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Full Length Article

Chemical Composition of Water from Tiger Shrimp *Penaeus monodon* Culture Ponds at Malacca, Malaysia

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ABSTRACT

The present study analyzed chemical characteristics of pond and pore water of *Penaeus monodon* culture pondsin Malacca, Malaysia for one production cycle. Major cation concentrations (Ca, Na, K & Mg) both in pond and pore water were found to decrease with the increases of culture duration. The increase was however, recorded when pond water was exchanged with the water from reservoir. Similar types of observation was found for few trace elements i.e., Al, Fe, Cu, Pb, V, Zn, Ti, Sb, As and Ni. Water element concentrations were found higher in new ponds than aged ponds. Almost all elements concentrations in pore water were found higher in the new ponds than old ponds. This study suggests that decreases of cation concentrations over culture time may probably be due to accumulation of biotic components or deposition onto the pond bottom together with suspended particles. © 2012 Friends Science Publishers

Key Words: Aquaculture; Pond water; Pore water; Chemical composition; Malaysia

INTRODUCTION

Marine shrimp farming is one of the prime aquaculture industries in many tropical and sub-tropical regions. In spite of its overall progress, this industry has been plagued with epidemics of various diseases and impaired water quality in culture ponds (Browdy & Hopkins, 1995). The production of shrimp declines over a period of culture duration due to progressive deterioration of pond water quality (Liao, 1990). Studies reported that the alterations of water chemistry (calcium & magnesium) may indirectly cause production failure by increasing physiological stresses and lowering the immune system of culture species (Simpson & Pedini, 1985; Stevensson, 1997).

In semi intensive shrimp culture ponds, significant quantities of organic materials in pond ecosystem through uneaten feed and shrimp faeces may be responsible for oxygen depletion and buildup of toxic metabolites (Boyd, 1995). Besides, an intense interchange of organic and mineral compounds between soil and water exists in pond ecosystem (Wrobel, 1983). Accumulation and decomposition of organic matter on the pond bottom results in elimination of certain macro elements from the pond water. The decomposition of organic matter releases inorganic substances, acids and dissolute minerals back to pond water; thus, influencing the aquatic biota and water quality (Das *et al.*, 2002).

Although few studies on the properties and chemistry of shrimp pond water had been reported by Ritvo *et al.* (1998) and Boyd and Thunjai (2003), study on the dynamic of macro and microelements of water in shrimp culture ponds throughout the culture period especially in tropical environment is scanty. Studies to define the relationships among chemical characteristics of water with shrimp production are still scarce. The techniques or research findings such as tilling, liming and drying have been devised for treating and/or improving the conditions of pond ecosystem (Munsiri *et al*., 1996), while wide fluctuations of production in different ponds is not well understood even though same management system is practiced. Therefore, the objective of this study was to investigate the dynamic of macro and microelements in the water of shrimp culture ponds throughout the culture period.

MATERIALS AND METHODS

Location of culture ponds: The study ponds were situated at Kampung Tedong (2º 08´ 50" N & 102º 24´ 00" E) in Merlimau, District Malacca, Malaysia. The ponds were managed by Farmers' Organization Authority Malaysia (Lembaga Pertubuhan Peladang). Four culture ponds were randomly selected for this study, of which two were ≥3 years old and considered as old culture ponds (4,225 m^2 each). Another two ponds were newly constructed on a former mangrove land and considered as new culture ponds (4,355 m^2 & 3,969 m^2). The soil type of the culture ponds was silty clay.

Description of culture protocol: All old (≥3 years) culture

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ponds were dried by draining the water. Surface sludge was removed manually by water jet. Lime was applied at 11.24 t ha^{-1} in each aged pond and 8.08-8.87 t ha^{-1} in new culture ponds. Tea seed cake (TSC) was applied at 1.15-1.26 t ha^{-1} in new culture ponds to eliminate the predators and pests. However, no TSC was applied in old culture ponds. At the beginning, the ponds were filled with about 20–30 cm seawater (filtered through 400–500 μm mesh net) from the reservoir and kept for 1 week, which allowed phytoplankton to grow. Water depth was then increased to 1 m prior to stocking. Average stocking density was 22.5 PL_{15} m^{-2} in old and new culture ponds. A set of four paddlewheels was used during the whole culture period (12 h d^{-1}) in each culture pond. During the culture period, 50% of water was exchanged once in old culture ponds. The decision of changing the water was based on the water quality. In new culture ponds, 50% of water was changed three times throughout the culture period. The water was discharged through a canal to the adjacent water body and refilled using pump from reservoir. A commercial 35-40% protein shrimp grow out feed (Gold Coin, Singapore) was given at 10% body weight day^{-1} for the first month and 4–6% for the rest of culture period.

Analysis of macro and microelements of pond and pore water: Samples were collected between 10 am and 12 pm. The pond and pore water samples were collected in every three week intervals throughout the culture period and brought back to the laboratory for further analysis. Water samples from culture ponds were collected in three plastic bottles (500 mL) following the procedure described by Yusoff *et al*. (2001; 2003) for element analysis. For pore waters, sediment samples were collected from different locations of the ponds by using an Ekman grab covering an area of 225 cm^2. All water and sediment samples were brought to the laboratory within 2-3 h after sampling. Pore water was extracted by filtration of the sediment sample over Whatman GF/C (32 cm) filter paper. From the collected samples, triplicates of pond and pore water samples were preserved by 2-3 drops of concentrated HCl. The samples were kept at 4°C until analysis. Pond and pore water macro and microelements were detected by Perkin Elmer ELAN 6000 ICP-MS at Malaysia Institute of Nuclear Testing (MINT), Bangi, Selangor, Malaysia.

Statistical analyses: Statistical Package for Social Science (SPSS- version-10) was used to analyze the data. One-way ANOVA was used to compare the variation of macro and microelements concentrations of water and pore water and within different sampling dates in each old and new culture ponds. Simple t-test was used to compare the means of two sets of observations at old and new culture ponds.

RESULTS AND DISCUSSION

The concentrations of macro elements in pond water fluctuated during the culture period and were at higher level at the end of culture period in the old culture ponds (Table I); whereas, no major trend was found in new culture ponds (Table II). Macro elements of water tended to increase sharply with the exchange of water. The mean concentration of water Ca, Na, Mg and K were significantly ($p<0.05$) higher in the new culture ponds compared to the old culture ponds (Table III). The mean concentration of Ca, Na, Mg and K were also found higher ($p<0.05$) in pore water of new culture ponds than the old culture ponds (Table IV).

The mean values of water microelements (Fe, V, Cu, Ti, Al & Ag) were higher in the new culture ponds while concentrations of Fe, Cr, Zn, As, Pb, Mn and Sb were found higher in the old culture ponds (Table III). The

Table I: Concentrations of pond water macro and microelements (mean ± standard error) of old *Peneaus monodon* culture ponds throughout the culture period

Element (mg L^{-1})	Culture period				
	Week 1	Week 4	Week 7	Week 10	Week 13
Calcium	227.5±6.98^a	205.5±7.08^a	335.5±15.75^a	223±5.94^a	234±5.57^a
Sodium	1080±21.60^b	735±14.31^a	1355±29.25^b	995±2.65^b	1440±12.47^b
Magnesium	1278±25.28^b	885.5±17.41^a	1658.5±33.45^b	1170±71.1^b	1785±14.31^b
Potassium	1980±27.63^a	1730±18.42^a	2490±36.46^b	1815±2.65^a	2740±16.81^b
Vanadium	1.84±0.39^a	1.53±0.69^a	1.58±0.38^a	1.68±0.60^a	2.06±0.31^a
Chromium	2.37±1.26^a	1.32±0.67^a	1.31±0.92^a	1.34±0.54^a	1.46±0.09^a
Cobalt	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	3.42±0.67^a	2.58±1.26^a	2.01±1.09^a	3.15±1.08^a	4.56±0.34^a
Zinc	1.47±0.87^b	0.25±0.53^a	1.01±0.05^b	3.89±0.33^b	0.73±0.98^a
Arsenic	4.96±0.83^a	3.89±1.44^a	3.87±0.79^a	4.53±1.24^a	5.99±0.55^a
Lead	2.16±0.45^b	0.68±0.09^a	0.84±0.70^a	0.49±0.24^a	2.82±1.59^b
Titanium	40.75±4.48^b	4.77±1.76^a	7.50±1.87^a	23.57±5.18^{ac}	29.10±5.50^b
Manganese	4.57±0.56^a	4.7±0.37^a	5.87±0.49^a	3.12±1.92^a	18.67±4.25^b
Aluminum	48.65±7.40^b	9.80±2.49^a	11.1±1.30^a	24.45±5.06^{ac}	4.80±1.06^a
Iron	40.75±3.53^a	41.05±3.17^a	48.6±5.34^a	41.0±2.43^a	36.2±2.68^a
Nickel	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	0.12±0.03^a	0.16±0.04^a	0.18±0.10^a	0.19±0.01^a	0.16±0.10^a
Cadmium	0.02±0.01^a	0.01±0.00^a	0.01±0.0	0.01±0.00^a	0.01±0.00
Antimony	1.85±0.54^a	0.69±0.14^b	0.70±0.02^b	0.59±0.14^b	0.53±0.10^b

Means in a row with different letter of superscripts are significantly different (Duncan, $p < 0.05$)

Table II: Concentrations of pond water macro and microelements (mean ± standard error) of new *Peneaus monodon* culture ponds throughout the culture period

Element (mg L^{-1})	Culture period					
	Week 1	Week 4	Week 7	Week 10	Week 13	Week16
Calcium	372.5±4.03^{a}	385.5±8.19^{a}	359.5±3.03^{a}	285±10.63^{a}	327.5±11.62^{a}	314±6.06^{a}
Sodium	2060±22.24^{b}	2015±5.94^{b}	2155±7.97^{b}	1425±34.77^{a}	1685±22.71^{a}	1850±16.39^{b}
Magnesium	2400±25.50^{b}	2180±21.92^{b}	2620±5.31^{b}	1721±36.44^{a}	2060±26.32^{b}	2295±17.83^{b}
Potassium	3695±21.43^{b}	3280±24.37^{b}	3895±18.23^{b}	2182.5±45.71^{a}	2690±35.47^{a}	3050±24.37^{b}
Vanadium	1.51±0.20^{a}	2.71±0.70^{a}	1.45±0.56^{a}	2.80±1.10^{a}	1.44±0.47^{a}	1.59±0.72^{a}
Chromium	0.69±0.06^{a}	0.92±0.02^{a}	0.88±0.08^{a}	1.08±0.82^{a}	0.58±0.06^{a}	1.69±0.95^{a}
Cobalt	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Copper	3.12±0.50^{a}	5.12±1.10^{a}	2.04±0.96^{a}	4.36±0.53^{a}	2.43±0.85^{a}	3.23±1.42^{a}
Zinc	0.05±0.56^{a}	1.79±0.0^{a}	0.05±0.0^{a}	2.04±0.67^{b}	0.05±0.0^{a}	0.78±0.01^{a}
Arsenic	3.73±0.66^{a}	5.13±1.76^{a}	3.44±1.04^{a}	4.54±1.02^{a}	3.46±0.99^{a}	4.95±1.81^{a}
Lead	0.80±0.30^{a}	0.44±0.04^{a}	0.47±0.07^{a}	0.31±0.02^{a}	0.48±0.01^{a}	0.55±0.10^{a}
Titanium	36.39±6.63^{b}	80.0±8.77^{b}	4.05±1.30^{a}	25.22±1.88^{b}	77.29±10.15^{b}	7.05±3.08^{a}
Manganese	7.87±0.97^{b}	4.29±2.35^{b}	6.23±0.47^{b}	0.82±0.83^{a}	7.60±1.27^{b}	8.79±2.91^{b}
Aluminum	49.35±7.45^{b}	55.45±8.28^{b}	9.75±2.04^{a}	14.1±3.76^{a}	11.8±2.05^{a}	16.55±3.39^{a}
Iron	35.3±2.19^{a}	41.35±2.11^{a}	116.5±9.84^{b}	84.3±7.58^{a}	31.4±1.18^{a}	39.9±1.30^{a}
Nickel	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Selenium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Silver	0.22±0.17^{a}	0.14±0.04^{a}	0.15±0.02^{a}	0.07±0.01^{a}	0.10±0.02^{a}	0.44±0.03^{a}
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Antimony	1.37±0.69^{b}	0.13±0.01^{a}	0.19±0.01^{a}	0.02±0.0^{a}	0.52±0.04^{a}	0.94±0.04^{a}

Table III: Macro and microelements concentrations (mean ± standard error) of culture pond water

Element (mg L^{-1})	Old culture ponds		New culture ponds	
	Mean	Range	Mean	Range
Calcium	245.1±28.91^{a}	160-511	340.67±19.87^{b}	205-433
Sodium	1121±124.21^{a}	590-1960	1865.0±145.63^{b}	570-2410
Magnesium	1355.4±163.23^{a}	671-2450	2212.67±173.15^{b}	782-2860
Potassium	2151±195.26^{a}	1440-3430	3132.08±289.37^{b}	705-4130
Vanadium	1.74±0.08^{a}	1.20-2.14	1.92±0.22^{a}	1.23-3.78
Chromium	1.56±0.24^{a}	0.06-3.51	0.97±0.16^{a}	0.28-2.34
Cobalt	<0.01^{a}	<0.01	0.03±0.009^{a}	0.01-0.09
Copper	3.15±0.33^{a}	1.16-4.65	3.38±0.39^{a}	1.38-5.98
Zinc	1.47±0.63^{a}	0.05-7.73	0.79±0.42^{a}	0.05-4.02
Arsenic	4.65±0.34^{a}	2.42-6.22	4.21±0.47^{a}	2.63-7.33
Lead	1.39±0.40^{a}	0.53-4.62	0.50±0.06^{a}	0.07-0.86
Titanium	21.14±5.69^{a}	4.55-55.0	38.33±15.05^{b}	2.85-150.5
Manganese	7.39±2.35^{a}	0.49-31.45	5.93±1.21^{b}	0.39-14.8
Aluminum	19.76±7.59^{a}	4.0-87.4	26.17± 9.70^{b}	4.1-104.0
Iron	41.52±3.50^{a}	31.1-68.8	58.12±13.67^{b}	30.4-185.0
Nickel	<0.01^{a}	<0.01	<0.01^{a}	<0.01
Selenium	<0.01^{a}	<0.01	<0.01^{a}	<0.01
Silver	0.16±0.01^{a}	0.09-0.26	0.18±0.05^{a}	0.003-0.69
Cadmium	0.007±0.001^{a}	0.004-0.02	0.005±0.001^{a}	0.001-0.02
Antimony	0.87±0.16^{a}	0.47-2.24	0.53±0.19^{a}	0.02-1.88

Means in a row with different letter of superscripts are significantly different (*t*-test, $p < 0.05$)

concentrations of pond and pore water microelements (Fe, Mn, Zn, Cu & Al) and other metals (Pb, Cr, Ag & Cd) were low to moderate in the present study (Tables III & IV). No distinct fluctuation of microelements concentrations in pond water were observed throughout the culture period (Tables I & II). The pore water microelement concentrations showed similar values with pond water (Tables V & VI). In pore water, concentrations of Cr, Cu, Pb, Fe, Se, Cd and Sb were higher ($p>0.05$) in the old culture ponds than in the new culture ponds. The other microelements concentrations e.g., V, Zn ($p>0.05$), As, Ti, Mn and Al ($p<0.05$) were detected higher in pore water in the new culture ponds (Table IV). Regression analysis showed that concentrations of pond water microelements were not dependent on the elements concentrations of pore water but on the pond water Mn ($r=0.43$, $p<0.05$).

Like culture pond soil, the water quality is important in any aquaculture system where cultured species grow (Boyd, 1990). Generally, in brackish water environment, soil could be able to adsorb macro elements from water (Boyd *et al*., 1994), which may be a possible cause for the fluctuations of macro elements in the pond water over culture period. The accumulation by pond biota, water exchange or precipitation of major elements as organic and

Table IV: Macro and microelements concentrations (mean ± standard error) of pore water of culture ponds

Element (mg L^{-1})	Old culture ponds		New culture ponds	
	Mean	Range	Mean	Range
Calcium	211.53±20.27[a]	128-307	625.67±115.4[b]	401-1740
Sodium	1091.0±106.37[a]	630-1750	2327.5±112.3[b]	2100-2500
Magnesium	1417.4±127.70[a]	849-2180	2874.08±96.3[b]	739-3390
Potassium	2063.0±224.35[a]	1100-3520	4084.17±104.4[b]	3840-4910
Vanadium	9.08±2.94[a]	1.48-37.09	11.66±0.37[a]	8.33-13.49
Chromium	5.20±0.62[a]	2.74-10.53	2.44±0.47[a]	0.73-6.01
Cobalt	0.71±0.53[a]	0.01-5.95	0.36±0.05[a]	0.19-0.83
Copper	16.76±10.72[a]	0.07-12.21	11.71±0.62[a]	8.98-15.20
Zinc	5.35±1.04[a]	0.45-13.4	6.41±1.33[a]	3.0-18.51
Arsenic	7.14±0.90[a]	2.98-11.12	19.39±2.82[b]	9.54-36.03
Lead	0.20±0.05[a]	0.02-0.56	0.14±0.04[a]	0.001-0.49
Titanium	75.86±19.14[a]	0.68-239.8	122.35±13.67[b]	30.89-197.7
Manganese	61.36±11.99[a]	0.02-124.6	95.49±16.17[b]	10.49-203.98
Aluminum	20.33±5.75[a]	5.4-66.4	39.42±14.76[b]	2.7-153.0
Iron	25.91±4.10[a]	15.5-176.0	23.08±4.05[a]	13.7-66.1
Selenium	8.57±1.02[a]	0.005-9.33	3.31±0.48[a]	1.29-6.91
Nickel	1.80±0.78[a]	2.65-12.84	12.19±0.52[a]	10.24-14.69
Silver	<0.01[\a]	<0.01	<0.01[a]	<0.01
Cadmium	0.19±0.15[a]	0.005-1.73	0.11±0.07[a]	0.001-0.97
Antimony	0.22±0.10[a]	0.002-1.18	0.18±0.02[a]	0.006-0.32

Table V: Concentrations of pore water macro and microelements (mean ± standard error) of old *Peneaus monodon* culture ponds throughout the culture period

Element (mg L^{-1})	Culture period				
	Week 1	Week 4	Week 7	Week 10	Week 13
Calcium	163.5±6.23[a]	217.5±11.25[a]	221±9.43[a]	167.5±7.47[a]	288.15±3.33[a]
Sodium	815±7.97[a]	1125±26.45[a]	975±11.28[a]	960±17.43[a]	1580±15.50[b]
Magnesium	1155±11.59[a]	1514.5±30.67[a]	1260±15.04[a]	1227.5±19.63[a]	1930±14.56[b]
Potassium	1480±18.42[a]	2000±35.67[a]	1715±12.75[a]	1930±27.11[a]	3190±21.60[b]
Vanadium	4.22±1.97[a]	5.72±2.11[a]	5.16±0.43[a]	21.85±4.64[a]	8.44±1.19[a]
Chromium	3.72±1.17[a]	3.91±0.98[a]	5.48±1.25[a]	4.84±0.19[a]	8.05±1.87[a]
Cobalt	0.06±0.01[a]	3.06±0.07[b]	0.16±0.05[a]	0.1±0.03[a]	0.16±0.06[a]
Copper	3.19±1.57[a]	3.38±2.16[a]	64.47±9.02[b]	5.68±0.07[a]	7.06±1.65[a]
Zinc	6.66±1.83[a]	3.71±0.57[a]	8.27±2.69[a]	2.03±1.49[a]	5.88±0.80[a]
Arsenic	6.35±2.18[a]	4.94±1.59[a]	8.00±2.09[a]	7.26±1.96[a]	9.11±1.38[a]
Lead	0.36±0.07[a]	0.10±0.06[a]	0.27±0.03[a]	0.14±0.09[a]	0.11±0.03[a]
Titanium	33.10±6.77[a]	58.15±7.81[a]	47.78±2.82[a]	155.82±10.89[b]	84.42±5.12[a]
Manganese	23.52±5.76[a]	116.21±3.44[b]	88.01±2.34[b]	27.85±5.84[a]	51.19±4.08[a]
Aluminum	21.05±3.86[b]	8.45±1.21[a]	38.05±6.33[b]	11.25±2.53[a]	22.85±4.96[b]
Iron	19.9±2.49[a]	19.1±1.45[a]	43.1±5.61[b]	23.8±2.03[a]	23.65±1.48[a]
Nickel	0.58±0.08[a]	0.97±0.09[a]	5.01±0.09[a]	0.91±0.08[a]	1.49±0.70[a]
Selenium	6.55±2.17[a]	7.74±2.68[a]	8.38±1.44[a]	8.54±1.49[a]	11.60±0.86[a]
Silver	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	0.01±0.00[a]	0.01±0.00[a]	0.87±0.21[a]	0.01±0.00[a]	0.03±0.01[a]
Antimony	0.66±0.08[a]	0.02±0.00[a]	0.26±0.05[a]	0.08±0.03[a]	0.06±0.12[a]

Means in a row with different letter of superscripts are significantly different (Duncan, $p < 0.05$)

inorganic particles onto the pond bottom over culture period may also influence the element concentrations in water. The ranges of water Ca, Na, Mg and K in the present ponds were 160-511, 570-2,410, 671-2,860 and 705-4,130 mg L^{-1}, respectively. Seawater contains 400, 10,700, 1,290 and 380 mg L^{-1} of Ca, Na, Mg and K, respectively (Brown *et al.*, 1989). The major factors that cause variation in concentrations of macro elements both in pond and pore water probably are differences in concentrations of major elements in the water source, pond age and liming activities or could be due to leaching (Ritvo *et al.*, 1998) of water. The possibility of re-dissolving of elements into the pond water from soils is less since there are lower concentrations of soil elements in the ponds (Ritvo *et al.*, 1998). Kinetically, the adsorbed or dissolved metals take sufficient time to completely re-dissolve or diffuse back into the pond water during the shrimp growth period.

The concentrations of Cr, Cu, Pb, Fe, Se, Cd and Sb in pore water were found higher in the old culture ponds suggesting that soil pores might have adsorbed these elements over the culture time through nutrient loading and accumulation into the soil pore water **(**Boyd *et al.*, 1994). Later on, the accumulated elements start to diffuse slowly when they contacted new water. Ritvo *et al.* (1998) also

Table VI: Concentrations of pore water macro and microelements (mean ± standard error) of new *Peneaus monodon* culture ponds throughout the culture period

Element (mg L^{-1})	Culture period					
	Week 1	Week 4	Week 7	Week 10	Week 13	Week16
Calcium	514.5±6.67[a]	541.5±9.91[a]	1080.5±30.53[b]	505.5±6.12[a]	458.5±9.01[a]	653.5±9.40[a]
Sodium	2395±2.65[a]	2500±2.50[a]	2230±13.55[a]	2395±12.18[a]	2225±9.58[a]	2220±7.52[a]
Magnesium	3150±3.76[b]	3280±12.47[b]	1864.5±39.89[a]	3155±13.29[b]	2920±9.21[b]	2875±7.03[b]
Potassium	4250±11.28[a]	4510±23.78[a]	3905±8.81[a]	4160±13.55[a]	3920±14.56[a]	3760±10.63[a]
Vanadium	12.03±0.35[a]	12.83±0.96[a]	10.45±1.72[a]	12.31±0.30[a]	11.22±0.66[a]	11.12±0.95[a]
Chromium	2.61±1.26[a]	3.32±0.51[a]	3.37±1.93[a]	2.79±1.43[a]	1.28±0.38[a]	1.25±0.11[a]
Cobalt	0.25±0.03[a]	0.59±0.01[a]	0.33±0.09[a]	0.32±0.04[a]	0.29±0.02[a]	0.41±0.06[a]
Copper	10.82±0.94[a]	14.05±1.27[a]	9.77±1.04[a]	12.47±1.00[a]	11.09±1.73[a]	12.07±1.94[a]
Zinc	8.43±2.39[b]	6.83±1.09[b]	3.55±0.59[a]	11.86±3.06[b]	4.10±1.24[a]	3.68±0.64[a]
Arsenic	9.75±0.55[a]	10.24±0.80[a]	14.84±1.80[a]	30.62±2.83[b]	27.72±3.23[b]	23.22±2.69[b]
Lead	0.14±0.06[b]	0.41±0.01[b]	0.06±0.02[b]	0.24±0.00[b]	0.001±0.0[a]	0.04±0.01[b]
Titanium	118.71±8.05[b]	163.93±6.91[b]	98.07±9.74[a]	150.18±3.73[b]	112.8±1.19[b]	90.38±4.61[a]
Manganese	114.07±7.00[b]	184.36±5.26[b]	47.02±7.18[a]	48.17±4.13[a]	75.92±5.18[a]	103.40±5.66[b]
Aluminum	6.05±0.70[a]	20.45±5.01[a]	78.2±10.28[b]	16.0±2.25[a]	20.75±2.14[a]	95.06±7.33[b]
Iron	20.2±2.60[a]	43.4±5.66[b]	19.65±1.38[a]	17.8±1.84[a]	17.8±2.40[a]	19.6±2.40[a]
Nickel	2.88±0.24[a]	4.97±1.36[a]	4.64±1.79[a]	2.81±1.12[a]	2.51±0.61[a]	2.02±1.01[a]
Selenium	11.32±1.23[a]	11.79±1.83[a]	11.85±1.80[a]	12.35±1.22[a]	11.92±0.87[a]	13.89±1.06[a]
Silver	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	0.07±0.02[b]	0.53±0.03[b]	0.01±0.00[a]	0.03±0.00[a]	0.001±0.0[a]	0.001±0.0[a]
Antimony	0.12±0.03[a]	0.07±0.01[a]	0.17±0.09[a]	0.29±0.04[a]	0.28±0.02[a]	0.16±0.11[a]

Means in a row with different letter of superscripts are significantly different (Duncan, $p < 0.05$)

Table VII: Comparison of water and pore water chemical properties with regional studies elsewhere

	Pond water (mg L^{-1})		Pore water (mg L^{-1})	
Element	Present study	Boyd and Thunjai (2003)	Present study	Ritvo *et al.* (1998)
Calcium	160-511	15-1263	128-1740	48-58
Sodium	570-2410	17-4812	630-2500	1272-1526
Magnesium	671-2860	5.0-686	739-3390	164-196
Potassium	705-4130	0-72	1100-4910	46-55
Vanadium	1.20-3.78	ND	1.48-37.09	ND
Chromium	0.06-3.51	ND	0.73-10.53.	ND
Cobalt	<0.01	ND	0.01-5.95	ND
Copper	1.16-5.98	ND	0.07-15.20	<1
Zinc	0.05-7.73	ND	0.45-15.51	<1
Arsenic	2.42-7.33	ND	2.98-36.03	ND
Lead	0.07-4.62	ND	0.001-0.26	ND
Titanium	2.85-150.5	ND	0.68-239.8	ND
Manganese	0.39-31.45	ND	0.02-203.98	<1
Aluminum	4.0-104	ND	2.7-153.0	ND
Iron	30.4-185.0	0.18-0.49*	13.7-176.0	<1 and 21.15-27.11*
Selenium	<0.01	ND	0.005-9.33	ND
Nickel	<0.01	ND	2.65-14.69	ND
Silver	0.003-0.69	ND	<0.01	ND
Cadmium	0.001-0.02	ND	0.001-1.73	ND
Antimony	0.02-2.24	ND	0.002-1.18	ND

*Masuda and Boyd (1994), ND = Not detected

noted that the concentrations of several elements increased appreciably over the production time in the shrimp pond environment. Sonnenholzner and Boyd (2000) revealed that the concentrations of major and minor elements in the water source are more likely to be influenced on shrimp production in the culture pond. However, information on the optimum concentrations of water macro and microelements verses shrimp growth is not established.

With some exception, concentrations of almost major and microelements were higher in pore water than pond water. Compared to other studies (Ritvo *et al*., 1998; Boyd & Thunjai, 2003), the concentrations of present pond and pore water macro elements were higher (Table VII). The concentrations of major elements in pond water have specific roles in many physiological processes of shrimp like moulting and growth. Moulting abnormalities have been observed in waters with less calcium (Boyd & Thunjai, 2003) and excess calcium in pond environment is counterproductive (Sonnenholzner & Boyd, 2000), which could lead to precipitate the phytoplankton communities in the pond ecosystem.

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