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Seasonal Dynamics of Heavy Metal and Arsenic Content of Water and Sediments of the Srepok River (Vietnam)

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Abstract—Accumulation of heavy metals (Fe, Cu, Zn, Cd, Pb) and arsenic in water and bottom sediments of the Srepok River in rainy and dry seasons has been assessed. Significant seasonal variations in the concentration of elements in water have been found. The Fe, Cu, Zn, As, and Pb content of sediments did not depend on the season, and the concentration of Cd was higher in the rainy season. At certain periods of time, the concentrations of these elements in river water exceeded those recommended by the national technical regulations of Vietnam: Fe, 2.3–9.5 times; Cu, 1.2–2.8 times; Zn, 1.2–4.5 times; Cd, 1.7–6.8 times; Pb, 1.1–17 times; and As, 1.1–3.7 times. The concentrations of all heavy metals and arsenic in the river water and bottom sediments of industrial zones tended to increase. The results showed, the examined elements can be divided into groups where their concentrations are closely interrelated. These groups are composed of Fe, Cu, Zn, and Pb in the river water, and of Cu, Zn, As, and Pb in sediments. The obtained data prove the necessity of monitoring the levels of heavy metals and arsenic in river water and bottom sediments of industrial zones.

Keywords: Vietnam, Srepok river, industrial zones, river water, sediments, heavy metals, arsenic, concentration levels

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INTRODUCTION

The Vietnamese government defines the main vector of the country's development as industrialization and modernization. More and more developed industrial zones and enterprises have appeared in recent years, the mining industry is working with greater intensity, and the rural handicraft model is expanding. As a rule, the consequence of these processes is pollution of the environment, including aquatic ecosystems. The rivers of Vietnam are experiencing a very heavy load, since they are receivers of direct and indirect waste streams from household, agricultural, industrial, and service human activities [1]. Most of these polluting streams are not treated, or they are treated in a very primitive way only before being discharged into rivers. That is why it is necessary to constantly monitor the environmental state of river basins, including heavy metal and arsenic pollution.

The Srepok River plays an important role in the agricultural, industrial, and household activities of people inhabiting the territory along which it flows. Its water is used to irrigate agricultural land where rice (26.457 ha), coffee (46.163 ha), fruit plants (1095 ha), and other crops (140 ha) are grown. About 14.4×10^6 m^3 of water is annually supplied for the needs of industrial enterprises, and 36×10^6 m^3 of water is consumed by livestock. Thus, the Srepok River has not escaped the negative impact of anthropogenic activity. However, apart from annual monitoring at a small number of points four times a year [2], no comprehensive studies of the accumulation of heavy metals and arsenic in river ecosystems have been carried out.

Numerous studies have shown that the concentration and distribution patterns of chemical elements in river water and bottom sediments significantly differ depending on the geographical location and seasons [3–14].

It is known that heavy metals accumulate in aquatic organisms, affect them, and affect human health through the food chain. Bottom sediments in water bodies play an important role in the absorption of heavy metals by adsorbing suspended organic and inorganic particles.

In many countries of the world, determination of the concentration of heavy metals in water and bottom sediments is an obligatory component of water quality monitoring programs, which belongs to a number of priority ones [5, 9, 15, 16].

In this connection, the goal of the present study was to determine the concentration of such heavy metals (Fe, Cu, Zn, Cd, Pb) and arsenic (As) in water and sediments of the Srepok River.

EXPERIMENTAL

The subjects of the study were water and bottom sediments of the Srepok River in the region from the Hóa Phúc and Tam Thang industrial zones to the hydroelectric power station on the Srepok 3 reservoir. Taking into account topographic features of the region and distribution of waste sources, the sampling points on the river were divided into four zones:

(a) Zone 1 is located upstream of the industrial zones; it is slightly affected by wastewater from the city;

(b) Zone 2 is the part of the river within industrial zones; it is affected by wastewater from the Hóa Phúc and Tam Thang industrial zones and by wastewater from the city through small streams and rainwater;

(c) Zone 3 covers the part of river located downstream of the industrial zones to the hydroelectric power station at the Đray H'linh reservoir (the distance from the industrial zones to the hydroelectric power plant at the Đray H'linh reservoir is 7.5 km); this zone is partially affected by wastewater from the city and industrial zones;

(d) Zone 4 includes the HPP at the Srepok 3 reservoir; it is located 17.4 km from the industrial zones downstream of the river. This sampling site is remote from the industrial zones and the city, so that the impact of wastewater from these sources is negligible.

Water and sediment samples were collected in the rainy and dry seasons in 4 stages: (1) October 2015 (rainy season); (2) March 2016 (dry season); (3) October 2016 (rainy season); and (4) March 2017 (dry season). Water samples were taken at a depth of 30 cm using a bottle. Measurements were carried out both at the sampling site and in the laboratory; the samples were conserved by adding 2 mL of concentrated nitric acid per liter of water. Sediment samples were taken at a distance of 5 cm from the river bottom using a sampling bucket. After sampling, the samples were stored in refrigerated plastic bags (<4°C) and sent to the laboratory for analysis.

Sediments were analyzed immediately after sampling. The samples were homogenized, then a part of them was placed in a stainless steel tray, the tray was placed in an oven for drying at a temperature of 40°C; the optimal drying time was chosen depending on the moisture content of the sample (as a rule, about 24 h). The dried samples were ground and sieved to remove particles larger than 2 mm in diameter. A 0.35-g sample was placed in a mixing vessel, and 45 mL of deionized water and a mixture of 4 mL of 65% HNO_3 and 1 mL of 37% aqueous HCl (37%) were added. Samples were dried using MW680 microwave equipment; the sample temperature was raised to 170±5°C over a period of 10 min and was maintained at that level for the next 10 min. After drying, the fan was turned on for 5 min to absorb toxic gas and cool the containers. The contents of the cooled containers were filtered through a filter paper using a filter funnel, and the filtrate was diluted with deionized water to a volume of 50 mL. Each parameter was analyzed separately according to an appropriate procedure.

The following procedures were applied to determine heavy metals and arsenic in water: As: Vietnamese standard 6626:2000; Pb: SMEWW 3113B:2012; Cd: SMEWW 3113B:2012; Cu: Vietnamese standard 6193:1996; Zn: Vietnamese standard 6193:1996; Fe: SMEWW 3111.B:2012. Heavy metals and arsenic in bottom sediments were determined according to the following procedures: As: EPA 3051A and Vietnamese standard 6626:2000; Pb: EPA 3051A and SMEWW 3113B:2012; Cd: EPA 3051A and SMEWW 3113B:2012; Cu: EPA 3051A and SMEWW 3111B:2012; Zn: EPA 3051A and SMEWW 3111B:2012; Fe: EPA 3051A and SMEWW 3111.B:2012.

All analyses were carried out in triplicate. The results were displayed as arithmetic mean and standard deviation ($M \pm m$). The data were processed using Microsoft Excel 2010, SPSS, and Statistica.

One way analysis of variance (ANOVA) in combination with Tukey's test for equal variance and Tamhane's test for unequal variance to compare differences between metal groups by zone, season and sampling location.

RESULTS AND DISCUSSION

Concentrations of heavy metals and arsenic in river water. The sampling points in the examined region of the Srepok River (through the industrial zones Hóa Phúc and Tam Thang to the Srepok 3 reservoir of the hydroelectric

Table 1. Concentrations of heavy metals and arsenic in the Srepok River water in different seasons

Element	Concentration, mg/L	
	rainy season	dry season
Fe	2.084 ± 1.289	0.312 ± 0.065
Cu	0.150 ± 0.149	0.066 ± 0.072
Zn	0.808 ± 0.818	0.434 ± 0.480
As	0.011 ± 0.012	0.014 ± 0.007
Cd	0.015 ± 0.007	0.023 ± 0.008
Pb	0.114 ± 0.109	0.020 ± 0.010

Table 2. Concentrations of heavy metals and arsenic in the Srepok River water in different zones

Element	Concentration, mg/L			
	zone 1	zone 2	zone 3	zone 4
Fe	1.033 ± 0.413	3.171 ± 1.845	1.251 ± 0.665	0.948 ± 0.455
Cu	0.019 ± 0.004	0.332 ± 0.105	0.122 ± 0.037	0.037 ± 0.023
Zn	0.153 ± 0.069	1.901 ± 0.454	0.561 ± 0.188	0.210 ± 0.057
As	0.028 ± 0.006	0.011 ± 0.002	0.003 ± 0.003	0.001 ± 0.000
Cd	0.015 ± 0.010	0.024 ± 0.004	0.012 ± 0.003	–
Pb	0.014 ± 0.013	0.097 ± 0.047	0.210 ± 0.128	0.033 ± 0.014

power station) are distributed evenly. Therefore, 4 stages of sampling gave fairly accurate data on variation of the concentrations of heavy metals and arsenic in river water. The ranges of Fe, Cu, Zn, As, Cd, and Pb concentrations in the river water were 0.25–2.96, 0–0.26; 0–1.46; 0–0.02; 0.01–0.03, and 0–0.19 mg/L, respectively. In general, these concentrations widely varied depending on the season and sampling site; in some cases, the coefficient of variation approached 100%. This is consistent with the results of a number of other studies [14, 17–19]. In certain periods, the concentration of elements in river water at many points exceeded the requirements of the national technical regulation QCVN 08:2015/BTNMT by a factor of 2.3–9.5 (Fe), 1.2–2.75 (Cu), 1.2–4.5 (Zn), 1.1–3.7 (As), 1.7–6.8 (Cd), or 1.1–17 (Pb).

Seasonal concentrations of heavy metals and arsenic in river water are presented in Table 1. As follows from these data, seasonal variations of the concentrations of particular elements are different. The difference in the concentrations of Zn and As in the rainy and dry seasons is not significant at $p < 0.05$. The seasonal differences in the concentrations of Fe, Cu, Cd, and Pb are statistically significant. The concentration of Fe and Pb in the river water in the rainy season is significantly higher than in the dry season, and the concentration of Cd in the rainy season is lower than in the dry season.

The patterns of seasonal variations of concentrations for each particular metal and particular zone vary significantly. In this regard, it is interesting to compare the data for the Srepok River with those for the Nhuệ and Tô Lịch rivers of Vietnam and the Gomti and Sabarmati rivers of India. As shown in [17], the concentration of Pb the Nhuệ river water in the rainy season is higher than in the dry season, while the opposite trend was observed for other metals such as Mn, Ni, and Zn. Seasonal differences in the concentrations of As, Cr, and Cu in Nhuệ were not statistically significant. The same study revealed no significant seasonal differences in the concentration of heavy metals in the Tô Lịch river. Analysis of samples collected from other parts of the Tô Lịch river showed that the concentration of Cd, Cr, Cu, Ni, Pb, and Zn in the dry season was higher than in the rainy season [20]. Gaur et al. [21] studied the concentration of elements in the Gomti River (India) and found a tendency for the Cd, Cr, Cu, Ni, Pb, and Zn content of the river water to increase in the rainy season [21]. According to the data of [22], the concentration of heavy metals in water of the Sabarmati River (near Ahmedabad, India) in the dry season of 2013 was higher than in the rainy season. However, the concentration of Ni, Zn, and Cr in a number of zones was higher during the rainy season.

According to national technical domestic water quality regulations (QCVN 02:2009/BYT, 2009), the concentration of Fe in the Srepok river in the rainy season exceed the permissible limits. According to the national technical regulation on surface water quality (QCVN

Table 3. Concentrations of heavy metals and arsenic in the Srepok River water at different sampling sites

Element	Concentration, mg/L		
	near the coast, Đắk Lắk province	middle of the river	near the coast, Đắk Nóng province
Fe	1.684 ± 1.417	1.488 ± 1.417	1.601 ±1.329
Cu	0.134 ± 0.139	0.111 ± 0.126	0.133 ± 0.150
Zn	0.773 ± 0.799	0.628 ± 0.724	0.698 ± 0.775
As	0.010 ± 0.010	0.011 ± 0.011	0.013 ± 0.013
Cd	0.016 ± 0.007	0.016 ± 0.009	0.019 ± 0.008
Pb	0.097 ± 0.111	0.075 ± 0.084	0.089 ±0.110

Table 4. Coefficients of correlations between the concentrations of heavy metals and arsenic in the Srepok River water

Element	Fe	Cu	Zn	As	Cd	Pb
Fe	1.00					
Cu	0.86[a]	1.00				
Zn	0.85[a]	0.98[a]	1			
As	–0.20	–0.46[a]	–0.38[a]	1.00		
Cd	0.26	0.48[a]	0.49[a]	–0.11	1.00	
Pb	0.92[a]	0.94[a]	0.90[a]	–0.45[a]	0.36[a]	1.00

[a] Statistically significant correlation was observed at $p < 0.05$.

08:2008/BTNMT, 2008), the concentration of all heavy metals and arsenic in the river water during the rainy season exceeded the values given in this regulation.

The concentrations of heavy metals and arsenic in the river water significantly varied depending on the distance between particular zones of the river and sources of pollution (Table 2).

The data in Table 2 show that the concentration of Fe, Cu, and Zn in the river water of zone 2 is significantly higher than in the other zones. There is no significant difference in the concentration of these metals in zones 1 and 4. The concentration of arsenic in the river water of zone 1 is higher than in zones 2–4. The Pb content in zone 2 is the same as in zone 3 but is higher than in zones 1 and 4. Thus, there is a general trend: the concentration of elements in the river water in zones 2 and 3 (industrial zones Hóa Phúc and Tam Thang) is much higher. This indicates that these industrial zones have a negative impact on the river water quality.

According to the national technical regulation on the quality of irrigation water (QCVN 39:2011/BTNMT, 2011), the concentration of Cu and Zn in zone 2 approached the permissible limit; the concentration of Cd exceeded the permissible limit in zones 1–3; and the concentration of Pb exceeded regulation in zones 2 and 3.

According to the national technical regulation for the quality of domestic water (QCVN 02:2009/BYT, 2009), the standard values for Fe content in river water of all 4 zones and for As in zones 1 and 2 were exceeded.

According to the national technical regulation for surface water quality (QCVN 08:2008/BTNMT, 2008), the concentration of Fe in river water of all 4 zones exceeded the permissible values for domestic water. The concentrations of As in river water of zones 1 and 2 and Cu and Zn in zones 2 and 3 were also higher than the reference values for water for domestic needs. The concentration of Cd in river water in zones 1–3, as well as the concentration of Pb in zones 2 and 3 exceeded all values given in the national technical regulation for various types of water use, i.e., the river water is not suitable for any purpose.

Variations of the heavy metal and arsenic content in the river water depending on the sampling site are given in Table 3.

The data given in Table 3 show that the differences in the concentrations of heavy metals and arsenic in the middle of the river in the Đắk Lắk and Đắk Nông provinces are not reliable; i.e., these elements are distributed relatively evenly in the water flow. This can be explained by the fact that both banks of the river are similar in natural and economic conditions; in particular, there are industrial zones and fairly similar agricultural production structures on both banks. In addition, strong

Table 5. Concentrations of heavy metals and arsenic in bottom sediments of the Srepok River in different seasons

Element	Concentration, mg/kg	
	rainy season	dry season
Fe	2919.2 ± 407.2	3020.4 ± 60.5
Cu	60.8 ± 32.5	61.4 ± 41.9
Zn	162.0 ± 133.9	171.2 ± 148.3
As	5.25 ± 3.31	3.54 ± 2.08
Cd	0.993 ± 0.562	0.274 ± 0.270
Pb	41.8 ± 15.1	44.5 ± 21.4

Table 6. Concentrations of heavy metals and arsenic in bottom sediments of the Srepok River in different zones

Element	Concentration, mg/kg			
	zone 1	zone 2	zone 3	zone 4
Fe	2584 ± 265	2774 ± 201	3111 ±39	3317 ±238
Cu	25.9 ± 2.4	110.8 ± 7.4	73.4 ± 5.1	33.7 ± 5.9
Zn	61.7 ± 9.1	391.1 ± 13.5	136.5 ± 22.6	68.9 ± 7.9
As	3.92 ± 0.96	9.38 ± 1.88	4.37 ± 0.77	1.50 ± 0.30
Cd	0.753 ± 0.339	1.57 ± 0.57	0.525 ± 0.276	0.341 ± 0.188
Pb	25.8 ± 4.0	67.4 ± 6.7	42.80 ± 5.54	34.2 ± 8.2

mixing of water in the river flow should be taken into account.

Very interesting interrelationships were found for the concentrations of various elements in the Srepok River. Table 4 contains the correlation coefficients for heavy metal and arsenic concentrations in the Srepok River through the Hóa Phúc and Tam Thang industrial zones to the Srepok 3 hydroelectric power station reservoir. These data indicate a a close relationship between the concentration of Fe, on the one hand, and concentrations of Cu, Zn, and especially Pb, on the other. The correlation coefficients for Cu and Zn and Cu and Pb are also very high. A close correlation was also observed between the concentrations of Pb and Zn. Thus, Fe, Cu, Zn, and Pb form a group of metals whose concentrations in the river water are closely interrelated. The concentration of As showed a negative correlation which is statistically significant for Cu, Zn, and Pb, but at a low level.

Comparison of our results with those of similar studies showed that the concentration of Fe in the Subarnarekha River water (Swarnarekha, India) closely correlates with the Pb concentration [23], which is consistent with our data. A close correlation between the concentrations of Cu, Zn, and Pb was also found for the Khoshk River water (Iran) [27]. However, a number of other studies [22–24] noted only a moderate or low correlation between the concentrations of Cu, Zn, and Pb.

Heavy metal and arsenic content of bottom sediments. Sediment samples of the Srepok River were collected at the same sites as water samples, along the section through the Hóa Phúc and Tam Thang industrial zones to the Srepok 3 reservoir. The concentrations of Fe, Cu, Zn, As, Cd, and Pb were estimated at 2946.8±350.0, 61.0±34.8, 164.6±136.3, 4.79±3.10, 0.80±0.59, and 42.6±16.9 mg/kg, respectively.

In general, the heavy metal and arsenic contents of bottom sediments of the Srepok River are much lower than in the bottom sediments of the Tô Lịch river [20, 25, 26]. The obtained values are within the permissible limits established by the national technical regulations for the quality of sediments (QCVN 43:2012/BTNMT, 2012). The concentrations of heavy metals and arsenic in the bottom sediments in different seasons are given in Table 5. The seasonal differences in the concentrations of Fe, Cu, Zn, As, and Pb are statistically insignificant. The concentration of Cd in river sediments during the rainy season was higher than in the dry season. Thus, it is obvious that the heavy metal and arsenic content of sediments of the Srepok River lies in a fairly stable range and does not have significant seasonal fluctuations.

According to national technical sediment quality regulations (QCVN 43:2012/BTNMT, 2012), the seasonal concentrations of all examined elements (except for Fe which is not included in the regulations) in river sediments are within acceptable limits.

Table 7. Concentrations of heavy metals and arsenic in bottom sediments of the Srepok River at different sampling sites

Element	Concentration, mg/L		
	near the coast, Đắk Lắk province	middle of the river	near the coast, Đắk Nóng province
Fe	2969 ± 357	2832 ± 301	2960 ± 367
Cu	73.6 ± 34.5	43.1 ± 27.7	54.0 ± 34.1
Zn	174.1 ± 139.2	121.7 ± 128.7	168.6 ± 140.2
As	4.03 ± 2.50	3.67 ± 3.35	5.90 ± 3.35
Cd	0.873 ± 0.645	0.337 ± 0.245	0.865 ± 0.570
Pb	50.2 ± 16.9	32.3 ± 9.2	38.1 ± 15.9

Table 8. Coefficients of correlations between the concentrations of heavy metals and arsenic in bottom sediments of the Srepok River

Element	Fe	Cu	Zn	As	Cd	Pb
Fe	1					
Cu	–0.05	1				
Zn	–0.22	0.94[a]	1			
As	–0.52[a]	0.80[a]	0.87[a]	1		
Cd	–0.57[a]	0.59[a]	0.71[a]	0.91[a]	1	
Pb	0.10	0.93[a]	0.93[a]	0.71[a]	0.53[a]	1

[a] Statistically significant correlation was observed at $p < 0.05$.

Table 6 shows variations of the concentrations of heavy metals and arsenic in bottom sediments along different zones (sections) of the Srepok River. In general, these variations are significant. The Fe content in bottom sediments of zones 1 and 2 is lower than in zones 3 and 4. The highest concentration of Cu, Zn, As, Cd, and Pb was found for zone 2, and it was slightly lower in zone 3. The difference in the concentrations of Zn and Cd in zones 1 and 4 is statistically insignificant, but a statistically significant difference was observed for the concentrations of Fe, Cu, As, and Pb. The concentrations of Fe, Cu, and Pb in bottom sediments in zone 4 were higher than in zone 1, whereas the concentration of As showed the opposite pattern. Increased heavy metal content of bottom sediments from zones 2 and 3, as well as their increased concentration in the river water of the same zones, is most likely related to the operation of industrial enterprises in the Hóa Phúc and Tam Thang regions.

In accordance with the national technical regulation on the quality of sediments (QCVN 43:2012/BTNMT, 2012), the concentrations of almost all studied elements in the bottom sediments of the examined areas are within the acceptable limits. Violation of permissible limits was observed only for Zn in bottom sediments of zone 2. The concentrations of Cu, As, Cd, and Pb in bottom sediments of zones 2 and 3 did not exceed acceptable limits, but they were significantly higher than in the other zones.

Table 7 shows variation of the heavy metal and arsenic content of bottom sediments, depending on the sampling site. The difference in the concentrations of Fe, Cu, Zn, As, and Cd in sediments sampled from the middle of the river and at the coast in the Đắk Lắk and Đắk Nông provinces are not significant. The Pb concentration near the coast of the Đắk Lắk province is higher than in the middle of the river, but these values differ slightly from the corresponding values near the coast of Đắk Nông. The invariance of the heavy metal and arsenic content of bottom sediments near the coast and in the middle of the river in both provinces correlates with the concentrations of the elements in the river water of these zones.

The correlation coefficients for the concentrations of heavy metals and arsenic in bottom sediments in different zones are given in Table 8. The concentration of Fe displayed a negative correlation with the concentration of As and Cd; however, the correlation coefficient is moderate. The correlation between the Fe content and concentrations of Cu, Zn, and Pb is not statistically significant, i.e., it is not reliable. On the other hand, there is a close relationship between the Cu content and concentrations of Zn, As, and Pb, and Cu–Cd correlation is moderate. Close interrelationships were found for the pairs Zn–As and As–Pb, and the Zn–Cd correlation was moderate. The correlation coefficient for As and Cd is fairly high, and for As and Pb, moderate. Obviously, Cu, Zn, As and Pb form a closely interrelated metal group in bottom sediments.

Our results were compared with those of a number of relevant studies. A close correlation within the group of Cd, Cu, Pb, and Zn (the correlation coefficient for Cu and Pb reached 0.97) was found for bottom sediments of the Nhuệ river [27–28]. The same metals also formed a closely interrelated group in sediments of the Gomti River (India); the Cu–Zn correlation coefficient reached 0.99 [21]. It should be noted that the correlation coefficient between metal pairs varied greatly over the seasons. The correlation coefficient for Cu and Cd changed from 0.65 in winter to 0.91 in the rainy season. The correlation coefficient between Zn and Pb was 0.77 in summer and 0.93 in winter. Another trend is observed in the bottom sediments of the Rio Tinto and Odiel (Spain) or Cauvery and Cabini (India), where the correlation of Cu, Pb, and Zn was estimated at a moderate or low level [29–32].

CONCLUSIONS

The results of our study of the heavy metal and arsenic content of the Srepok River water and bottom sediments led us to draw the following conclusions:

(1) At certain periods of the year, the concentration of heavy metals in river water at many points exceeded the values recommended by the national technical regulation QCVN 08: 2015/BTNMT: Fe, 2.3–9.5 times; Cu, 1.2–2.75 times; Zn, 1.2–4.5 times; As, 1.1–3.7 times; Cd, 1.7–6.8 times; Pb, 1.1–17 times.

(2) The concentration of a number of heavy metals in the river water varies significantly with seasons: the concentration of Fe and Pb in the rainy season is higher than in the dry season, and the Cd content in the rainy season is lower than in the dry season.

(3) The concentration of heavy metals in the river water of the Hóa Phúc and Tam Thang industrial zones tend to increase relative to their concentration in the areas located before and after the industrial zones.

(4) In accordance with the state technical regulations for the quality of sediments (QCVN 43:2012/BTNMT), the concentration of all studied elements (with the exception of Fe, which is not included in the regulation) in bottom sediments is within acceptable limits by season.

(5) The Fe, Cu, Zn, As, and Pb content in bottom sediments shows no seasonal change, while the Cd content of bottom sediments in the rainy season is higher than in the dry season.

(6) In most cases, the concentrations of heavy metals and arsenic in the bottom sediments of zones 2 and 3 are higher than in zones 1 and 4.

(7) Increased concentration of heavy metals and arsenic in the Srepok River water and bottom sediments in zones 2 and 3 is associated with the activities of industrial enterprises in the Hóa Phúc and Tam Thang territories.

(8) The examined heavy metals and arsenic form groups in which their concentrations are closely interrelated: these are Fe, Cu, Zn, and Pb in the river water and Cu, Zn, As, and Pb in bottom sediments.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

1. Vietnam National Environmental Report 2010. http://vea.gov.vn/vn/hientrangmoitruong/baocaomtquoc-gia/Pages/. Accessed December 25, 2019.
2. Action Planto Combat Climate Change in Dak Lak Province Together with a Short Project Report Climate Change Assessment and Scenario Development. Dak Lak Provincial People's Committee. Decision no. 2309/QD-UBND of August 27, 2015, *Clim. Change*, 2015, pp. 43–54.
3. Baeva, Yu.I. and Chernykh, N.A., *Sudebnaya ekologiya: uchebnoe posobie v 6 tomakh. Tom II. Issledovanie ekologicheskogo sostoyaniya vodnykh ob''ektov* (Forensic Ecology: A Tutorial. Volume II: Investigation of the Ecological State of Water Bodies), Moscow: Ross. Univ. Druzhby Narodov, 2018.
4. Venicyanov, E.V., Miroshnichenko, S.A., Lepikhin, A.P., and Gubernatorova, T.N., *Vodn. Khoz. Rossii: Probl., Tekhnol., Upravl*., 2015, no. 3, p. 50.
5. Davydova, O.A., Klimov, E.S., Vaganova, E.S., and Vaganov, A.S., *Vliyanie fiziko-khimicheskikh faktorov na soderzhanie tyazhelykh metallov v vodnykh ekosistemakh* (Influence of Physicochemical Factors on the Heavy Metal Content of Aquatic Ecosystems), Ul'yanovsk: Ul'yanovsk. Gos. Tekh. Univ., 2014.
6. Danilov-Danil'yan, V.I., *Vodnye resursy mira i perspektivy vodokhozyaistvennogo kompleksa Rossii* (World Water Resources and Prospects of Waterworks Facilities in Russia), Moscow: Tipografiya LEVKO, 2009.
7. Dzhamalov, R.G., Medovar, Yu.A., and Yushmanov, I.O., *Analiz, prognoz i upravlenie prirodnymi riskami v sovremennom mire (GEORISK-2015)* [Analysis, Prognosis, and Management of Natural Risks in the Modern World (GEORISK-2015), Moscow, 2015, p. 176.
8. Nurtaeva, K.S. and Tarakova, K.A., *Mezhdunar. Zh. Eksp. Obraz*., 2016, no. 6, p. 223.

9. Chernykh, N.A. and Sidorenko, S.N., *Ekologicheskii monitoring ekotoksikantov v biosfere* (Environmental Monitoring of Pollutants in the Biosphere), Moscow: Ross. Univ. Druzhby Narodov, 2003.
10. Bui Thi Nga and Nguyen Van Tho, *Tạp chí Khoa học*, 2009, vol. 11, p. 356.
11. Ferati, F., Kerolli-Mustafa, M., and Kraja-Ylli, A., *Environ. Monit. and Assess*., 2015, vol. 187, p. 338. https://doi.org/10.1007/s10661-015-4524-4
12. Karadede-Akin, H. and Unlu, E., *Environ. Monit. Assess*., 2007, vol. 131, p. 323. https://doi.org/10.1007/s10661-006-9478-0
13. MacDonald, D.D., Ingersoll, C.G., and Berger, T.A., *Arch. Environ. Contam. Toxicol*., 2000, vol. 39, p. 20. https://doi.org/10.1007/s002440010075
14. Salati, S. and Moore, F., *Environ. Monit. Assess*., 2010, vol. 164, p. 677. https://doi.org/10.1007/s10661-009-0920-y
15. Chernykh, N.A., Cuong, N.T., Chan, H.K., Baeva, Y.I., and Grachev, V.A., *J. Pharm. Sci. Res*., 2018, vol. 10, no. 4, p. 800.
16. Baeva, Y.I., Chernykh, N.A., Kurganova, I.N., Lopes de Gerenyu, V.O., and Ovsepyan, L.A., Abstracts of Papers, *19th Int. Multidisciplinary Scientific Geoconference* (SGEM 2019), 2019, p. 483. https://doi.org/10.5593/sgem2019/3.2/S13.063
17. Kikuchi, T. and Furuichi, T., Huynh Trung Hai, and Tanaka S., *Bull. Environ. Contam. Toxicol*., 2009, vol. 83, p. 575. https://doi.org/10.1007/s00128-009-9815-4
18. Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M., and Kouimtzis, Th., *Water Res*., 2003, vol. 37, p. 4119. https://doi.org/10.1016/S0043-1354(03)00398-1
19. Vega, M., Pardo, R., Barrado, E., and Deban, L., *Water Res*., 1998, vol. 32, no. 12, p. 3581.
20. Nguyen, T.T., Yoneda, M., Shimada, Y., and Matsui, Y., *Environ. Earth Sci*., 2015, vol. 73, no. 7, p. 3925. https://doi.org/10.1007/s12665-014-3678-7
21. Gaur, V.K., Sanjay, K.G., Pandey, S.D., Gopal, K., and Misra, V., *Environ. Monit. Assess*., 2005, vol. 102, p. 419. https://doi.org/10.1007/s10661-005-6395-6
22. Kumar, R.N., Solanki, R., and Kumar, J.I.N., *Environ. Monit. Assess*., 2013, vol. 185, p. 359. https://doi.org/10.1007/s10661-012-2558-4
23. Manoj, K., Padhy, P.K., and Chaudhury, S., *Bull. Environ., Pharmacol. Life Sci*., 2012, vol. 1, no. 10, p. 7.
24. Kucuksezgin, F., Uluturhan, E., and Batki, H., *Environ. Monit. Assess*., 2008, vol. 141, p. 213. https://doi.org/10.1007/s10661-007-9889-6
25. Nguyen, T.L.H., Ohtsubo, M., Li, L.Y., and Higashi, T., *J. Fac. Agric., Kyushu Univ*., 2007, vol. 52, no. 1, p. 141.
26. Nguyen, T.L.H., Ohtsubo, M., Li, L.Y., Higashi, T., Nguyen, T., Yoneda, M., Ikegami, M., and Takakura, M., *Environ. Monit. Assess*., 2013, vol. 185, p. 8065. https://doi.org/10.1007/s10661-013-3155-x
27. Huong, N.T.L., Ohtsubo, M., Higashi, T., and Kanayama, M., *Soil Sediment Contam*., 2012, vol. 21, p. 364. https://doi.org/10.1080/15320383.2012.649379
28. Nguyen, T.L.H., Kanayama, M., Higashi, T., Le, V.C., Doan, T.H., and Chu, A.D., *J. Fac. Agric., Kyushu Univ*., 2014, vol. 59, no. 1, p. 143.
29. Borrego, J., Morales, J.A., Torre, M.L., and Grande, J.A., *Environ. Geol*., 2002, vol. 41, p. 785. https://doi.org/10.1007/s00254-001-0445-3
30. Sanchiz, C., García-Carrascosa, A.M., and Pastor, A., *Marine Ecol*., 2000, vol. 21, no. 1, p. 1. https://doi.org/10.1046/j.1439-0485.2000.00642.x
31. Hejabi, A.T., Basavarajappa, H.T., Carbassi, A.R., and Monavari, S.M., *Environ. Monit. Assess*., 2011, vol. 182, p. 1. https://doi.org/10.1007/s10661-010-1854-0
32. Raju, K.V., Somashekar, R.K., and Prakash, K.L., *Environ. Monit. Assess*., 2012, vol. 184, p. 361. https://doi.org/10.1007/s10661-011-1973-2