

Analysis of spatial variation of phosphates in Batang Arau River, Indonesia

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Abstract. This study aims to study the spatial variation of phosphates (orthophosphate, total phosphate, and organic phosphate) in the Batang Arau River, West Sumatera, Indonesia. Sampling was conducted at eight stations along the river from March to May 2014. The results indicate that the three types of phosphates have similar spatial distribution patterns, with an increasing trend in concentration from upstream to downstream. The results also showed that the average orthophosphate and total phosphates concentrations at most of sampling sites had exceeded the quality standard for river water in West Sumatera (class II < 0.2 mg/L) except in the upstream. The mean concentrations of orthophosphate, total phosphates and organic phosphate were 0.054-0.423 mg/L, 0.067-0.446 mg/L, and 0.013-0.072 mg/L, respectively. Analysis of spatial variation with ANOVA at 95% confidence level indicated that differences in land use and human activities along the Batang Arau River resulted in significant differences in phosphates concentration ($p < 0.05$), except for organic phosphate.

1 Introduction

Phosphorus (P) is an essential nutrient for plants, animals, and humans. Phosphorus occurs naturally in rocks and other mineral deposits. During the natural process of weathering, the rocks gradually release the phosphorus as phosphate ions which are soluble in water, and the mineralize phosphate compounds break down. Phosphates exist in three forms, orthophosphate, metaphosphate (or polyphosphate), and organically bound phosphate.

Under natural conditions, phosphorus is typically scarce in water. Human activities like urbanization and agricultural intensification, however, have resulted in excessive loading of phosphorus into many freshwater systems. This can cause water pollution by promoting eutrophication in surface water. The most common effects of eutrophication are enhanced vegetation growth, algae blooms, and the imbalance of the aquatic ecosystems [1]. Water quality can be further impaired when bacteria consume dead algae and use up dissolved oxygen, suffocating fish and other aquatic life. Furthermore, the degradation of water resources by eutrophication also has effects such as fishing and boating recreation use losses, reduced biodiversity and conservation values, human health threat through the production of toxic cyanobacterial blooms [1-4]. Rivers are particularly vulnerable due to their proximity to population centers and sensitivity to land use changes [5].

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2.2 Sampling points

Surface water samples were collected from eight stations along the Batang Arau River at biweekly intervals between March and May 2014. The sampling stations were classified as one baseline station (S1) and seven impact stations (S2, S3, S4, S5, S6, S7, and S8). The baseline station is referred to the natural and unpolluted state of the river basin that is located upstream of the river, and the impact stations are used for measuring the quantity of pollutant and extent of pollution because of human interference. The seven impact stations (S2–S7) represented the industrial, domestic, agricultural, and commercial activities. The sampling point locations and sampling points description are seen in Fig. 1 and Table 1.

Table 1. Description of eight sampling points.

Stations	Latitude	Longitude	Elevation	Distance (from S1)	Description
			m.a.s.l.* (m)	(km)	
S1	0°56'49.9"	100°30'31.5"	229	0	Upstream of the Batang Arau River which is located in a forested area.
S2	0°57'30.4"	100°27'08.0"	124	4.2	Located on a drain which is carrying wastewater from a limestone mill and agricultural activities.
S3	0°57'39.7"	100°25'29.7"	72	10.1	Received wastewater from households and commercial activities. The water load increases as a result of the merging of two nearby tributaries in this area.
S4	0°57'40.8"	100°24'02.3"	18	13.8	The river has passed through agricultural and industrial areas.
S5	0°57'43.3"	100°22'54.1"	7	16.7	The streams have received wastewater from rubber industry and the discharge of the river water has been reduced as a result of diverting to the nearby flood control channel.
S6	0°57'26.8"	100°22'41.1"	6	17.6	Located after the streams couple with the secondary drainage channels, called Batang Jirak, which receive wastewater from the domestic and commercial areas.
S7	0°57'41.4"	100°22'28.4"	3	18.9	The stream couples with the channel of Jati Drain that receives wastewater from domestic and commercial activities.
S8	0°57'44.8"	100°21'51.5"	1	19.9	Downstream of the river; all pollutants along the river accumulated.

*m a.s.l.: meters above sea level

2.3 Sample collections

Five sampling trips by grab method were performed from March to May 2014. Water samples were collected in 1 L glass bottles. Temperature, pH, and dissolved oxygen were determined in the field. All sample bottles were placed in cooler boxes with ice at approximately 4°C before analysis.

2.4 Analytical methods

The in-situ measurements of pH and temperature were taken with the corresponding portable meters (Hanna, USA) while DO use DO-meter (Lutron, Taiwan). The total phosphorus test measures all the forms of phosphorus in the water sample (orthophosphate, condensed phosphate, and organic phosphate). This is accomplished by first "digesting" (heating and acidifying) the sample to convert all the other forms to orthophosphate. Then the orthophosphate is measured by the ascorbic acid method. Each sample was analyzed in triplicate, and average readings were automatically determined. The measurements were conducted according to the standard method [12].

2.5 Statistical analysis

SPSS version 20.0 was used for statistical analysis. Data analysis was carried out using Microsoft Excel 2013 and data were presented in tables and graphs. One-way analysis of variance (ANOVA) was used to examine the significant spatial distribution of phosphates.

3 Results and discussion

3.1 Spatial variation of phosphates in the Batang Arau river

Spatial variation of phosphates including orthophosphate, total phosphate, and organic phosphate in the Batang Arau River are illustrated by box-whisker plots (Fig. 2), whereas overall means, standard deviations, and minimum, and maximum values of environmental parameters and phosphates concentrations at the eight sampling points are summarized in Table 2. The values of DO and pH at eight sampling points decreased from upstream to downstream of the Batang Arau River, whereas the temperature tends to increase. This may be due to differences in land use and the presence of several effluents entering the Batang Arau River from upstream to downstream of the Batang Arau River. However, the values of the environmental parameters were still in the range of quality standard for river water in West Sumatera based on Regulation of Governor of West Sumatera No. 5/2008 for class II.

The concentrations of phosphates including orthophosphate, total phosphate, and organic phosphate were in the range of 0.054 to 0.423 mg/L, 0.067 to 0.446 mg/L, and 0.013 to 0.02 mg/L, respectively. Typically, phosphates have similar spatial distribution patterns, with an increasing trend in concentration from upstream to downstream in the Batang Arau River. For instance, the mean concentration of orthophosphate increased from 0.054 ± 0.076 mg/L upstream to 0.423 ± 0.012 mg/L downstream. The upstream area represents a natural and unpolluted river reflecting the natural background concentrations of metals. S1 is located in a forested area and there is no influence from human activities on water quality in this area, thus, it can be the reference stream for the other stations. Generally, in unaffected environments, the concentration of most of pollutants in rivers is very low and mostly derived from the weathering of rock and soil [7, 13]. Hence, the phosphates concentrations at S1 station are relatively lower than at the other stations. The increase in phosphates concentrations downstream may cause by anthropogenic influences such as agricultural, domestic, and industrial activities along the Batang Arau River, as the concentration of phosphates at all stations had much higher average values than those in water samples from the upstream, S1. This defines that increased phosphates concentrations most likely originated from anthropogenic activities.

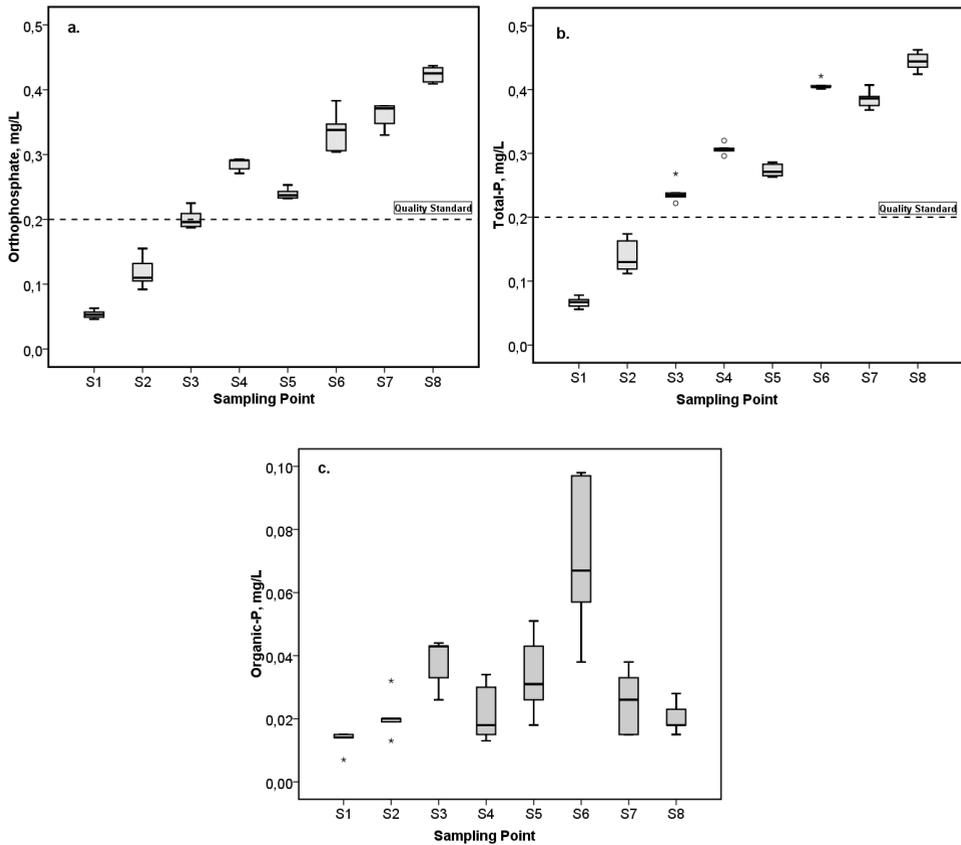


Fig. 2. Spatial variations of (a) Orthophosphate, (b) Total-P, and (c) Organic-P in Batang Arau river.

Moreover, as also shown in Fig. 2, phosphates concentrations were compared with quality standard for river water in West Sumatera based on Regulation of Governor of West Sumatera No. 5/2008 for class II [14]. The mean concentrations of orthophosphate and total phosphates at S3 until S8 were higher than the maximum permissible concentrations established by Regulation of Governor of West Sumatera for the river water quality standard of class II (Table 2). At S1 dan S2, orthophosphate and total phosphates concentrations were, respectively, in the range of 0.054 to 0.199 mg/L and 0.067 to 0.139 mg/L, while at S3 until S8 those concentrations were in the range of 0.201 to 0.423 mg/L and 0.232 to 0.446 mg/L. The quality standard for river water in West Sumatera based on Regulation of Governor of West Sumatera No. 5/2008 for class II is 0.2 mg/L. Therefore, much greater attention should be paid to phosphates concentration in water to protect aquatic life from phosphates pollution and eutrophication.

One-way analysis of variance (ANOVA) was carried out to examine significant spatial variations in phosphates concentrations. Table 3, 4, and 5 show the p values of comparison of orthophosphate, total phosphate, and organic phosphate concentrations at eight sampling points.

Table 3 and Table 4 show that the concentrations of orthophosphate and total phosphates demonstrate significant spatial variability at the eight sampling points ($p < 0.05$). The concentration of orthophosphate and total phosphates increased significantly at S2, S3, S4, S5, S6, S7, and S8. These results indicate that anthropogenic activities and different land use along the Batang Arau River may lead to significant variability in the

spatial distribution of orthophosphate and total phosphates concentrations in the river. Wastewater from industrial, agricultural, and domestic sources are released into the river from S2 to S8 stations resulting in the significant differences in phosphates concentrations.

Table 2. The means, standard deviations, minimum, and maximum values of environmental parameters and concentrations of phosphates at the eight sampling points (n= 5).

Parameters		Stations								Water quality standard
		S1	S2	S3	S4	S5	S6	S7	S8	
DO (mg/l)	Mean	8.5	7.16	7.42	6.24	6.94	7.18	6.96	6.68	Min. 4
	Std dev	0.3	0.716	0.867	1.820	1.085	0.268	0.537	0.934	
	Min	8.0	6.4	6.1	3.3	5.2	6.9	6.6	5.5	
	Max	8.9	8.3	8.2	7.9	7.9	7.6	7.9	8	
pH	Mean	8.4	8.72	8.40	7.86	7.76	7.60	7.64	7.54	6-9
	Std dev	0.4	0.449	0.706	0.416	0.568	0.418	0.378	0.577	
	Min	8.0	8.1	7.8	7.4	7.1	7.2	7.2	6.9	
	Max	8.9	9.1	9.6	8.5	8.2	8.1	8.2	8.1	
Temperature (°C)	Mean	25.8	28.64	30.8	30.56	30.52	30.50	30.42	30.44	± 3
	Std dev	0.4	1.820	2.477	1.665	1.802	1.735	1.071	1.135	
	Min	25.2	26.4	28.1	29.3	29.2	29.6	29.7	29.5	
	Max	26.2	31.2	34.7	33.4	33.7	33.6	32.3	32.4	
Ortho-phosphate (mg/L)	Mean	0.054	0.119	0.201	0.271	0.240	0.335	0.360	0.423	0.2
	Std dev	0.0076	0.0245	0.0158	0.027	0.008	0.033	0.02	0.012	
	Min	0.046	0.09	0.013	0.187	0.225	0.304	0.330	0.409	
	Max	0.063	0.15	0.155	0.225	0.293	0.383	0.375	0.437	
Total phosphate (mg/L)	Mean	0.067	0.139	0.238	0.299	0.273	0.407	0.381	0.446	0.2
	Std dev	0.0059	0.028	0.017	0.020	0.010	0.008	0.016	0.012	
	Min	0.056	0.052	0.222	0.268	0.263	0.401	0.368	0.433	
	Max	0.078	0.084	0.267	0.320	0.286	0.421	0.407	0.462	
Organic phosphate (mg/L)	Mean	0.013	0.021	0.037	0.022	0.034	0.072	0.025	0.02	0.2
	Std dev	0.003	0.0068	0.0078	0.0093	0.013	0.0673	0.01	0.005	
	Min	0.007	0.013	0.026	0.013	0.018	0.038	0.015	0.015	
	Max	0.015	0.032	0.044	0.034	0.051	0.098	0.038	0.028	

* Regulation of Governor of West Sumatera No. 5/2008 for class II

There were no significant differences in orthophosphate and total phosphates concentrations were observed at S3, S4, S5, as well as at S6, and S7 ($p > 0.05$). The similar condition in anthropogenic activities and land use at those stations may cause the results.

Tabel 3. *p* values of comparison of orthophosphate concentrations at eight sampling points ($\alpha = 0.05$).

	S1	S2	S3	S4	S5	S6	S7	S8
S1	-							
S2	0.000	-						
S3	0.000	0.000	-					
S4	0.000	0.000	0.000	-				
S5	0.000	0.000	0.094	0.251	-			
S6	0.000	0.000	0.000	0.001	0.000	-		
S7	0.000	0.000	0.000	0.000	0.000	0.577	-	
S8	0.000	0.000	0.000	0.000	0.000	0.000	0.001	-

Tabel 4. *p* values of comparison of total phosphates concentrations at 8 sampling points ($\alpha = 0.05$).

	S1	S2	S3	S4	S5	S6	S7	S8
S1	-							
S2	0.000	-						
S3	0.000	0.000	-					
S4	0.000	0.000	0.000	-				
S5	0.000	0.000	0.043	0.234	-			
S6	0.000	0.000	0.000	0.001	0.000	-		
S7	0.000	0.000	0.000	0.000	0.000	0.254	-	
S8	0.000	0.000	0.000	0.000	0.000	0.000	0.001	-

Tabel 5. *p* values of comparison of organic phosphate concentrations at 8 sampling points ($\alpha = 0.05$).

	S1	S2	S3	S4	S5	S6	S7	S8
S1	-							
S2	0.974	-						
S3	0.095	0.514	-					
S4	0.935	1.000	0.634	-				
S5	0.150	0.077	1.000	0.787	-			
S6	0.000	0.000	0.001	0.001	0.001	-		
S7	0.756	0.999	0.864	1.000	0.949	0.000	-	
S8	0.979	1.000	0.491	1.000	0.654	0.000	0.999	-

On the other hand, for organic phosphate, significant differences in concentration were not obtained at all station, except at S6 (Table 5). S6 is located after the river couples with a secondary drainage channel. This location receives wastewater from commercial and domestic areas such as auto services and public market.

The ratio of organic phosphate concentration and inorganic phosphate (orthophosphate) is illustrated in Fig. 3, where the percentage of inorganic phosphate is greater than organic phosphate at all sampling points. Based on land use, almost all sampling sites are residential areas that produce domestic wastewater. The primary source of phosphate, both inorganic phosphate (orthophosphate) and organic phosphate, may come from human activities. The concentration of orthophosphates may increase by the use of detergents and cleaners in domestic activities and discharged the effluent directly into water bodies, while the organic phosphates may derive from human feces along the river.

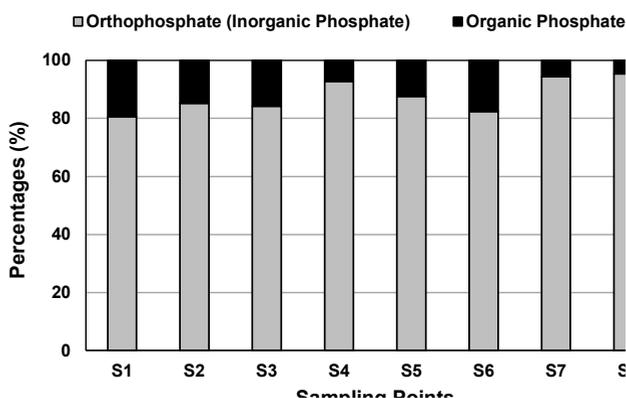


Fig. 3. Ratio of orthophosphate and organic phosphate in total phosphates concentrations at 8 sampling points.

4 Conclusions

The results reveal that phosphates in the Batang Arau River, typically, have a similar spatial variation pattern, with an increasing trend in concentration from upstream to downstream. It reflects that the natural and anthropogenic activities along the river affect the variability of the phosphate concentration. The mean concentrations of orthophosphate and total phosphates at most of the sampling points were higher than the maximum permissible concentrations established by Regulation of Governor of West Sumatera for river water quality standard of class II, indicating that phosphates could be potential pollutants to lead eutrophication in the Batang Arau River. Significant spatial variabilities were found in the concentration of orthophosphate and total phosphates along the Batang Arau River, but neither in the concentration of organic phosphate. This defines that the different land uses and anthropogenic activities along the Batang Arau River may change their spatial distributions.

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