Journal of Sustainability Science and Management
Volume 9 *Number* 2, December 2014: 31-42
ISSN: 1823-8556

IMPACTS OF LAND USE AND RAINFALL ON THE WATER QUALITY OF TRIBUTARIES OF SERIN RIVER, SARAWAK

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Abstract: Water quality of the tributaries could be affected by land use such as agricultural activities. Thus, a study was conducted to determine the water quality at the mouth of six tributaries of the Serin River from September 2009 to September 2010. The study shows that in February 2010, when there was no rain two days before sampling and when the water level was low, higher concentrations of ammoniacal-nitrogen, nitrite-nitrogen, nitrate-nitrogen and soluble reactive phosphorus than other months were observed. Furthermore, 92.7% and 93.6% of the inorganic nitrogen in Pam River and Bukah River were in the form of ammoniacal-nitrogen. Nitrate was significantly higher and occasionally dissolved oxygen was below 5 mg/L at Bujang River. TSS ranged from 2.0-84.4 mg/L with the highest value observed during rainfall event. At Pam River, reactive phosphorus and ammoniacal-nitrogen exceeded 0.2 mg/L and 0.3 mg/L respectively throughout the sampling period and 50% of the dissolved oxygen values were less than 3 mg/L. For Bukah River 50% of the measured dissolved oxygen were less than 5 mg/L and occasionally reactive phosphorus was more than 0.2 mg/L. BOD_5 at all tributaries exceeded 3 mg/L and 60%, 50%, 44% and 40% of the readings at Bukah, Pam, Bukar and Penat exceeded 12 mg/L respectively. Both Pam and Bukah watershed have animal farming actvities. This study shows that land use affected the water quality and over the sampling period rainfall events and water level played an important role in the nutrient concentrations as some of the highest concentrations were observed during low water level when less dilution occurred though concentrations were also influenced by the timing of effluent outflow.

KEYWORDS: Water quality, agricultural impact, animal farm effluent, temporal variations.

Introduction

Tropical tributaries have been reported to be important grounds for spawning of fishes (Winemiller *et al.,* 2008). However, tributaries are often polluted by different land uses. Runoff of nitrogen and phosphorus rich fertilizers used to optimize crop yields as well as the wastewater discharged from animal farming and residential areas which ultimately end up in the river may deleteriously affect the aquatic ecosystems of the river (Ling *et al.,* 2010). Wastewater, which comprises animal manure and effluent from pen washings, contains potential pollutants such as nitrogen, phosphorus, organic matter, heavy metals (Cu, Zn, Fe, Mn, Co, Cd) and pathogens (Chadwick & Chen, 2002). The excess accumulation of these pollutants can contribute to eutrophication, unwanted algal growth and growth of microorganisms which alter the chemical characteristics of the receiving river system, in particular dissolved oxygen and pH that affect fish distribution (Sabater *et al.,* 2000; Yang *et al.,* 2007).

In Sarawak, the Serin River, the upstream river of Batang Samarahan, is polluted by domestic and agricultural activities including animal farming and crop production (Ling *et al.,* 2006; 2010; 2013). These studies showed that dissolved oxygen at a tributary was below the minimum required for healthy aquatic life. According to Ling *et al.,* (2006; 2013), the animal farm effluent receiving tributary has shown elevated levels of *Escherichia coli* (*E. coli*), total suspended solids, biochemical oxygen demand, chemical oxygen demand, ammonia-nitrogen and soluble reactive phosphorus. In addition, Ling *et al.,* (2010) reported that this tributary contained the highest Cu concentrations when compared to other parts of the river studied. Higher concentrations of organic matter, nutrients and some trace metals (Ni, Zn and Cd) were observed near fish farming, agricultural crops and residential areas. However, tributaries studied were limited and the duration of the study was short. Therefore, a more comprehensive study was conducted to evaluate the water quality of all major tributaries of the Serin River.

Methodology

Study Site and Sample Collection

Ten samplings were conducted from September of 2009 to September of 2010. One sampling station from each tributary upstream of the confluence was selected to compare the water quality among the tributaries as five out of six tributaries were small rivers and thus their water quality was not expected to be much different along the river. Water samples were collected between 9:00 am and 2:00 pm using 2 L polyethylene bottles from six tributaries of Serin River, namely Penat River (Pe), Bukah River (Bu), Pam River (Pm), Bukar River (Br), Bujang River (Bj) and Dara River (Da), as illustrated in Figure 1. Dara River was dry in October of 2009 and August and September of 2010 and therefore water samples were not available. *In-situ* temperature, pH and dissolved oxygen were measured during each sampling trip by using a multi-parameter water quality monitor (YSI 6600). Triplicate readings were measured and the mean values were calculated. Table 1 shows the daily rainfall data of Kuching during the sampling period.

Laboratory Analysis

Water samples collected were analyzed in triplicates for total suspended solids (TSS), biochemical oxygen demand (BOD_5), ammoniacal-nitrogen, nitrate-nitrogen, nitrite-nitrogen, and soluble reactive phosphorus. TSS and BOD_5 were analyzed according to Standard Methods (APHA 1998). For TSS analysis, 0.45 µm membrane filter papers (GFB, Whatman) with measured initial weight were dried in an oven at 103-105 °C. Then, 500 mL of water sample was filtered using this membrane filter and was dried in the oven at the same temperature for a duration of 2 hours, cooled and weighed. Drying process was repeated until there was no change in weight. TSS was calculated based on the weight of dry solids in 500 mL of sample. For BOD_5, 100 mL aerated distilled water was added to 200 mL of water sample in a 300 mL bottle in the field. The difference between initial and five days dissolved oxygen and sample proportion were used in its computation. Ammoniacal-nitrogen, nitrate-nitrogen, nitrite-nitrogen, and soluble reactive phosphorus in filtered samples were analyzed using colorimetric method according to Hach (2000) and the concentrations were determined using a spectrophotometer (Hach DR2800). Ammoniacal-nitrogen was determined using Nessler method where three drops of a mineral stabilizer and polyvinyl alcohol dispersing agent respectively were added to 25 mL of the sample and the concentration of ammoniacal-nitrogen in the yellow color solution was determined. The concentration of nitrate-nitrogen was analyzed according to cadmium reduction method. In this method, cadmium reduces nitrates in 30 mL samples to nitrite. Nitrite was determined by diazotization method where it reacted in acidic medium with sulfanilic acid to form diazonium salt. The salt coupled with chromotropic acid to form a pink-colored complex which was measured at 507 nm. Ascorbic acid method was used to determine reactive phosphorus concentration whereby orthophosphate in a 10 mL sample reacted with molybdate in an acid medium to produce a mixed phosphate/molybdate complex which was reduced by ascorbic acid giving it an intense molybdenum blue colour. The concentration of orthophosphates was then measured at 890 nm wavelength.

Table 1: Daily Rainfall Data Over the Study Period

Days	**Precipitation (mm)**									
	Sep-09	**Oct-09**	**Dec-09**	**Jan-10**	**Feb-10**	**Mar-10**	**Apr-10**	**May-10**	**Aug-10**	**Sep-10**
1	18.54	0.00	14.73	5.59	0.51	1.02	1.02	0.25	24.89	0.00
2	15.24	4.32	92.71	11.68	0.00	4.32	0.00	39.88	9.91	3.30
3	0.00	0.00	0.00	0.25	26.16	5.59	0.00	5.08	23.62	1.27
4	4.32	0.00	4.83	103.12	0.00	0.00	69.09	0.00	0.25	1.27
5	0.00	90.42	25.40	51.05	4.06	0.00	0.00	0.00	3.30	25.65
6	0.76	10.67	16.51	49.28	20.32	0.00	0.00	0.00	10.16	25.40
7	21.34	20.83	0.25	0.00	0.25	0.00	0.25	0.00	0.00	54.36
8	0.25	25.40	2.54	40.39	64.26	17.02	19.30	0.00	57.40	1.02
9	0.00	6.10	0.00	15.24	0.51	7.37	0.00	1.02	0.00	0.00
10	33.78	59.69	9.14	0.00	3.30	5.59	0.00	25.65	23.11	27.43
11	0.00	0.00	0.00	0.00	34.29	26.16	3.05	19.30	33.78	0.51
12	0.76	93.22	23.11	0.25	0.00	0.25	0.51	1.52	0.00	38.86
13	0.00	10.92	15.49	38.10	19.81	26.42	7.62	91.19	0.00	0.51
14	0.00	7.11	1.02	189.48	112.01	0.00	7.87	8.89	0.00	9.91
15	0.00	0.00	23.11	128.47	9.65	12.19	0.00	30.48	9.91	0.00
16	3.30	14.73	6.60	49.53	13.72	1.52	0.00	0.76	19.05	37.08
17	9.40	0.25	0.00	11.43	6.10	29.72	14.99	0.51	8.89	18.54
18	12.45	27.94	26.67	59.94	19.56	0.51	0.00	13.21	34.29	0.00
19	0.51	0.00	4.57	102.36	29.72	9.65	8.13	6.60	1.02	0.00
20	3.30	0.00	45.47	0.25	76.71	60.20	2.29	2.29	105.66	26.42
21	0.25	0.00	1.02	1.52	0.25	0.00	0.00	23.88	0.00	6.35
22	10.92	13.72	0.00	0.00	0.00	36.07	0.00	0.00	4.32	0.00
23	0.00	28.70	23.88	0.76	0.00	5.08	37.08	9.14	0.00	1.52
24	0.76	0.00	12.45	0.00	0.00	46.48	2.03	4.06	0.00	2.54
25	0.00	5.33	29.72	3.56	0.00	0.25	55.12	0.00	2.29	0.00
26	7.11	0.00	0.00	7.87	0.00	0.00	0.00	0.00	0.00	0.51
27	1.27	0.00	13.72	0.00	0.00	2.29	19.81	69.60	0.00	10.92
28	0.00	0.76	0.00	2.29	0.51	3.56	4.32	0.00	35.81	43.43
29	5.59	0.00	8.89	8.64		0.51	0.00	0.00	0.00	0.00
30	0.00	2.54	9.65	0.25		0.00	19.81	0.00	45.21	0.25
31		55.12	65.53	30.48		4.32		55.88	0.51	
Total	149.85	477.77	477.01	911.78	441.70	306.09	272.29	409.19	453.38	337.05

(Source: Historical meteorological databases from www.tutiempo.net/en/Climate/Kuching/964130.htm)

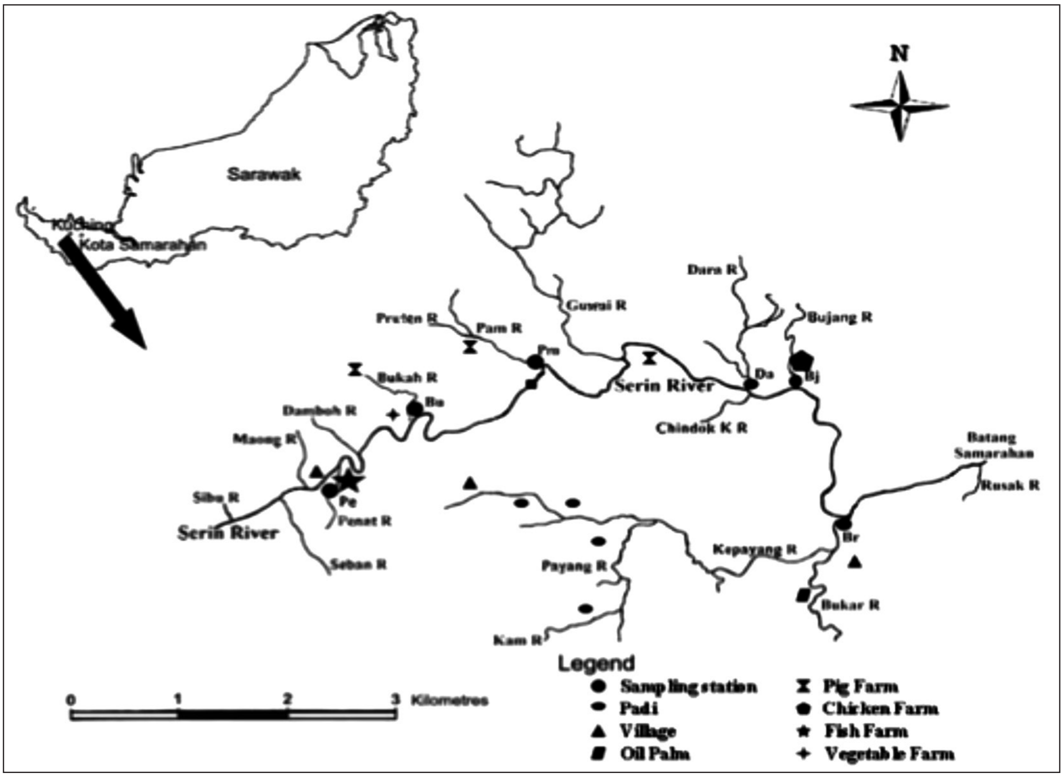

Figure 1: Sampling Stations on Tributaries of the Serin River and Human Activities in the Watershed

Statistical Analysis

Statistical tests were performed using SPSS version 17.0. Univariate analysis of variance was conducted to find possible differences among sampling stations. Tukey's method was used for multiple comparisons.

Results

Monthly temperature trend indicates that the lowest temperature occurred in September of 2009 where it recorded 22.0 °C at Pe and Bu and the highest was 28.3 °C at Pe in February and September of 2010 (Figure 2). In spite of the low temperature at Pe and Bu, temperature at Pm was 3 °C higher in September of 2009. Temperature of Bu and Pm did not fluctuate as much from October 2009 to September 2010 compared to other tributaries. Pe recorded the highest temperature four times over the sampling period. Mean temperature of the sampling stations over the sampling period ranged from 26.0 °C to 27.5 °C (Table 1). Da was also observed to have the highest temperature four times over the sampling period and overall it showed the highest mean temperature and the statistical results indicated that it is significantly different from all other stations ($0.006<P<0.016$) except Pe (Table 1).

Generally, there was an increasing trend of pH from January 2010 to September 2010 as the season moved from wetter to drier part of the year. The monthly pH values observed at the sampling stations were in the range of 6.13 to 7.62 (Figure 3) with the highest occurring in Pe, the fish aquaculture tributary in September 2010 which was dry season. Over the sampling period, the highest monthly pH value occurred at Pe six times (Figure 3). The mean results over the sampling period showed that the pH of the tributaries were slightly acidic (6.72-6.94) with Br showing the lowest mean and Pe the highest as shown in Table 2.

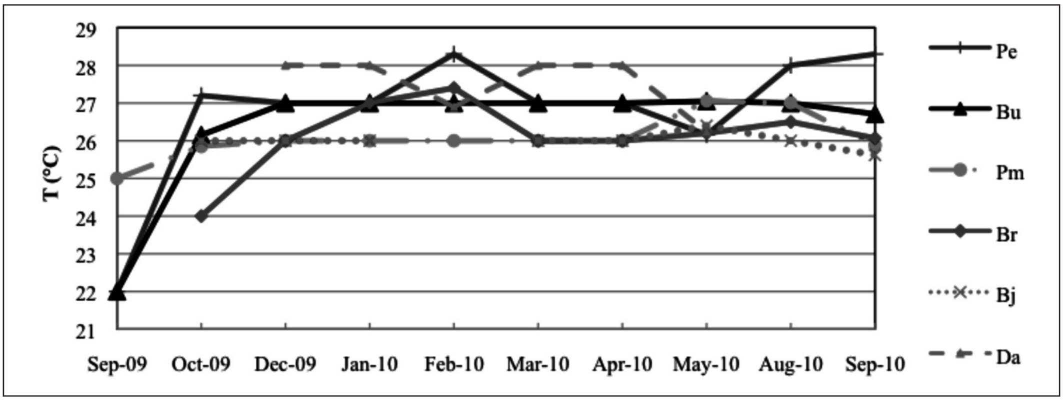

Figure 2: Temperature of the Six Tributaries Over the Sampling Period

Table 2: Mean Temperature, pH, Dissolved Oxygen (DO), Ammoniacal-nitrogen (NH_3-N), Nitrite-nitrogen (NO_2-N), Nitrate-nitrogen (NO_3-N), Soluble Reactive Phosphorus (RP), Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD_5) of the Six Sampling Stations

Station	Temperature (°C)	pH	DO (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	RP	TSS	BOD5
Pe	26.83 ± 1.77[ab]	6.94 ± 0.30[a]	5.34 ± 1.24[ab]	0.180 ± 0.133[a]	0.004 ± 0.005[a]	0.016 ± 0.019[a]	0.125 ± 0.125[a]	7.43 ± 4.86[a]	10.51 ± 4.59[a]
Bu	26.37 ± 1.49[a]	6.90 ± 0.28[a]	5.30 ± 1.52[ab]	0.761 ± 0.874[a]	0.023 ± 0.025[ab]	0.097 ± 0.071[ab]	0.338 ± 0.434[a]	14.67 ± 12.01[a]	11.83 ± 4.12[a]
Pm	26.06 ± 0.56[a]	6.87 ± 0.24[a]	3.37 ± 1.52[a]	6.085 ± 8.561[b]	0.046 ± 0.040[b]	0.109 ± 0.134[ab]	2.494 ± 3.370[b]	16.52 ± 12.55[a]	12.50 ± 6.56[a]
Br	26.13 ± 0.94[a]	6.72 ± 0.44[a]	6.23 ± 1.76[b]	0.195 ± 0.088[a]	0.005 ± 0.005[a]	0.027 ± 0.018[ab]	0.109 ± 0.109[a]	15.09 ± 7.33[a]	9.63± 4.45[a]
Bj	26.00 ± 0.21[a]	6.83 ± 0.31[a]	5.41 ± 2.13[ab]	0.248 ± 0.239[a]	0.006 ± 0.006[a]	0.133 ± 0.098[b]	0.083 ± 0.025[a]	16.55± 27.52[a]	9.34± 3.21[a]
Da	27.52 ± 0.77[b]	6.84 ± 0.13[a]	6.21 ± 0.76[b]	0.146 ± 0.066[a]	0.002 ± 0.002[a]	0.014 ± 0.016[a]	0.133 ± 0.198[a]	15.01 ± 15.91[a]	8.49 ± 3.87[a]

*Means within a column followed by same letters are not significantly different at 5% level.

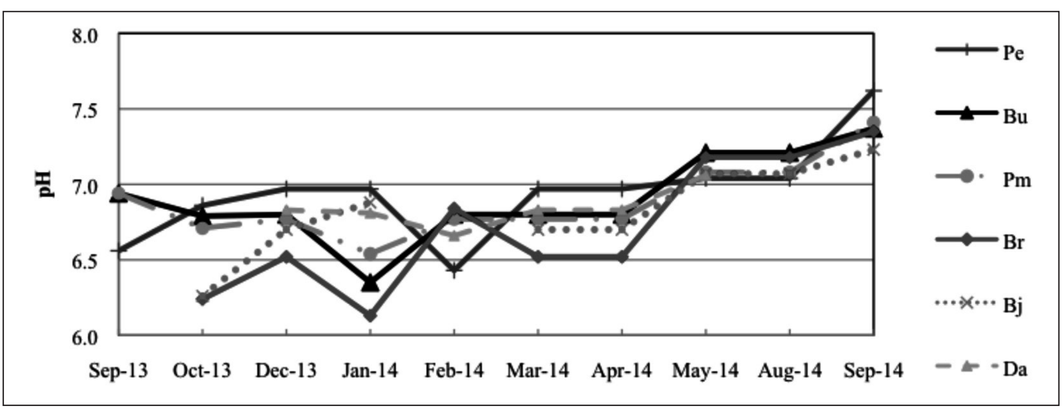

Figure 3: pH of the Six Tributaries Over the Sampling Period

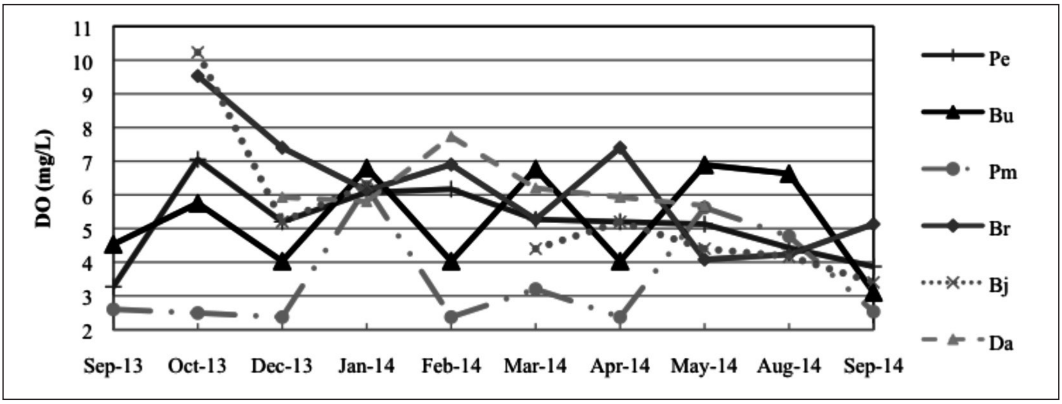

Figure 4: Dissolved Oxygen (DO) of the Six Tributaries Over the Sampling Period

Monthly dissolved oxygen values of Pm were low, ranging from 2.37 mg/L to 4.77 mg/L, with the exception of January 2010 and May 2010 (Figure 4). It shows the lowest dissolved oxygen among the stations 70% of the sampling months and 50% of the dissolved oxygen values were below 3 mg/L. Only 20% of the dissolved oxygen values at Pm were above 5 mg/L. At Bu, 50% of the sampling months showed dissolved oxygen below 5 mg/L and the trend of dissolved oxygen was similar to Pm. Br showed lower dissolved oxygen during dry season of May 2010 to September 2010. At Pe, dissolved oxygen fluctuated little from December 2009 to September 2010 compared to other tributaries and 70% of the dissolved oxygen values were above 5 mg/L. The mean dissolved oxygen of the tributaries ranged from 3.37 mg/L to 6.23 mg/L (Table 2) and Br and Da showed significantly higher dissolved oxygen than Pm ($P<0.05$) with dissolved oxygen values at Br and Da not significantly different ($P<0.05$).

The results indicated that ammoniacal-nitrogen at Pm tributary was consistently higher than other tributaries over the sampling period (Figure 5). Furthermore, the highest ammoniacal-nitrogen at Pm occurred in September 2009 followed by February 2010 and March 2010. Similar trend was observed for nitrite-nitrogen at Pm (Figure 6). However, nitrate-nitrogen at Pm showed a different trend with the highest concentration occurring in February 2010 followed by October 2009 and then September 2009 (Figure 7). Bj and Bu also showed some spikes in nitrate-nitrogen in January, April and August 2010 and March, August and September 2010 respectively. Reactive phosphorus at Pm also showed the same trend as ammoniacal-nitrogen and nitrite-nitrogen (Figure 8). In September 2009 at Pm, the values of ammoniacal-nitrogen, nitrite-nitrogen and reactive phosphorus were extremely high compared to other months. In February 2010, at Pm, the highest value of nitrate-nitrogen (0.333 mg/L) coincided with high values of ammoniacal-nitrogen (5.320 mg/L) and nitrite-nitrogen (0.083 mg/L) and at Bu, the highest ammoniacal-nitrogen (2.183 mg/L), nitrite-nitrogen (0.066 mg/L) and reactive phosphorus (1.481 mg/L) concentrations were also observed (Figures 5, 6, 7 and 8). The mean nutrients concentrations of the tributaries over the sampling period are shown in Table 2. The highest mean ammoniacal-nitrogen (6.085 mg/L) and reactive phosphorus (2.494 mg/L) observed at Pm were significantly higher than all the other stations ($P<0.05$). Nitrite-nitrogen concentration (0.046 mg/L) at Pm was significantly higher than all the other tributaries ($P<0.001$) except Bu. The highest mean nitrate-nitrogen (0.133 mg/L) was observed at Bj and it was significantly higher than Da and Pe ($P<0.05$).

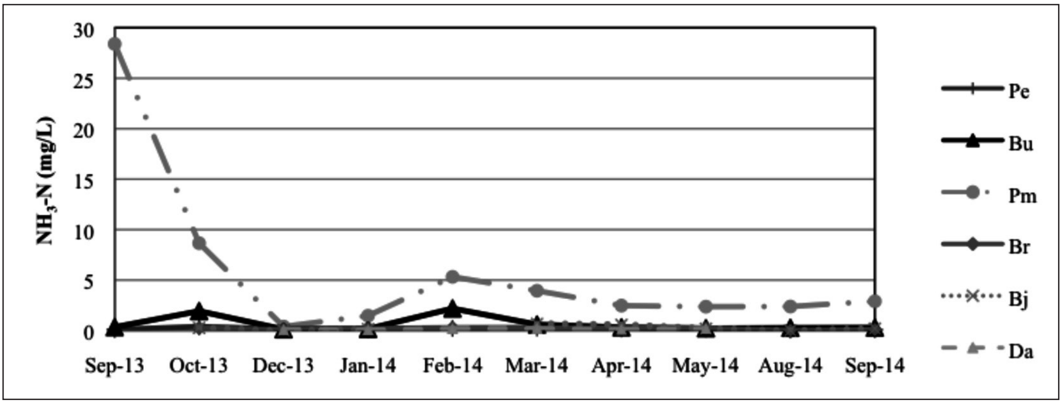

Figure 5: Ammoniacal-nitrogen (NH3-N) of the Six Tributaries Over the Sampling Period

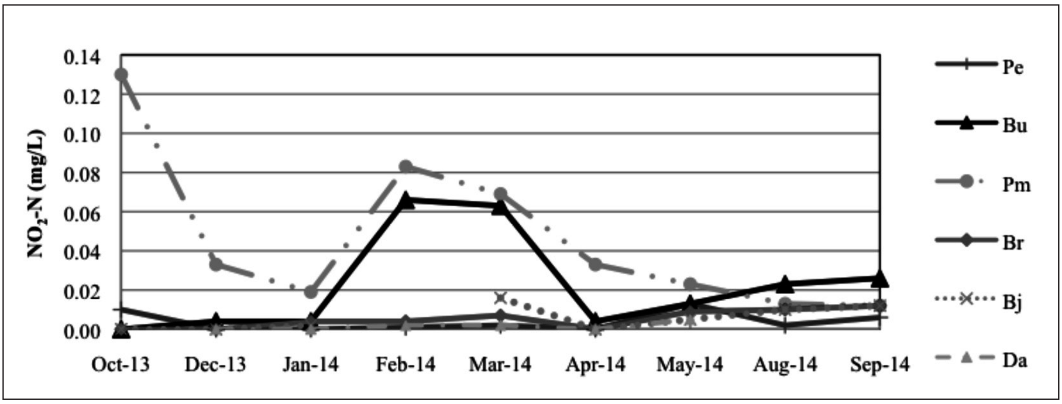

Figure 6: Nitrite-nitrogen (NO2-N) of the Six Tributaries Over the Sampling Period

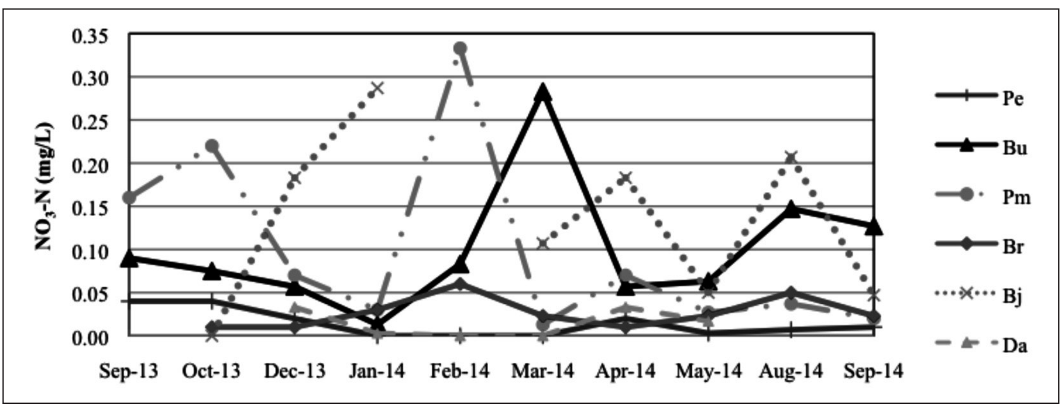

Figure 7: Nitrate-nitrogen (NO3-N) of the Six Tributaries Over the Sampling Period

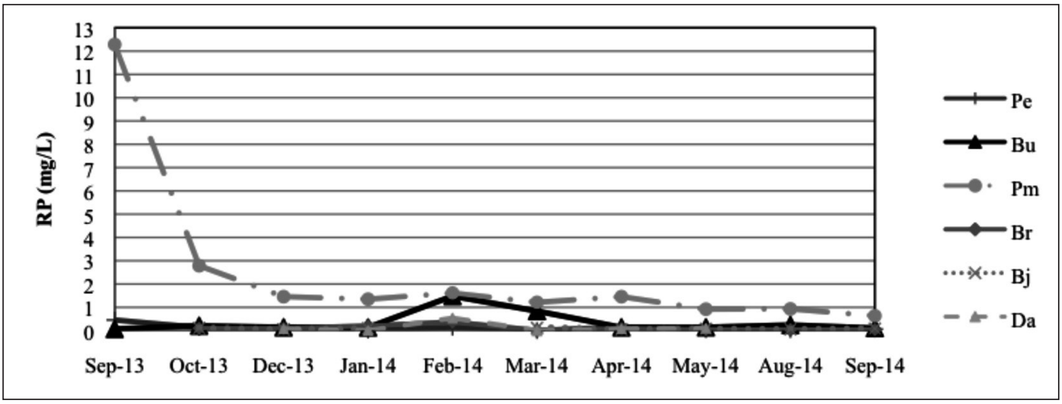

Figure 8: Soluble Reactive Phosphorus (RP) of the Six Tributaries Over the Sampling Period

The lowest TSS concentrations were recorded during August and September 2010 (Table 3) when the water level was low. In March 2010, the highest TSS level was observed at Bj (84.4 mg/L) followed by Br (22.9 mg/L). For Pm and Bu, TSS concentration were the highest in December 2009 (40.0 mg/L) and October 2009 (37.0 mg/L) respectively where water levels were also low. Overall, the mean TSS concentrations of the tributaries varied from 7.4 mg/L at Pe to 16.5 mg/L at Bj and Pm (Table 2).

The BOD_5 concentrations in each month are tabulated in Table 4. In general, the studied site exhibited higher BOD_5 values in October 2009, December 2009, February 2010 and March 2010 than other months. The highest BOD_5 concentration was observed at Pm (20.7 mg/L) in March 2010. Overall, the mean BOD_5 concentrations ranged from 8.5 mg/L at Da to 12.5 mg/L at Pm. The highest value at Pm was followed by Bu (11.8 mg/L) and Pe (10.5 mg/L) (Table 2).

Table 3: Total Suspended Solids (TSS) During the Sampling Period

Station	Oct-09	Dec-09	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Aug-10	Sep-10
Pe	10.67 ± 0.58[b]	14.71 ± 4.16[a]	3.81 ± 1.71[a]	14.60 ± 6.10[a]	3.46 ± 1.90[a]	3.81 ± 1.71[a]	5.26 ± 3.36[a]	2.28 ± 0.27[a]	8.30 ± 1.26[a]
Bu	37.00 ± 1.00[d]	13.33 ± 4.71[a]	23.78 ± 7.75[c]	17.67 ± 7.99[a]	3.27 ± 2.08[a]	23.78 ± 7.75[c]	2.21 ± 1.67[a]	2.00 ± 0.20[a]	9.00 ± 1.61[a]
Pm	28.67 ± 3.51[c]	40.00 ± 0.00[b]	15.33 ± 2.69[bc]	25.47 ± 9.36[a]	8.98 ± 1.79[ab]	15.33 ± 2.69[bc]	1.62 ± 3.03[a]	8.00 ± 2.08[a]	5.30 ± 2.18[a]
Br	25.67 ± 2.27[c]	9.02 ± 8.04[a]	17.95 ± 2.41[bc]	9.00 ± 9.20[a]	22.92 ± 12.15[b]	17.95 ± 2.41[bc]	17.64 ± 1.89[a]	13.00 ± 3.75[a]	2.63 ± 0.80[b]
Bj	3.50 ± 0.79[a]	8.33 ± 2.36[a]	6.53 ± 0.39[ab]	Dry	84.44 ± 16.14[c]	6.53 ± 0.39[ab]	11.15 ± 8.61[a]	6.00 ± 0.39[a]	5.90 ± 1.85[a]
Da	Dry	6.19 ± 4.71[a]	6.13 ± 5.95[ab]	43.22 ± 18.36[a]	24.98 ± 3.70[b]	6.13 ± 5.95[ab]	3.40 ± 2.44[a]	Dry	Dry

Table 4: BOD_5 of the Sampling Stations During the Sampling Period

Station	Sep-09	Oct-09	Dec-09	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Aug-10	Sep-10
Pe	14.82 ± 0.07^{ab}	16.00 ± 0.09^{ab}	12.89 ± 0.16^{a}	5.26 ± 0.20^{b}	13.31 ± 0.32^{c}	10.79 ± 0.35^{a}	6.62 ± 0.25^{cd}	10.46 ± 0.15^{c}	5.71 ± 0.13^{a}	3.75 ± 0.67a
Bu	14.01 ± 0.24^{a}	17.03 ± 0.09^{ab}	13.95 ± 0.05^{d}	6.17 ± 0.10^{b}	13.95 ± 0.52^{a}	12.54 ± 0.14^{abc}	7.28 ± 0.15^{d}	12.50 ± 0.17^{a}	10.45 ± 0.06^{c}	5.19 ± 0.17^{b}
Pm	15.88 ± 0.06^{b}	17.72 ± 0.71^{a}	15.05 ± 0.14^{e}	11.10 ± 0.23^{c}	19.26 ± 0.27^{b}	20.73 ± 0.37^{d}	6.42 ± 0.47^{a}	7.47 ± 0.69^{d}	3.16 ± 0.17^{d}	3.04 ± 0.31^{d}
Br	NA	16.22 ± 0.24^{a}	13.61 ± 0.44^{d}	4.01 ± 0.16^{a}	12.95 ± 0.34^{c}	12.13 ± 0.98^{ac}	5.97 ± 0.04^{b}	10.79 ± 0.57^{c}	6.29 ± 0.15^{b}	4.71 ± 0.33^{b}
Bj	NA	13.61 ± 0.33^{b}	12.62 ± 0.13^{ac}	5.61 ± 0.43^{b}	Dry	12.98 ± 0.20^{bc}	7.07 ± 0.05^{d}	8.73 ± 0.08^{b}	6.93 ± 0.15^{b}	7.20 ± 0.43^{c}
Da	NA	Dry	6.24 ± 0.91^{b}	3.69 ± 0.16^{a}	12.51 ± 0.12^{c}	13.63 ± 0.53^{b}	6.48 ± 0.04^{bc}	8.38 ± 0.36^{b}	Dry	Dry

*Means within a column followed by the same letters are not significantly different at 5% level.

Discussion

Both Bu and Pm received effluent from animal farms. As a result, the trends of water quality at those tributaries were similar, the difference being the concentrations of each parameters. In September of 2009, in spite of the high water level which would mean high dilution, Pm tributary showed low dissolved oxygen, high TSS and BOD_5, extremely high nutrients such as ammoniacal-nitrogen, nitrite-nitrogen and reactive phosphorus. The poor water quality in September 2009 where the samples were collected at 12:30 pm from this tributary was consistent with the report of Ling *et al.,* (2008) as the results of hourly sampling conducted at Pm tributary showed that the poorest water quality in terms of dissolved oxygen and *E. coli* count was recorded at 12:30 pm and 1:30 pm as it coincided with the daily cleaning of animal pens and bathing of animals which led to the overflow from the overloaded oxidation pond to the receiving river. In January 2010 and May 2010, Pm and Bu tributaries showed higher dissolved oxygen and lower nitrogen forms due to higher dilution as the water level were high due to heavy rain the day before sampling. In February 2010, there were no rainfall two days before sampling and water level was very low. As a result, there was less dilution and this explained the low dissolved oxygen and high concentrations of TSS, BOD_5, ammoniacal-nitrogen, nitrite-nitrogen, nitrate-nitrogen, and reactive phosphorus at both Pm and Bu. Even though there was a spike of nitrate-nitrogen together with ammoniacal-nitrogen, 92.7% and 93.6% of total inorganic nitrogen at Pm and Bu respectively was still in the form of ammoniacal-nitrogen indicating the lack of oxygen for its oxidation to nitrite-nitrogen and nitrate-nitrogen. Pm and Bu showed the highest mean TSS values in December 2009 and October 2009 respectively due to the discharge of effluent coupled with low dilution. Pm and Bu tributaries showed high TSS, $BOD_{5,}$ mean ammoniacal-nitrogen, nitrite-nitrogen and reactive phosphorus as animal farm wastewater have been found to be low in dissolved oxygen (0.2 mg/L), high in BOD_5 (120-210 mg/L) and high in total nitrogen (200-340 mg/L) (Ling *et al.*, 2007) and Ainon *et al.,* (2005) reported TSS levels of 135.7-214.3 mg/L at the discharge points of modern and traditional pig farms. In addition, animal farm effluent presents itself mainly in ammoniacal-nitrogen and organic-nitrogen forms, often in equal ratios (Hooda *et al.,* 2000; Wang *et al.,* 2004). Ammonia is oxidized quickly by nitrifying bacteria only if adequate oxygen is present (Stone *et al.,* 1998). However, the low dissolved oxygen level at Pm is insufficient for complete nitrification process to occur (Yang *et al.,* 2007). Thus, Pm recorded the highest amounts of ammoniacal-nitrogen and nitrite-nitrogen among the tributaries. According to Chadwick & Chen (2002), excess of inorganic phosphorus was present in animal feed, and thus, was excreted in manures in significant quantities, some of which was in organic forms. In addition, dietary phosphorus supplements are added to livestock feed in order to promote growth, productivity and fertility (Leinweber *et al.,* 2002) and the optimum digestible phosphorus is 0.12-0.26% dry matter (Nagera *et al.,* 2008). In terms of dissolved oxygen, Pm had significantly lower mean dissolved oxygen level ($0.001<P<0.044$) than other tributaries and 50% of the levels were below 3 mg/L (Class IV) of NWQS due to the high organic matter evidenced by the BOD_5 which fell in Class V 50% of the sampling months. Based on a research on oxidation ponds water quality in an animal farm upstream of Pm, the dissolved oxygen concentration of effluent discharged was reported to be between 1.30 mg/L and 2.30 mg/L (Ling *et al.,* 2007). This result was concordant with previous studies conducted by (Ling *et al.*, 2006; 2010), which reported the lowest dissolved oxygen concentration at this farm effluent receiving tributary. The low dissolved oxygen value was due to microbial consumption of dissolved oxygen in the degradation of excessive organic matters and transformation of nutrients in the river (Ling *et al.*, 2006; Ainon *et al.,* 2006). For Pm tributary, compared to results of previous studies in Ling *et al.,* (2010), the present study shows higher mean ammoniacal-nitrogen and nitrate-nitrogen concentrations. This is probably due to the more comprehensive investigation carried out in the present study which covered different months of the year, both dry and wet months.

Over the sampling period, the monthly temperature at Pe was the highest among the tributaries occasionally as the stagnant water retained for fish aquaculture was heated by solar radiation which translates to higher temperature. In addition, pH at Pe were frequently the highest among tributaries including the highest pH value that occurred in dry month of September 2010. These are contributed by higher algal photosynthesis in the lentic system. There was relatively constant dissolved oxygen at Pe from December 2009 to September 2010 as there is less reaeration for the stagnant water than flowing streams. BOD_5 at Pe was mainly due to the excess fish feed and excretion of fish cultured. Compared to results of previous studies in Ling *et al.* (2010) in Pe, the present study shows higher mean ammoniacal-nitrogen and nitrate-nitrogen concentrations.

Upstream at Br, large land areas are utilized for padi and oil palm plantation (Figure 1). In addition, there are some villages in the watershed. Those land use affected the water quality of that tributary. Overall mean ammoniacal-nitrogen was higher than Pe and reactive phosphorus higher than Bj. Dissolved oxygen in Br was the lowest among stations in May 2010. In October 2009 where water level was low, pH at Br was below 6.5; BOD_5 was significantly higher than Bj but not significantly different from Pm, Bu and Pe and TSS was not significantly different from Pm due to organic matter and nutrients. Sources of nutrients are the fertilizers used at padi and oil palm plantations. In addition, organic matter and nutrients are also contributed by the villages in the watershed where household wastewater and partially treated effluent were discharged into the river. Household wastewater contains high organic matter and nutrients (Ling *et al.,* 2010; 2012) and the end products of decomposition of organic matter and nitrification-denitrification transformation process leads to acidification and lowered pH values (Sumagaysay-Chavoso *et al.*, 2004; Ling *et al.,* 2010). In spite of the extensive land use in this watershed, the dissolved oxygen were above 5 mg/L except for two months and nutrients concentrations were not the highest due to the large reaeration and large dilution due to its large discharge.

The highest mean nitrate-nitrogen was observed at Bj where there were agricultural activities and a newly operated poultry farm upstream. The higher dissolved oxygen concentration at this tributary indicates that dissolved oxygen was available for nitrification to occur and hence the higher nitrate-nitrogen concentration. In March 2010, though low water level, the highest TSS level among stations was observed at Bj followed by Br because rainfall coincided with sample collection at those stations and thus eroded solids transported in runoff to the rivers led to the high values. Pe showed the lowest TSS because with still water of the dam, the suspended particles had enough time to settle out as sediment (Nathanson, 1986).

In terms of compliance with the NWQS, for pH, all tributaries complied with Class II throughout the sampling period. However, for dissolved oxygen, Da is the only tributary that complied with Class II throughout the sampling period. For Pm, it only complied 20% of the time and for Bu, the compliance was 50% of the time. For other tributaries, during dry months, they violated the Class II standard of 5-7 mg/L in dissolved oxygen. For ammoniacal-nitrogen, Pm violated the Class II standard and Bu occasional violated the Class II standard. For nitrite, only Pm violate the Class II standard once, that is, September 2009. All the other months in Pm and also in other tributaries nitrite complied with Class II. For nitrate, all tributaries complied with Class II standard. For phosphorus, Pm violated the Class II standard of 0.2 mg/L throughout the sampling period; Bu violated during February, March and August of 2010; Da and Br violated the Class II standard during February 2010. The TSS levels of all studied tributaries were classified under Class I and IIA/IIB of NWQS except at Bj in March 2010 which falls in Class III. For BOD_5, all stations exceeded Class II NWQS with 60%, 50%, 44%, 40% of Bu, Pm, Br and Pe readings respectively classified in Class V (>12 mg/L).

Conclusion

This study shows that both land use and rainfall are important factors affecting the water quality in the tributaries studied. It was observed that the concentrations of nutrient parameters were high during low water levels when there was no rain for two days prior to sampling trip. Among the six tributary river mouths, Pam and Bukah tributaries with animal farms in the watershed showed frequent low dissolved oxygen and high ammoniacal-nitrogen levels. BOD_5 values ranged from 3.04-20.73 mg/L with the highest value observed at Pam River during low water level. With large scale agriculture such as oil palm and padi and wastewater from villages, Bukar River water showed occasional low dissolved oxygen and low pH. Dara River mouth showed the lowest mean inorganic nitrogen and BOD_5.

Acknowledgements

The authors appreciate the financial support provided by the Malaysian Ministry of Science, Technology and Innovation (e-Sci Grant No. 06-01-09-SF0026) and Ministry of Higher Education (Grant No. FRGS/07(02)/749/2010(35) and the facilities provided by Universiti Malaysia Sarawak.

References

Ainon, H., Mohd Jefrin Azlan A. & Ling, T. Y. (2006). Comparison of Modern and Traditional Pig Wastewater Treatment in Serian, Sarawak. *Malaysian Applied Biology,* 34(2): 75-82.

APHA. (1998). *Standards Methods for the Examination of Water and Wastewater.* (20th ed.). American Water Works Association and Water Environment Federation, Washington D. C, USA: American Public Health Association.

Chadwick, D. R. & Chen, S. (2002). Manures. *In:* P. M. Haygarth and S. C. Jarvis (eds.) *Agriculture, Hydrology and Water Quality,* New York: CABI Publishing. 106-129.

Hach. (2000). *Manual for Hach Spectrophotometer DR2010*. USA: Hach Company.

Hooda, P. S., Edwards, A. C., Anderson, H. A. & Miller, A. (2000). A Review of Water Quality Concerns in Livestock Farming Areas. *The Science of the Total Environment,* 250: 143-167.

Leinweber, P., Turner, B. L. & Meissner, R. (2002). Phosphorus. *In:* P. M. Haygarth and S. C. Jarvis (eds.) *Agriculture, Hydrology and Water Quality,* New York: CABI Publishing. 29-56.

Ling, T. Y., Layang, H. W. & Apun, K. (2008). Water Quality Variations and Decay Rates of *E. coli* in Water and Sediment of the Serin River. *Proceedings of the 10th MSAB Symposium, Kuching*. 108-111.

Ling, T. Y., Layang, H. W., Then, Y. P. & Apun, K. (2006). Impacts of Pig Farming on the Water Quality of Serin River, Sarawak. *Sains Malaysiana,* 35(1): 45-50.

Ling, T. Y., Liew, C. F. & Modingin, A. (2007). Optimization of Oxidation Pond Efficiency in Animal Farm Wastewater Treatment. *Journal of Engineering Science,* 3: 51-61.

Ling, T. Y., Srikaran, R., Kho, C. P. & Nyanti, L. (2010). Organic Matter, Nutrients and Trace Metals of Serin River. *World Applied Sciences Journal*, 8(4): 496-502.

Ling, T. Y., Dana, M. J., Bostam, S. & Nyanti, L. (2012). Domestic Wastewater Quality and Pollutant Loadings from Urban Housing Areas. *Iranica Journal of Energy & Environment*, 3(2): 129-133.

Ling, T. Y., Lim, S.W., Lesley, M. B. & Nyanti, L. (2013). Impact of Different Land Uses on the *Escherichia coli* Concentrations, Physical and Chemical Water Quality Parameters in a Tropical Stream. *Borneo Journal of Resource Science and Technology,* 2(2): 34-43.

Ling, T. Y., Siew, T. F. & Nyanti, L. (2010). Quantifying Pollutants from Household Wastewater in Kuching, Malaysia. *World Applied Sciences Journal,* 8(4): 449-456.

Nagera, H., Somiya, I. & Fujii, S. (2008). Influence of the Short-period Disturbance on Phosphorus Concentration in Lake Biwa, Japan. *Proceedings of Taal 2007: The 12th World Lake Conference*. 231-236.

Nathanson, J. A. (1986). *Basic Environmental Technology: Water Supply, Waste Disposal and Pollution Control.* New Jersey: Regents/Prentice Hall, 135.

Sabater, S., Armengol J., Comas E., Sabater F., Urrizalqui I. & Urrutia I. (2000). Algal Biomass in a Disturbed Atlantic River: Water Quality Relationships and Environmental Implications. *The Science of the Total Environment,* 263: 185-195.

Stone, K. C., Hunt P. G., Humenik F. J. & Johnson M. H. (1998). Impacts of Swine Waste Application on Ground and Stream Water Quality in an Eastern Coastal Plain Watershed. *American Society of Agricultural Engineers,* 41(6): 1665-1670.

Sumagaysay-Chavoso, N. S., Diego-McGlone M. L. S. & David, L. T. (2004). Environmental Capacity of Receiving Water as Basis for Regulating Intensity of Milkfish (*Chanos chanos Forsskal*) Culture. *Journal of Applied Ichthyology,* 20: 476-487.

Wang, H. L., Magesan G. N. & Bolan N. S. (2004). An Overview of the Environmental Effects of Land Application of Farm Effluents. *New Zealand Journal of Agricultural Research,* 47: 389-403.

Winemiller, K. O., Agostinho, A. A. & Caramaschi, E. P. (2008). Fish Ecology in Tropical Streams. *In*: D. Dudgeon (ed.) *Tropical Stream Ecology*, London: Academic Press. 107-140.

Yang, H. J., Shen Z. M., Zhang J. P. & Wang, W. H. (2007). Water Quality Characteristics along the Course of the Huangpu River (China). *Journal of Environmental Sciences,* 19: 1193-1198.