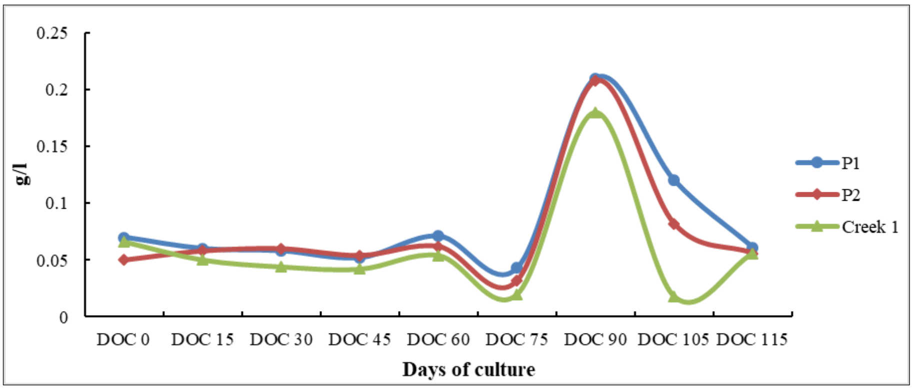

Fig 9: The variation of TSS (g/l) at FRIC(M) experimental shrimp ponds during the study period.

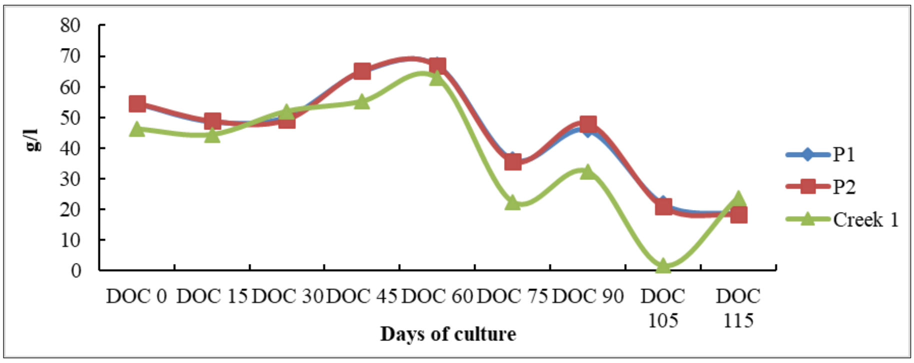

Fig 10: The variation of TDS (g/l) at FRIC(M) experimental shrimp ponds during the study period

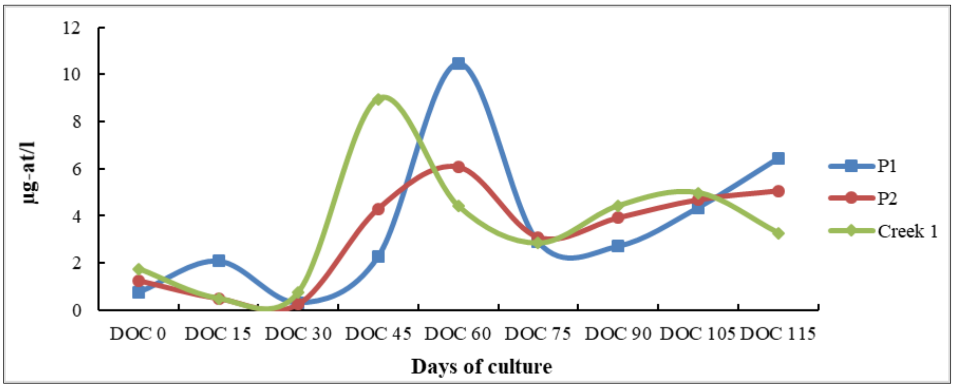

Fig 11: The variation of ammonia-N (µg-at/l) at FRIC(M) experimental shrimp ponds during the study period.

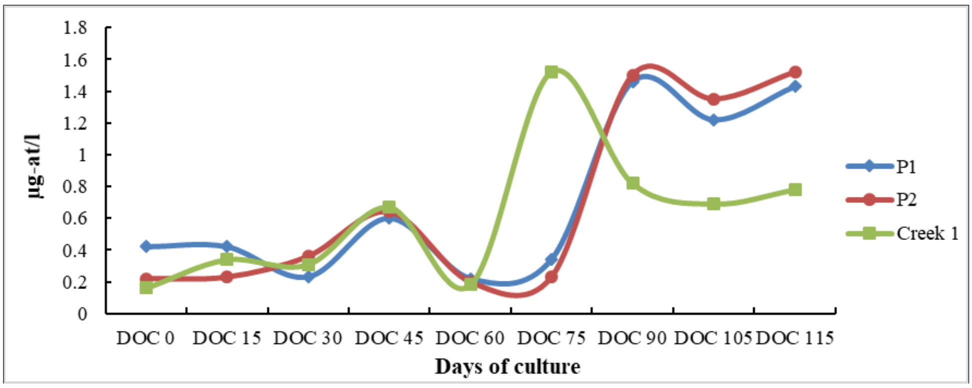

Fig 12: The variation of Nitrite-N (µg-at/l) at FRIC(M) experimental shrimp ponds during the study period.

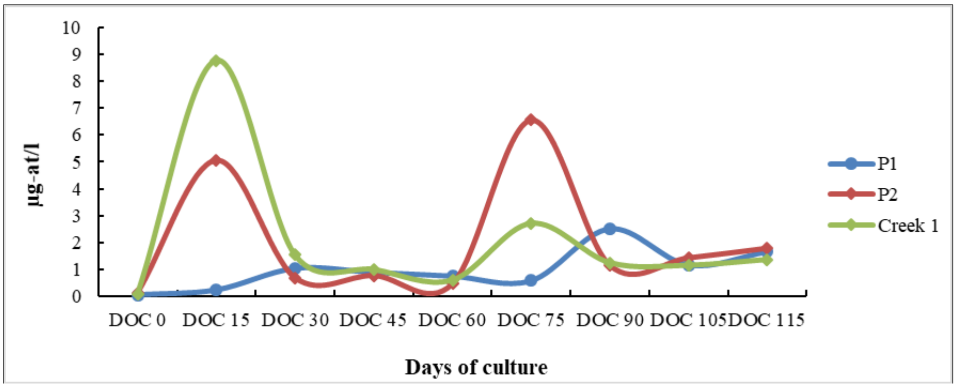

Fig 13: The variation of Nitrate-N (µg-at/l) at FRIC(M) experimental shrimp ponds during the study period.

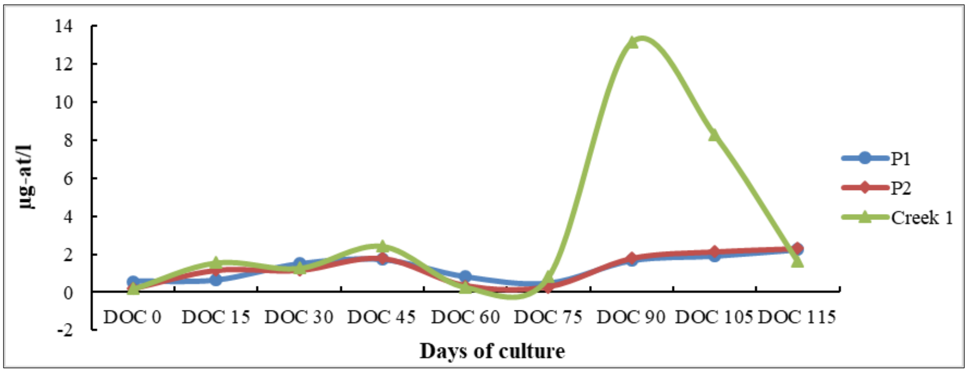

Fig 14: The variation of Phosphate-P (µg-at/l) at FRIC(M) experimental shrimp ponds during the study period.

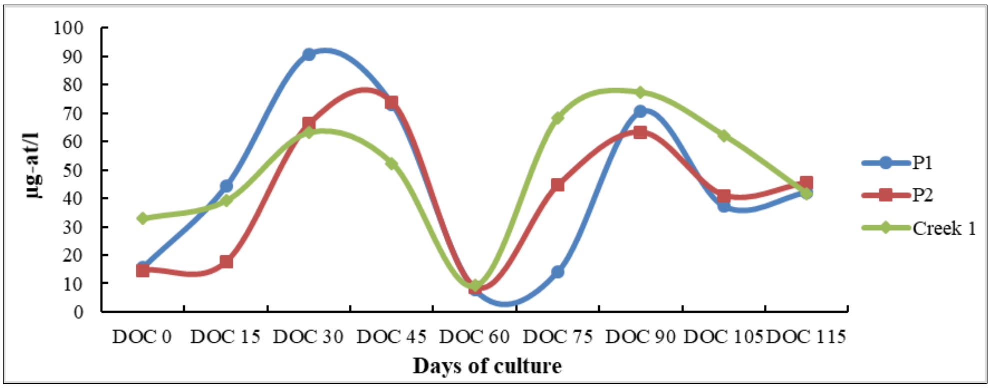

Fig 15: The variation of Silicate-Si (µg-at/l) at FRIC(M) experimental shrimp ponds during the study period.

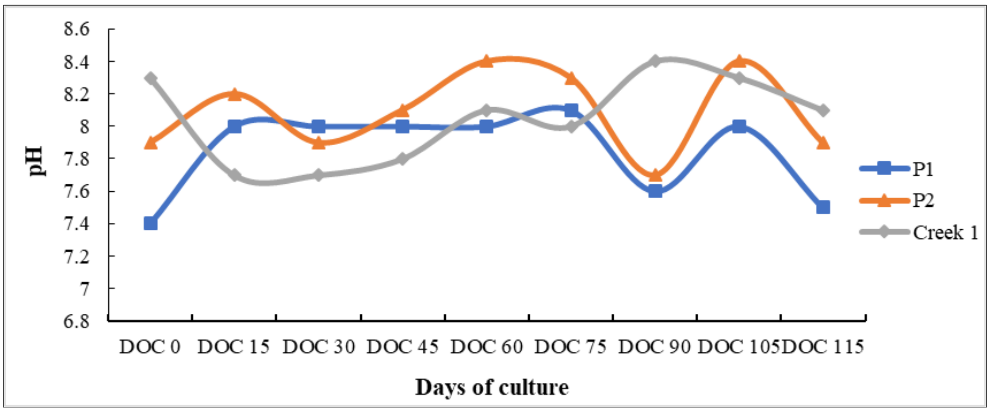

Fig 16: The variation of sediment pH at FRIC(M) experimental shrimp ponds during the study period.

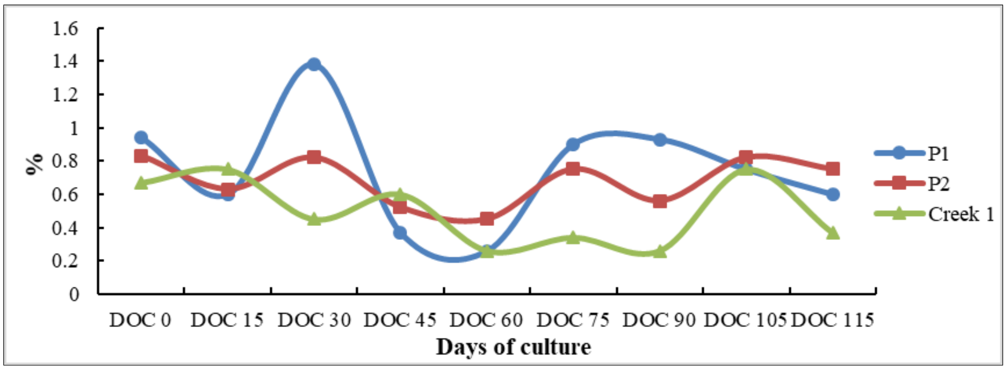

Fig 17: The variation of Sediment organic carbon (%) at FRIC(M) experimental shrimp ponds during the study period.

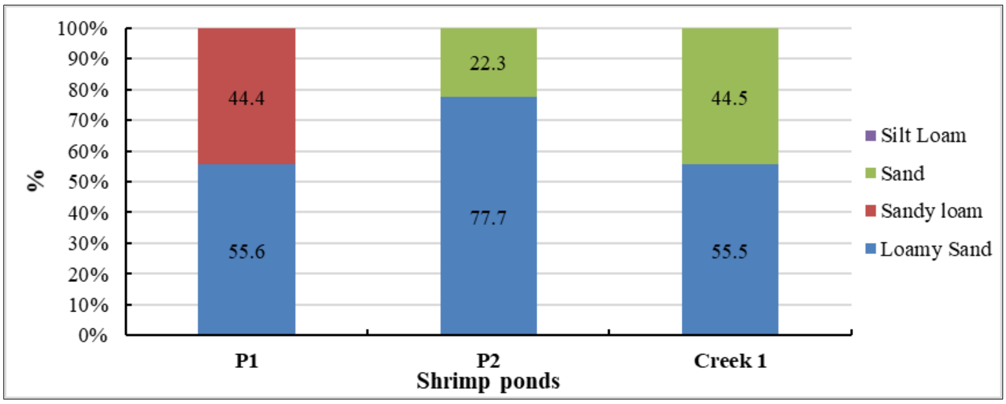

Fig 18: The variation of sediment textural composition (%) at FRIC(M) experimental shrimp ponds during the study period.

Table 2: Variations of water quality and soil characteristics during cultured period of Vannamei shrimp ponds.

Parameters	FRIC (M) Vannamei Shrimp Ponds - P1 (Range (Average))	FRIC (M) Vannamei Shrimp Ponds - P2 (Range (Average))	Keni Creek 1 (Range (Average))
Air Temperature (°C)	27.00-33.50 (30.17)	27.00-33.50 (30.17)	27.00-33.50 (30.17)
Water Temperature (°C)	29.50-34.00 (31.94)	28.50-34.00 (31.72)	29.00-34.50 (32.00)
Water pH	7.80-8.20 (7.96)	7.80-8.20 (8.91)	7.10-8.50 (7.93)
Salinity (PSU)	14.00-34.00 (27.22)	14.00-35.00 (28.22)	0.00-31.00 (23.22)
Alkalinity (ppm)	75-113 (97.11)	73-115 (98.78)	25-118 (94.22)
Dissolved Oxygen (mg l^{-1})	4.07-8.95 (5.96)	5.29-8.54 (7.01)	4.88-8.14 (6.56)
Biochemical Oxygen Demand (mg l^{-1})	2.03-5.29 (4.16)	2.85-6.10 (4.63)	1.43-5.28 (3.06)
Total Suspended Solids (g l^{-1})	0.043-0.21 (0.054)	0.032-0.208 (0.074)	0.018-0.18 (0.059)
Total Dissolved Solids (g l^{-1})	18.48-67.04 (45.38)	18.23-66.69 (45.25)	1.63-62.78 (37.84)
Ammonia-Nitrogen (µg-at l^{-1})	0.31-10.48 (3.59)	0.25-6.06 (3.23)	0.50-8.96 (3.55)
Nitrite-Nitrogen (µg-at l^{-1})	0.22-1.46 (0.70)	0.20-1.52 (0.69)	0.16-1.52 (0.61)
Nitrate-Nitrogen (µg-at l^{-1})	0.06-2.51 (0.99)	0.13-6.57 (2.01)	0.10-8.76 (2.06)
Phosphate-Phosphorus (µg-at l^{-1})	0.46-2.25 (1.28)	0.17-2.31 (1.24)	0.17-13.14 (3.28)
Silicate-Silicon (µg-at l^{-1})	7.63-90.8 (43.99)	8.79-73.7 (41.70)	9.29-77.19 (49.56)
Sediment Temperature (°C)	30.00-34.50 (32.28)	29.00-34.00 (32.11)	29.50-35.50 (32.83)
Sediment pH	7.40-8.10 (7.84)	7.70-8.40 (8.09)	7.70-8.40 (8.04)
Sediment Organic Carbon (%)	0.26-1.38 (0.75)	0.45-0.83 (0.68)	0.26-0.75 (0.49)
Sediment Texture - Sand (%)	59.51-84.30 (73.20)	75.80-86.45 (80.74)	78.00-89.20 (84.47)
Sediment Texture - Silt (%)	14.20-38.04 (20.05)	11.55-22.80 (17.58)	7.20-20.05 (13.94)
Sediment Texture - Clay (%)	1.30-2.45 (1.16)	1.35-2.10 (1.68)	1.20-1.95 (1.59)

Table 3: Polymerase Chain Reaction (PCR) analysis for health status of experimental shrimp samples during the study period

Ponds	Viruses	DOC 30	DOC 60	DOC 90	DOC 105	DOC 115
P1	WSSV	Negative	Negative	Negative	Negative	Negative
	MBV	Negative	Negative	Negative	Negative	Negative
	IHHNV	Negative	Negative	Negative	Negative	Negative
	HPV	Negative	Negative	Negative	Negative	Negative
	EHP	Negative	Negative	Negative	Negative	Negative
P2	WSSV	Negative	Negative	Negative	Negative	Negative
	MBV	Negative	Negative	Negative	Negative	Negative
	IHHNV	Negative	Negative	Negative	Negative	Negative
	HPV	Negative	Negative	Negative	Negative	Negative
	EHP	Negative	Negative	Negative	Negative	Negative

Table 4: Significant correlation coefficient between water and soil quality parameters in P1 & P2 shrimp ponds during the study period

Parameters	AT	WT	SAL	W-pH	ALK	DO	BOD	TDS	TSS	NH_3	NO_2	NO3
WT	.883$^{**(P1)}$ .896$^{**(P2)}$											
SAL	.765$^{**(P1)}$ .755$^{**(P2)}$	.756$^{**(P1)}$ .793$^{**(P2)}$										
W-pH			.608$^{*(P1)}$									
ALK	.608$^{*(P1)}$ .623$^{*(P2)}$	.793$^{**(P1)}$ .774$^{**(P2)}$	.813$^{**(P)}$ .608$^{*(P2)}$									
DO	-.594$^{*(P1)}$	-.814$^{**(P1)}$	-.591$^{*(P1)}$		-.776$^{**(P1)}$							
BOD				-.780$^{**(P2)}$		.678$^{*(P1)}$						
TDS	.719$^{*(P1)}$ .696$^{*(P2)}$	.854$^{**(P1)}$ .832$^{**(P2)}$	.909$^{**(P1)}$ .917$^{**(P2)}$		.945$^{**(P1)}$ .951$^{**(P2)}$	-.750$^{**(P1)}$						
TSS	-.593$^{*(P1)}$											
NO_2	-.830$^{**(P1)}$ -.770$^{**(P2)}$	-.643$^{*(P1)}$	-.754$^{**(P1)}$ -.776$^{**(P2)}$		-.588$^{*(P1)}$ -.652$^{*(P2)}$			-.658$^{*(P1)}$ -.624$^{*(P2)}$	.678$^{*(P1)}$			
NO_3						.661$^{*(P2)}$	.700$^{*(P1)}$		.738$^{*(P1)}$		.797$^{**(P1)}$	

PO_4			-.660$^{*(P1)}$ .684$^{*(P2)}$	.669$^{*(P2)}$			.650$^{*(P1)}$ .733$^{*(P2)}$				.757$^{**(P1)}$ .863$^{**(P2)}$	.731$^{*(P1)}$
SiO_3									.603$^{*(P2)}$			
ST	.932$^{**(P1)}$ .901$^{**(P2)}$	.959$^{**(P1)}$ .985$^{**(P2)}$	.719$^{*(P1)}$ .807$^{**(P2)}$		.665$^{*(P1)}$ .803$^{**(P2)}$	-.658$^{*(P1)}$		.757$^{**(P1)}$ .822$^{**(P2)}$			-.615$^{*(P1)}$	
SOC		-.613$^{*(P2)}$						-.645$^{*(P2)}$		-.693$^{*(P1)}$		

AT-air temperature, WT-water temperature, SAL-salinity, WpH-water pH, ALK-total alkalinity, DO-dissolved oxygen, BOD-biological oxygen demand, TDS-total dissolved solids, TSS-total suspended solids, NH_3-ammonia, NO_2-nitrite, NO_3-nitrate, PO_4-phosphate, SiO_3-silicate, ST-sediment temperature, SOC-sediment organic carbon.

Note: *. Correlation is significant at the 0.05 level **. Correlation is significant at the 0.01 level

Discussion

Water, sediment and soil quality are fundamental determinants of shrimp pond productivity, influencing growth, survival, and overall pond ecosystem health. The physico-chemical and nutrient parameters assessed in the experimental shrimp ponds provide insights into pond dynamics, crop period variations, and management effectiveness.

- **Temperature:** Temperature is a critical factor affecting water quality and metabolic activity of aquatic organisms. During the study, air and water temperatures ranged from 27-33.5°C and 28.5-34.0°C, respectively, with sediment temperatures ranging from 29-34.5°C. Maximum water and sediment temperatures were observed during May, coinciding with high solar radiation and low water depth, which increased thermal conductivity. Elevated temperatures influenced bacterial load and microbial activity, consistent with Abdelrahman *et al*. (2018) [1] who noted that deviations in air temperature can directly alter water temperatures. Temperature regulates shrimp feeding, metabolism, and growth, where higher temperatures can increase specific growth rates if food supply is adequate (Brett, 1979; Talbot, 1993) [13,39]. The observed temperature range supports optimal metabolic activity in *Litopenaeus vannamei* ponds, aligning with previous studies in Indian shrimp farms (Priyadarsani and Abraham, 2016; Govindasamy *et al*., 2000) [35,22].
- **Water pH:** Water pH, reflecting acidity or alkalinity, is vital for maintaining pond health and controlling chemical reactions. In the FRIC(M) ponds, water pH ranged from 7.8-8.2 in P1 and P2, and 7.1-8.5 in Creek 1. These slightly alkaline values fall within the optimal range (6.5-8.5) for most aquatic organisms (Boyd, 2015) [11] corroborating observations from Priyadarsani and Abraham (2016) [35] and Chittem and Kunda (2017) [17]. Maintaining pH in this range supports enzymatic activity, shrimp physiology, and microbial decomposition processes essential for pond productivity.
- **Sediment pH:** Sediment pH significantly affects organic matter decomposition and nutrient cycling. In the study, sediment pH ranged from 7.4-8.4 in ponds and 7.7-8.4 in creek1 water, slightly higher than the optimal 6.5-7.5 (Banerjea, 1967) [7]. Elevated sediment pH is attributed to the application of calcium carbonate and dolomite to buffer pond water, promoting microbial activity and decomposition. Similar alkaline conditions have been reported in Andhra Pradesh and other coastal shrimp farms (Chittem and Kunda 2017; Priyadarsani and Abraham, 2016) [17,35]. Slightly alkaline sediment is favorable for aquaculture, enhancing nutrient availability and pond ecosystem stability (Schaeperclaus, 1933) [37].
- **Salinity and Total Dissolved Solids (TDS):** Salinity and TDS are crucial for osmotic regulation in shrimp. Salinity in P1 and P2 varied from 14-35 PSU, with higher values during pre-monsoon due to evaporation and seawater intrusion, and lower values (14 PSU) during July due to precipitation dilution. These values are within the recommended 10-25 PSU range for shrimp culture (Chien, 1992; Boyd, 1995) [16,10]. TDS values mirrored salinity trends, ranging from 18.23-67.04 g/L, with peaks during summer months due to low rainfall and evaporation. The seasonal fluctuations in salinity and TDS reflect natural hydrological dynamics while maintaining suitable conditions for *L. vannamei.*
- **Alkalinity:** Alkalinity, an indicator of the water's buffering capacity and productivity, ranged from 73-115 ppm, within the optimum range for shrimp culture (Mazid, 2009) [32]. Adequate alkalinity supports molting, primary productivity, and carbon availability for phytoplankton (Raven *et al*., 2012) [36], ensuring a stable culture environment.
- **Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD):** Dissolved oxygen, essential for aerobic respiration, ranged from 4.07-8.95 mg/L in ponds and 4.88-8.14 mg/L in Creek 1, exceeding the minimum requirement of 2-4 mg/L (Law,1988; Chien, 1992) [28,16]. BOD reflecting the biodegradable organic matter, ranged from 2.03-6.10 mg/L. Seasonal fluctuations in BOD were observed, with higher values during summer due to increased microbial activity and organic matter decomposition. Overall, DO and BOD values indicate good oxygen availability for shrimp growth and minimal pollution stress (Davies *et al*., 2008) [18].
- **Total Suspended Solids (TSS):** TSS influences light penetration, oxygen availability, and nutrient dynamics. P1 and P2 exhibited TSS concentrations of 0.032-0.21 g/L, initially low, increasing mid-culture due to feed input and phytoplankton, and declining at the end of culture due to sedimentation and precipitation. The observed TSS was suitable for shrimp development and did not limit culture productivity (Lien and Giao, 2020) [30].
- **Nitrogenous Nutrients: Ammonia, Nitrite, and Nitrate:** Ammonia levels were 0.25-10.48 µg-at/L, remaining below the recommended <0.1 mg/L for shrimp (Boyd, 1989; Chien, 1992) [9,16], with higher concentrations toward the end of culture due to feeding and metabolic excretion. Nitrite ranged from 0.2-1.52 µg-at/L, slightly elevated during the rainy season but

within safe limits (Smith and Russo, 1975; Molnar *et al*., 2013). Nitrate levels were 0.06-6.57 µg-at/L, influenced by organic matter accumulation and microbial nitrification, remaining well below toxic thresholds of <0.1 mg/L (Karthikeyan and Srimurali, 1995) [24]. These nitrogenous nutrient levels indicate effective pond management, preventing toxic accumulation while supporting primary productivity.

- **Phosphorus and Silicate:** Phosphate (PO_4-P) ranged from 2.25-2.31 µg-at/L in ponds, within the optimal range of 0.01-3.0 ppm (Precilla and Myrana, 1991) [34], with higher values in Creek 1 during monsoon due to runoff. Silicate concentrations ranged from 7.63-90.8 µg-at/L, sufficient to support diatom growth and primary productivity, aligning with recommended thresholds (Kilham, 1986; Barua and Rahman, 2020) [27,8]. Controlled nutrient levels maintained a balanced planktonic community, supporting the pond food web.
- **Sediment pH:** Sediment pH influences nutrient cycling, microbial activity, and shrimp health. Acidified sediments (pH 6.0-7.0) can increase hemolymph osmotic pressure in shrimp, affecting growth, while optimal decomposition occurs at pH 6.5-7.5 (Banerjea, 1967) [7]. In FRIC(M) ponds, sediment pH ranged from 7.4-8.4, and Creek 1 water ranged from 7.7-8.4, slightly above the optimal range. These alkalinity likely results from routine liming with calcium carbonate and dolomite, which buffers pond systems and enhances microbial decomposition. Similar alkaline sediments were reported in Andhra Pradesh (Chittem and Kunda 2017) [17] and in inlet waters of shrimp ponds (Priyadarsani and Abhram, 2016) [35]. Slightly alkaline sediments are favourable for aquaculture, promoting nutrient availability and microbial activity (Schaeperclaus, 1933) [37].
- **Sediment organic carbon:** Sediment organic carbon ranged from 0.26-1.38% at P1 and 0.45-0.83% at P2. While P1 fell within the optimal 1-3% range (Boyd and Green, 2002) [12], P2 exhibited lower values, likely due to limited phytoplankton biomass or reduced feed deposition. Adequate organic carbon supports microbial activity, benthic organisms, and nutrient cycling, critical for sustaining shrimp growth (Ameeri and Cruz, 1992; Anna and Dinesh, 2021) [3,4].
- **Sediment texture:** Soil texture analysis revealed coarse soils in both ponds: sandy loam (P1) and loamy sand (P2), with clay contents of 1.68-1.75%. Such coarse soils have higher seepage and lower intrinsic fertility compared to clay-rich soils, which can retain water and nutrients better (Boyd, 1995; Ilyas *et al*., 1987) [10,23]. Therefore, these ponds may be classified as lower in natural productivity, requiring supplemental water and nutrient management to optimize shrimp culture.
- **Health status analysis:** The threat of infections persisted due to inadequate implementation of biosecurity measures such as pond preparation, water filtering and disinfection before and after pumping water into the pond, failure to set up bird and crab fencing and obtaining seed from unregistered hatcheries that sell non-SPF seed (Siripong *et al*., 2016) [38]. The FRIC(M) experimental shrimp ponds (P1 and P2) showed negative results for all tested pathogens namely White Spot Syndrome Virus (WSSV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), Enterocytozoon heoatopenaei (EHP), Monodon Baculovirus (MBV) and Hepatopancreatic Parvo (HPV) viruses throughout the culture period, as effective biosecurity measures were implemented and the ponds were maintained without any dissolved oxygen (DO) problems.

Conclusion

The experimental shrimp ponds exhibited favorable water, sediment, and soil characteristics for *L. vannamei* shrimp culture. Physico-chemical parameters, nutrient levels, and sediment properties largely fell within optimal ranges, while soil texture and minor variations in organic carbon suggest the need for continued water management and supplementary inputs. Crop period variations influenced nutrient concentrations, dissolved solids, and water temperature, underscoring the importance of adaptive pond management practices. Health status analysis showed negative results for all tested pathogens throughout the culture period due to good pre-stocking management practices and effective biosecurity measures. Collectively, these results demonstrate that the FRIC(M) ponds provide a suitable environment for sustainable shrimp aquaculture.

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