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Spatial and Temporal Variations of Heavy Metals in a Tropical River

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Abstract: Previous water quality assessment conducted at the Serin River identified human and agricultural activities, especially livestock farming as the main sources of pollution. However, the number of stations studied was limited. In view of the use of the river water for various domestic purposes such as drinking water supply, heavy metals status in the river water was assessed at twelve stations in ten samplings trips. The results show that the mean concentrations of heavy metals in the river water followed the sequence of Fe>Zn>Pb>Cu>Cd. Rainy month led to an increase in heavy metals and it was associated with agriculture and animal farms. Thus, it indicates contributions from fertilizers in runoff and overflow of oxidation ponds. In addition, an increase in lead indicates vehicular contributions. Tributaries have higher heavy metals concentrations but had minimal impact on the main river due to dilutions. Near the water intake station, chromium, cadmium and lead occasionally exceeded the WHO drinking water guideline.

Key words: Heavy metals · Serin river · Animal farming · Agricultural activities · Road runoff

INTRODUCTION

One of the current issues of public concern is heavy metals contamination of soil and water as heavy metals are detrimental to health when they are in excess [1]. Various activities and processes have lead to heavy metals contamination. Discharge from municipal wastewater treatment plant, accelerated industrial activities, atmospheric deposition, as well as rapid agricultural development and/or non-point source runoff containing pesticides and fertilizers were reported to be the main culprits of heavy metal pollution in rivers [2-4]. Excessive inputs of trace metals, especially cadmium copper and zinc due to poor management practices from agricultural activities accelerated the leaching of metals to ground and surface waters, thus deteriorating its water quality and affecting aquatic organisms [5]. Heavy metals could cause poisoning in aquatic organisms, even when the exposure is low [6, 7]. Due to their persistence and through bioaccumulation and food chain, human beings are potentially affected. Amongst trace metals, cadmium, lead and mercury are of great concern due to their acute and chronic poisoning effects [5]. Excess intake of cadmium and mercury can cause itai itai and minamata diseases respectively [7].

The Serin River, is located at Samarahan division of Sarawak state in Malaysia. Its water quality was a concern as local inhabitants use the river for many purposes such as bathing, laundry, fishing, crop irrigation, aquaculture as one of the village development projects and the most important of all, a source of drinking water. However, the river receives wastewater from different land and water uses such as aquaculture and animal farming. As such contamination of river water could occur through both point and non-point sources. Animal farm wastewater is well-known to contain various hazardous heavy metals, commonly copper, zinc and lead [8]. According to Ling *et al*. [9], the concentration of heavy metals in feed and manure were correlated and they were in decreasing order of Cu>Zn>Cr>Pb>Ni>Cd. After oxidation pond treatment, the trend was Cr>Zn>Cd>Pb>Ni>Cu with low concentration of less than 0.9 mg/L and 0.1 mg/L for Cr and all other trace metals respectively, but Cd concentration exceeded the limit of standard for wastewater discharge into receiving water proposed by Malaysian Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979. Previous studies conducted by Ling *et al*. [10] at the Serin River and some of the tributaries showed that trace metals were detected. However, only three tributaries were studied and the

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study only covered a few months of the year. As human contact and the demand of the river water for drinking, domestic, industrial and irrigation are increasing in the basin, it is therefore important that a more comprehensive study be conducted to monitor the heavy metals concentration in that river. Hence, the objective of the present study was to determine the concentration of heavy metals over rainy and dry months.

MATERIALS AND METHODS

Study Site and Sampling: The sampling stations at the Serin River were shown in Figure 1. Samplings were conducted from headwater (S1) to the Batang Samarahan (S6). Six stations were located on the Serin River and six stations on its tributaries. The tributaries were investigated as they might be the channel or source of contaminants. The descriptions of the twelve sampling stations are listed in Table 1.

Laboratory Analysis: Ten sampling trips were carried out from September 2009 to September 2010. Water samples for heavy metals analysis were collected in 1 L glass bottles and acidified with 65% concentrated nitric acid to pH less than 2 at the field. All sample bottles were placed in cooler boxes with ice at approximately 4°C. Analysis of water samples were carried out within two weeks. The water samples were filtered using 0.45 μm glass fiber filters

Table 1: Descriptions of the twelve sampling stations.

Station	Description
S1	This is the farthest upstream station of the Serin River where a village is located nearby. The villagers carried out their daily routine, such as bathing and laundry at the river.
S2	The villagers fishing at this station.
S3	Downstream of water abstraction for drinking purpose. A bridge is located nearby.
S4	Some solid domestic wastes disposed of at the station, for example, used diapers, plastics, glass bottles and car tyres and electronic wastes, such as television and computer monitor.
S5	Downstream of a large tributary, the Bukar River.
S6	Next to the Kuching-Serian highway and a densely populated housing area along the river. Small speed boat is one of the means of transportation of the villagers.
Pe	Blocked by the villagers for fish aquaculture.
Bu	Crop farming was carried out along this tributary.
Pm	Received effluent from a pig farm.
Br	Located next to moderate-traffic-volume roadside.
Bj	A newly operated chicken farm was located upstream. This tributary dried up during February 2010.
Da	A small tributary of Serin River without any specific landuse. This tributary dried up during August and September of 2010.

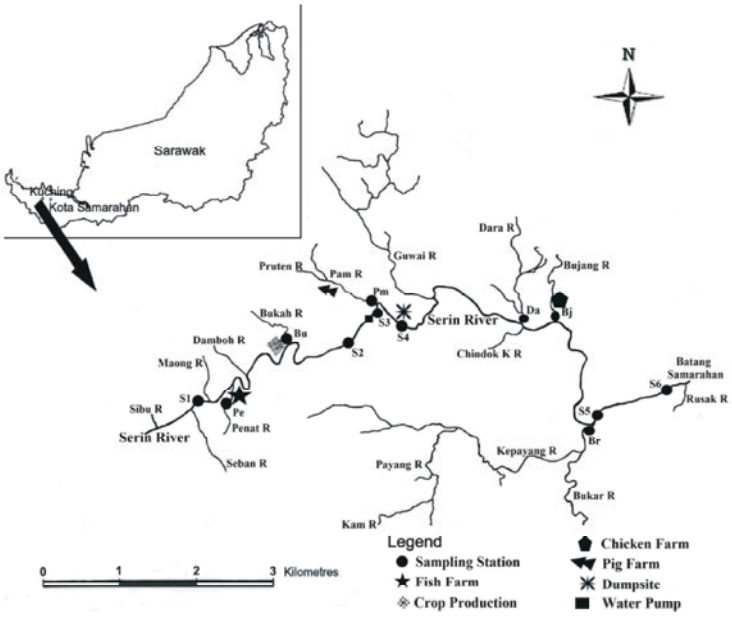

Fig. 1: Sampling stations on Serin River and human activities in the watershed

(Advantec, Japan) before analysis. Acidified samples of 100 mL were added with 1% of concentrated HNO_3 (approximately 1.5 ml) in 100 mL volumetric flask [11]. Lastly, the solution was analyzed for Cd, Cr, Cu, Zn, Pb and Fe using an atomic absorption spectrophotometer (Thermo Scientific, AAS iCE3500) after calibration with respective standard solution of 0 mg/L, 2 mg/L, 4 mg/L and 6 mg/L. Each sample was analyzed in triplicates and readings in average were automatically determined.

Statistical Analysis: Univariate analysis of variance was conducted to find possible differences in heavy metals concentrations among sampling stations. Tukey's method was used for multiple comparisons. Statistical analyses were performed using SPSS version 17.0.

RESULTS AND DISCUSSION

The monthly trends of different heavy metals concentrations in the river water were illustrated in Figures 2 to 7, while the overall mean concentration, standard deviation and range of heavy metals were summarized in Table 2. In general, the relative abundance of heavy metals in Serin River was in decreasing order of Fe>Zn>Cr>Pb>Cu>Cd.

The monthly Cr levels of most sampling stations increased from February 2010 and achieved maximum concentrations during May, August and September 2010 (Fig. 2a and 2b). This is most probably due to the fact that under aerobic condition, hexavalent chromium, which is soluble in water, is the most prevailing form in water at pH values above 7 as pH of those months ranged 7.04 to 7.68 [12]. The highest overall mean Cr concentration (0.085 mg/L) was observed at Bu (Table 2). The application of inorganic fertilisers on the crop farms, particularly phosphate fertilisers, contributed to the high Cr content at this station. The mean Cr concentration of this station exceeded the permissible limit of WHO drinking water guideline (0.05 mg/L). The monthly sampling data indicated that the Cr concentrations of Bu were high and violated the WHO guideline on most of the sampling months except October and December of 2009 and January of 2010 (Fig. 2b). A possible explanation for the low Cr concentrations on these months could be at pH above 6 as recorded on these months (6.79, 6.80 and 6.35 respectively), most soluble trivalent chromium compounds precipitated as insoluble chromium (III) hydroxide [12]. However, S2, the downstream station of Bu, was not impacted due to dilution of the small loading. As shown in Table 2, the mean Cr levels of most of the sampling stations, for instance, S1 (0.062 mg/L), S3 (0.073 mg/L), S4 (0.063 mg/L), Pe (0.059 mg/L), Pm (0.051 mg/L), Br (0.057 mg/L) and Bj (0.075 mg/L) exceeded the WHO recommended value. The runoff of detergents and paints on buildings at S1, brake pads on vehicles from S3 and Br with moderate traffic volume, magnetic storage

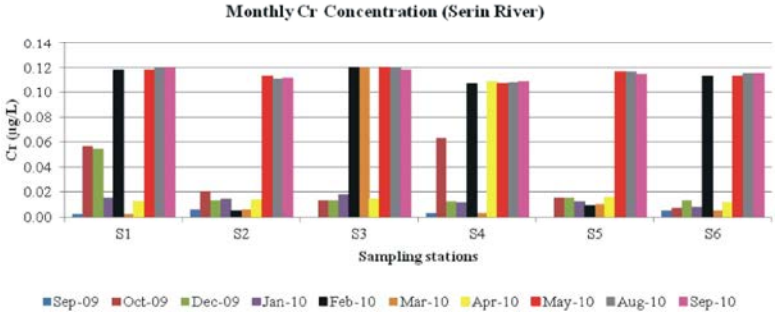

Fig. 2a: Cr concentrations of Serin River during sampling period

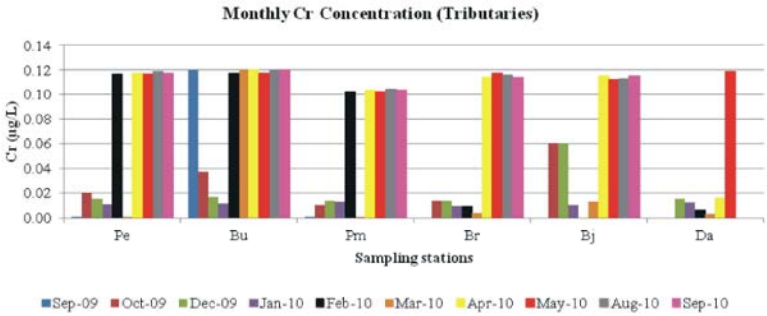

Fig. 2b: Cr concentrations of tributaries of Serin River during sampling period

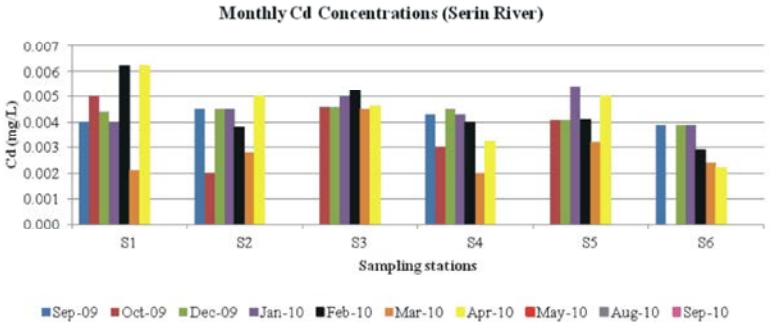

Fig. 3a: Cd concentrations of Serin River during sampling period

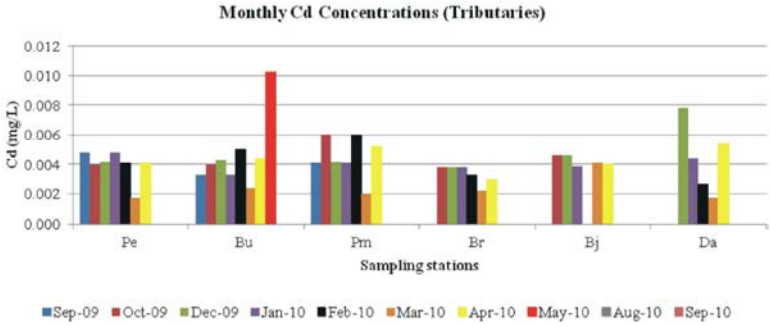

Fig. 3b: Cd concentrations of tributaries of Serin River during sampling period

media for computers at S4, the unconsumed fish feed at Pe as well as discharges of animal farming at Pm and Bj contributed to the high Cr concentrations at these stations [12-15].

The monthly Cd concentrations of all sampling stations were in the range of 0.002 mg/L-0.006 mg/L from the beginning of the sampling month to April 2010, with the exception of high Cd concentration observed at Bu (0.010 mg/L) in May 2010 and Da (0.0078 mg/L) in December 2009 (Fig. 3a and 3b). The marked increase of Cd level of Bu on May 2010 indicated the surplus of soluble Cd in water due to fertiliser runoff although the pH was above 7 (pH 7.21). Besides, high Cd levels that violated the permissible limit of WHO guideline for drinking water (0.003 mg/L) were also observed in October and December of 2009; February, April and May of 2010 at Bu; and in January and April of 2010 at Da. The trend of Cd levels of Da followed that of S4. The possible explanation for this could be the contributions from its upstream station, S4. Deposition of Cd-containing waste, such as plastics and electronic equipments can lead to mobilization of Cd by leaching resulting in the contamination of the downstream station, Da [16]. Therefore, this contributed to the overall mean Cd concentration at Da, as high as at Bu (0.004 mg/L) (Table 2). However, Cd was not detectable at all sampling stations during May, August and September of 2010 (Fig. 3a and 3b). Dojlido and Best [15] reported that Cd is readily precipitated as carbonate or adsorbed onto particulate matter and incorporated into bottom sediments. At pH above 7, practically all the ions of the metal will be adsorbed. This could explain why concentrations of Cd were very low on those months. Bu showed the highest overall mean Cd level (0.004 mg/L) (Table 3b). As stated earlier, this might due to the inorganic fertilisers, particularly phosphate fertilisers applied on crop farms [5, 17]. This is further supported by Nair *et al*. [18] who reported that runoff from agricultural soil was the possible source of contamination of Cd due to the fact that Cd is a common impurity found in phosphorus fertilisers. The mean Cd level at Bu and Da were above the WHO recommended limit. Nonetheless, the downstream station of Bu, S2, was not significantly affected due to the small loading. The overall mean Cd content at S2 (upstream of drinking water intake) and S3 (downstream and near drinking water intake), were both 0.003 mg/L and thus, must be controlled to preserve its water quality.

As shown in Figures 4a and 4b, the Cu concentrations of all sampling stations exhibited similar trend throughout the sampling period with the exception of S2 and Pm. Cu introduced into a river system is rapidly incorporated into the sediment near the source [15]. This explains the low Cu levels recorded. One of the possible

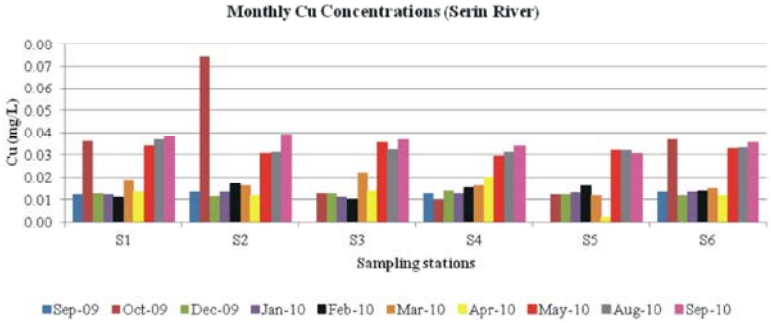

Fig. 4a: Cu concentrations of Serin River during sampling period

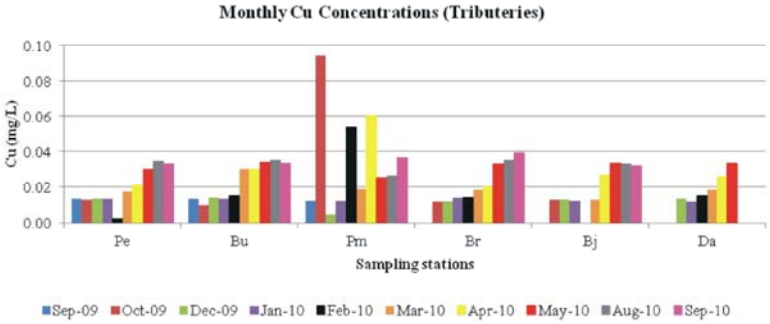

Fig. 4b: Cu concentrations of tributaries of Serin River during sampling period

explanations for the spikes can be this metal reached river through flushing from various point and non-point sources at the onset of high rainfall period. Dojlido and Best [15] stated that higher Cu concentrations are usually associated mainly with the discharge of wastewater. Therefore, the elevated Cu concentrations observed at Pm were most probably due to the overflows of lagoons during high rainfall period, which discharged surplus wastewater into receiving river [10]. Pm had the highest overall mean concentration of Cu (0.040 mg/L) (Table 2). This is consistent with other rivers of Malaysia exposed to pig farm effluent where high Cu concentration has been reported [19]. Furthermore, Nicholson *et al*. [17] stated that pig slurry contains the highest Cu concentration whilst Ling *et al*. [9] demonstrated that the highest Cu concentration was found in the pig feeds and manures compared to other trace metals. Cu are normally introduced to animal feed or given as diet supplementation as growth promoter [20]. Consequently, animal faeces or urine contains high concentrations of Cu [8, 21]. However, the small loading from Pm impacted the water quality of the downstream station, S4, minimally. As shown in Figures 4a and 4b, during the spikes of October 2009, February 2010 and April 2010 at Pm, the Cu concentrations recorded at S4 were higher than S3 in February 2010 and April 2010. The Cu levels recorded throughout sampling period were below the permissible limits in accordance to WHO guideline for drinking water (2 mg/L). Thus, there is no detrimental effect when the water is used for drinking water supply at the level obtained in this study.

The Fe levels of the sampling stations were found to fall mostly below 0.7 mg/L and three tributaries (Pe, Bu and Pm) showed the highest mean Fe concentrations (Fig. 5a and 5b). However, some stations studied showed elevated concentrations on October 2009 and April 2010. The elevated results showed at S6, Pe and Bu in October 2009 most likely due to the onset of high rainfall period, as discussed earlier. Rainfall would contribute to contaminations, by surface runoff contributions [22]. Furthermore, rainfall contributed to the overflows of lagoons, resulting in the elevated Fe level at Pm [10]. As noted earlier, the high concentration of Fe observed at Da during April 2010 might due to the contributions of S4 as it showed high Fe level at the same month. The discarded domestic wastes are likely the major sources of Cd and Fe [14]. The highest overall mean Fe concentration was found at Pm (0.379 mg/L) (Table 2). As discussed earlier, trace metals are used as feed additives or diet supplement to prevent deadly diseases and to promote growth. Hence, it is not surprising that high Fe content was found at Pm. The corresponding increase in Fe levels at S4 when there was an increase in Fe concentrations at Pm indicated possible contributions from Pm (Fig. 5a and 5b). Besides,

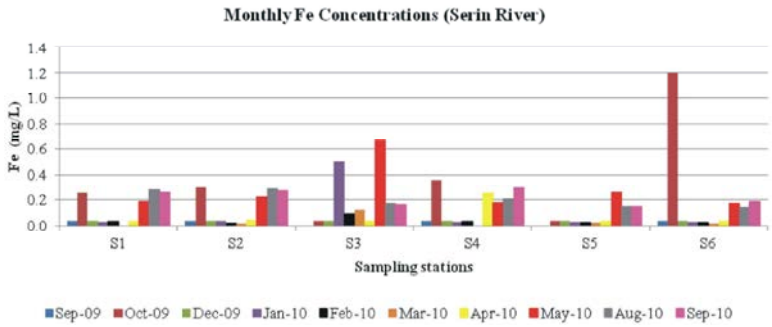

Fig. 5a: Fe concentrations of Serin River during sampling period

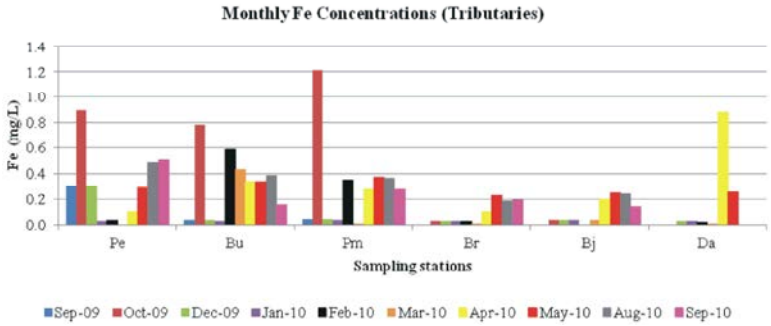

Fig. 5b: Fe concentrations of tributaries of Serin River during sampling period

the high overall mean Fe levels also showed at Bu (0.353 mg/L) where high readings were recorded throughout the sampling period, except September 2009, December 2010, January 2010 and September 2010, as well as Pe (0.348 mg/L), which showed high Fe concentrations on October 2009, August 2010 and September 2010 (Table 2 and Fig. 5b). The high mean Fe concentrations at Bu and Pm could be due to the fact that livestock waste contains valuable plant nutrients and other micronutrients such as Mg, Ca, Mn, Fe and Zn. It is usually used in agricultural activities to increase soil fertility and ability to hold water. Furthermore, it is also used as a source of fish feed [21]. The loadings from Bu and Pe affected the water quality of the downstream staion, S2, in most of the months studied in where the monthly Fe concentrations recorded at S2 were higher than that of S1 (Fig. 5a). However, the contributions were not significant due to the small loadings and it depends mostly on rainfall event. According to the latest WHO standard, there is no proposed guideline value for Fe in drinking water as it is an essential element in human nutrition.

As shown in Figures 6a and 6b, the concentrations of Zn of the stations throughout sampling period fall in the range of 0.005 mg/L-0.200 mg/L, except S4 in August 2010. Furthermore, Pe, Bu and Pm tributaries showed higher overall concentrations than Br, Bj and Da, the lowest in overall mean Zn concentration (Table 2). Discarded batteries, old tyres, glasses, fabrics and plastics contain Zn compounds that can dissolve and release Zn in water [13, 23]. Besides, animal waste has very high zinc content, in the same magnitude as Cu [9]. S4, being downstream of all these waste, could have Zn accumulated in the sediment as shown by Ling *et al*. [24]. The high variation in concentrations observed at S4 could be due to the impact of pH on the solubility of Zn [25] as this station received inflow of lagoon effluent which could be acidic as reported by Ling *et al*. [26] and this influence was not found at other stations upstream. Generally, higher Zn levels were observed across sampling stations during May 2010, August 2010 and September 2010 (Fig. 6a and 6b). It is due to Zn salts that hydrolyse with the formation of more soluble zincate ion, $[Zn(OH)_4]^{2-}$ at pH 7-7.5 as pH of those months ranged 7.04 to 7.68 [15]. Pe, a fish aquaculture station, had the highest overall mean Zn value (0.112 mg/L) (Table 2). The high Zn concentration observed at Pe reflects dietary supplementation. Zinc sulphate, the supplement, which usually added in fish feed and fertilisers are often used to enhance fish growth and production and therefore, high levels of Zn may be present in the unconsumed feed and excretory products [10, 17, 23]. Zn was high at Bu due to fertilizers and pesticides [25]. There is no guideline value for Zn in WHO drinking water standard. Nevertheless, it was stated that drinking water containing Zn at levels more than 3 mg/L may not be acceptable to consumers.

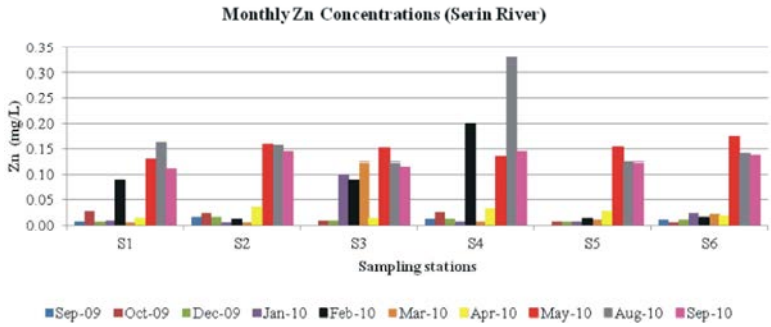

Fig. 6a: Zn concentrations of Serin River during sampling period

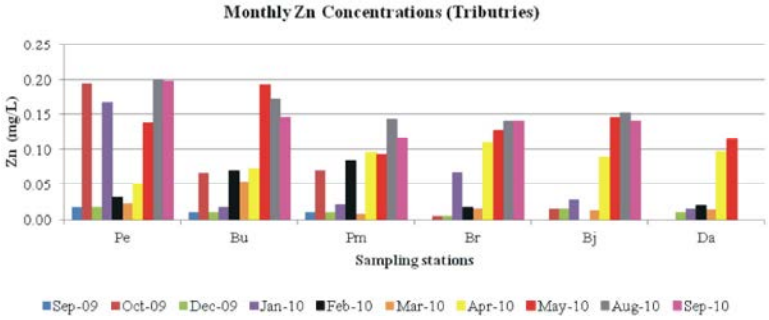

Fig. 6b: Zn concentrations of tributaries of Serin River during sampling period

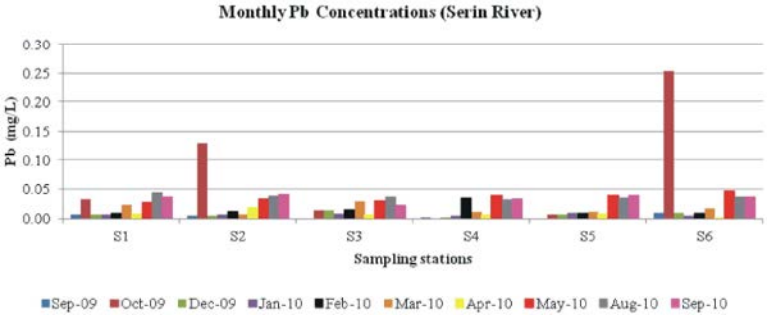

Fig. 7a: Pb concentrations of Serin River during sampling period

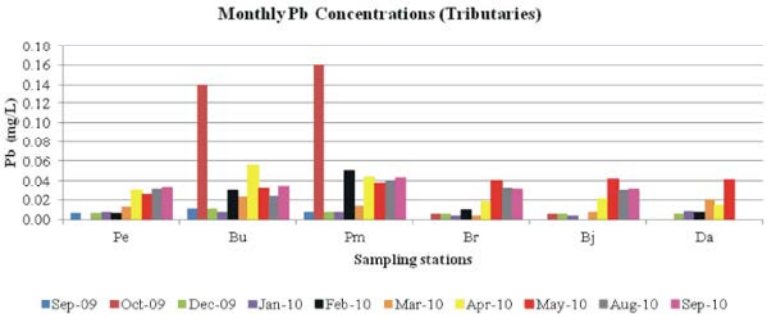

Fig. 7b Pb concentrations of tributaries of Serin River during sampling period

For Pb, all sampling stations recorded relatively consistent concentrations throughout the study period, except S2, S6, Bu and Pm which showed elevated results during the early monsoon season, October 2009 (Fig. 7a and 7b). The higher Pb at Bu could be due to pesticides other than vehicular source [27]. Dojlido and Best [15] stated that wash off from road surfaces during high rainfall periods contributed mainly to the increase in Pb content of river water due to the fact that Pb exists in particulate form on roadside dust. This could explain the high Pb content at S2 with moderate traffic volume and S6 with high traffic volume. The downstream station of Serin

Table 2: Overall mean, standard deviations and range of temperature, pH, Cr, Cd, Cu, Pb, Zn and Fe concentrations at the twelve sampling stations

Station	T (°C)	pH	Cr (mg/L)	Cd (mg/L)	Cu (mg/L)	Fe (mg/L)	Zn (mg/L)	Pb (mg/L)
S1	25.38±1.42[a]	7.09±0.28[a]	0.062±0.059[a]	0.003±0.002[a]	0.024±0.012[a]	0.125±0.114[a]	0.053±0.058[ab]	0.021±0.015[a]
	(22.00-27.11)	(6.91-7.68)	(0.002-0.120)	(0.000-0.006)	(0.011-0.038)	(0.000-0.279)	(0.005-0.163)	(0.006-0.044)
S2	26.12±1.74[ab]	6.88±0.46[a]	0.039±0.047[a]	0.003±0.002[a]	0.030±0.024[a]	0.140±0.127[a]	0.054±0.064[a]	0.038±0.046[a]
	(22.00-27.80)	(6.06-7.62)	(0.005-0.113)	(0.000-0.005)	(0.011-0.074)	(0.017-0.293)	(0.005-0.158)	(0.005-0.127)
S3	26.72±0.41[ab]	6.97±0.51[a]	0.073±0.056[a]	0.003±0.002[a]	0.021±0.011[a]	0.201±0.225[a]	0.081±0.056[ab]	0.019±0.011[a]
	(25.90-27.00)	(6.37-7.67)	(0.013-0.120)	(0.000-0.005)	(0.010-0.037)	(0.036-0.662)	(0.008-0.151)	(0.005-0.036)
S4	26.00±1.48[ab]	6.93±0.46[a]	0.063±0.048[a]	0.003±0.002[a]	0.019±0.009[a]	0.161±0.139[a]	0.085±0.106[ab]	0.014±0.016[a]
	(22.00-27.00)	(5.93-7.44)	(0.003-0.109)	(0.000-0.005)	(0.010-0.034)	(0.000-0.357)	(0.007-0.330)	(0.000-0.040)
S5	26.71±0.45[bc]	6.82±0.46[a]	0.047±0.052[a]	0.003±0.002[a]	0.018±0.011[a]	0.082±0.084[a]	0.053±0.062[ab]	0.018±0.015[a]
	(26.00-27.30)	(6.24-7.43)	(0.009-0.117)	(0.000-0.005)	(0.002-0.032)	(0.019-0.258)	(0.007-0.154)	(0.006-0.039)
S6	26.37±0.89[bc]	6.94±0.35[a]	0.047±0.054[a]	0.002±0.002[a]	0.023±0.011[a]	0.278±0.459[a]	0.051±0.065[ab]	0.061±0.096[a]
	(24.77-27.90)	(6.27-7.40)	(0.005-0.115)	(0.000-0.004)	(0.012-0.037)	(0.016-1.197)	(0.005-0.175)	(0.001-0.253)
Pe	26.83±1.77[bc]	6.94±0.30[a]	0.059±0.056[a]	0.003±0.002[a]	0.019±0.010[a]	0.348±0.322[a]	0.112±0.083[b]	0.014±0.013[a]
	(22.00-28.30)	(6.43-7.62)	(0.000-0.119)	(0.000-0.005)	(0.003-0.035)	(0.000-0.895)	(0.018-0.201)	(0.000-0.033)
Bu	26.37±1.49[ab]	6.90±0.28[a]	0.085±0.048[a]	0.004±0.003[a]	0.022±0.011[a]	0.353±0.279[a]	0.080±0.063[ab]	0.046±0.048[a]
	(22.00-27.05)	(6.35-7.37)	(0.011-0.120)	(0.000-0.010)	(0.010-0.035)	(0.030-0.782)	(0.010-0.193)	(0.008-0.140)
Pm	26.06±0.56[ab]	6.87±0.24[a]	0.051±0.050[a]	0.003±0.002[a]	0.040±0.032[a]	0.379±0.434[a]	0.066±0.047[ab]	0.052±0.056[a]
	(25.00-27.05)	(6.54-7.41)	(0.001-0.104)	(0.000-0.006)	(0.005-0.094)	(0.004-1.208)	(0.008-0.143)	(0.007-0.160)
Br	26.13±0.94[ab]	6.72±0.44[a]	0.057±0.056[a]	0.002±0.002[a]	0.022±0.011[a]	0.092±0.086[a]	0.070±0.060[ab]	0.016±0.014[a]
	(24.00-27.40)	(6.13-7.35)	(0.004-0.118)	(0.000-0.004)	(0.012-0.039)	(0.006-0.226)	(0.006-0.141)	(0.003-0.040)
Bj	26.00±0.21[ab]	6.83±0.31[a]	0.075±0.046[a]	0.003±0.002[a]	0.022±0.010[a]	0.122±0.097[a]	0.075±0.064[ab]	0.018±0.015[a]
	(25.62-26.40)	(6.26-7.23)	(0.010-0.115)	(0.000-0.005)	(0.012-0.033)	(0.034-0.246)	(0.013-0.152)	(0.004-0.042)
Da	27.52±0.77[c]	6.84±0.13[a]	0.028±0.044[a]	0.004±0.003[a]	0.020±0.008[a]	0.204±0.343[a]	0.045±0.047[a]	0.016±0.014[a]
	(26.24-28.00)	(6.66-7.06)	(0.003-0.119)	(0.000-0.008)	(0.012-0.034)	(0.009-0.879)	(0.011-0.115)	(0.005-0.041)
Drinking water standard								
WHO**			0.05	0.003	2	NGV	NGV	0.01

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

** Source: WHO, 2004

NGV-No guideline value

River, S6, recorded the highest overall mean Pb concentration (0.061 mg/L) (Table 2). S6 is located next to the major Kuching-Serian highway with extremely heavy traffic. Moreover, there is high density of human settlements around this area. Water samples of S6 showed high Pb content most likely due to atmospheric deposition. The surface runoff of particulate Pb from automobile exhaust and Pb-containing-gasoline from fish boat and high vehicular traffic volume during high rainfall period brings the pollutants into the receiving river [28, 29, 30]. Chappell *et al*. [31] reported that the highest Pb concentration in Greater Cairo was observed in street dust and high traffic areas and a significant difference in Pb concentration between high traffic volume areas and low traffic volume areas was observed due to automobile emissions. Furthermore, to some extent, the chilled or peeled lead-based paint from the older residences may contribute to lead contamination of the river [28]. On the other hand, the surface runoff of fertilisers and the overflows of flooded oxidation ponds might have contributed to the high Pb concentrations at Bu and Pm respectively during rain storm. The contributions from these tributaries increased the Pb contents to their downstream stations, S2 and S4 in some months (Fig. 7a and 7b). However, the increase was not significant most probably due to the small loadings. On the other hand, the mean Pb concentration found at the station near water intake, S3, which is located near to a bridge with moderate traffic volume exceeded the permissible limits of WHO guideline value (0.01 mg/L) throughout study period, except January and April of 2010. Generally, the overall mean Pb concentrations of all stations violated the recommended value for drinking water.

CONCLUSIONS

There are high variations in heavy metals concentrations over the sampling period especially those associated with different land use indicating the impact of rain and discharge. Rainy month led to an increase in heavy metals associated with agriculture and animal farms indicating contributions from fertilizers in runoff and overflow of oxidation ponds and an increase in Pb indicating vehicular contributions. The mean Cr, Cd and

Pb concentrations at the main river stations exceeded the WHO guideline for drinking water 50% of the time due to various anthropogenic inputs. However, the Cu and Zn concentrations recorded at all sampling stations were low throughout study period. At the station near water intake, the mean concentration of Cr and Pb exceeded the WHO guideline. Higher levels of heavy metals were found at tributaries compared to that of main river stations due to agricultural activities, mainly discharges of animal farms and fertiliser runoff. However, small loadings from these tributaries have minimal impacts on the water quality of the main river due to dilution.

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