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Chemoecological Monitoring of Water Quality in the Ham Luong River (Mekong Delta, Vietnam)

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Abstract: Investigation of concentrations of organic and inorganic pollutants (hydrocarbons, including oil hydrocarbons, and trace elements – heavy metals and metalloids) in the Ham Luong River in the Mekong Delta was carried out and water quality was assessed by comparing the obtained levels of values with the regulatory limits of concentration. The determination of the total content of hydrocarbons and oil hydrocarbons was made by gas chromatography method; the trace elements were measured by ICP-MS technique after chemical treatment of samples. The content of oil hydrocarbons in the Ham Luong River water ranged from 0.042 to 0.076 mg/l. These values were quite high, exceeding the sanitary standard (0.05 mg/l) for fishery reservoirs, or approaching it, but they were lower compared to Vietnam national standard for domestic supply water (0.1 mg/l). The content of hydrocarbons in suspended matter was in the range of 0.011–0.37 mg/l. The concentrations of 15 trace elements were studied, nine of them (Ni, Fe, V, As, Se, Be, Cd, Sb, Tl) did not exceed any of the established regulatory limits of concentration for surface water. However, concentrations of six trace elements (Pb, Zn, Cu, Co, Ag, Mo) were found to exceed the standard regulatory limits. Among the studied 15 trace elements, critical and potentially critical elements were identified, which are subject to primary monitoring control. Chemoecological studies of water quality are important for monitoring of the ecological and sanitary water state for ensure the quality of consumed natural resources and to preserve the biological diversity of the Mekong Delta ecosystems.

Keywords: water quality, oil hydrocarbons, heavy metals, metalloids, pollution, Ham Luong River, Mekong Delta, Vietnam.

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RESEARCH ARTICLE

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1. Introduction

The Mekong Delta is one of the most important river systems in Vietnam. The area of the Mekong Delta is about 39,000 km^2, which is 13% of the country's territory. The population living in the Mekong Delta is about 18 million people (19% of the country's population). It contributes to 75% of Vietnam's total agricultural-fishery-forestry production, over 50% of agricultural exports, and 90% of rice exports [*Dinh et al.*, 2019]. However, indiscriminately disposed waste and sewage discharge along the river's length has turned the Mekong into one of the world's ten most polluted rivers. The waste includes pollutants coming from land, such as untreated waste and waste water, hazardous substances, heavy metals, oil and oil products – a result of domestic, agricultural and industrial activities. The Ministry of Natural Resources and Environment reports the total annual discharge of all rivers of the country to be 880 km^3 of water and about 270–330 million tons of alluvium, carrying pollutants to the ocean [*Viet Nam News*, 2016].

The oil pollution is becoming more and more serious. In theory, the 0.1 mg per liter concentration is large enough to kill plankton species and affect larvae of benthic organisms. In addition, one of the most toxic technogenic substances are heavy metals and metalloids, which, being trace elements, and depending on the toxicity class they can have a toxic effect on living organisms in micrograms and smaller amounts [*Kostyleva and Racheva*, 2016]. These substances are subject to monitoring observations in aquatic ecosystems, and especially in rivers, whose waters often bring substances from vast catchment basin of the river system.

The Mekong is a trans-boundary river that runs through China, Myanmar, Laos, Thailand, Cambodia, and finally Vietnam before discharging into sea. It moves 475 km^3 of water annually and supports over 70 million people who rely on it as their main source of water. The Mekong River enters the territory of Vietnam in the form of 2 branches (the Hau River and the Tien River) each 200–250 km long. Both rivers are further divided into a vast general delta, the arms of which flow into the East Sea. The Tien River (R.) is divided into 6 branches (My Tho R., Ba Lai R., Cua Dai R. (forks at the sea into Cua Dai R. and Cua Tieu R.), Ham Luong R. and Co Chien R.) [*Phung*, 2015]. The Ham Luong R. was chosen as the object of research as the largest and the most full-flowing branch of the Tien R. Ham Luong R. is about 70 km long, with a width of up to 2800 m and an average depth of 11.3 m [*Phung*, 2015].

The Ham Luong R., like all branches of the Mekong Delta, serves as a source of fish, shrimp, shellfish, as well as a source of drinking water and for water supply of irrigated agricultural lands for growing rice and fruits. The food products obtained are used both to satisfy the country's internal needs and to make up a significant part of the state's exports. At the same time, its riverbed serves as a transport system in the region and a recipient of wastewater from industrial, agricultural and domestic sources. Studies conducted in the rivers of Vietnam indicate the presence of elevated concentrations of certain heavy metals in river ecosystems [*Ngo*, 2018; *Pham*, 2011; *Savichev and Phung*, 2014; *Tereshchenko et al.*, 2023]. Therefore, the assessment of the ecological state of the waters in the Ham Luong R. is relevant in the modern period – the time of accelerating development of the country's economy. In this regard, the purpose of this work was to determine the water concentrations of pollutants of organic and inorganic nature (hydrocarbons, including oil hydrocarbons, and trace elements, including heavy metals and metalloids) throughout the entire riverbed of the Ham Luong R. in the Mekong Delta and to assess the water quality on the basis of accepted values of the regulatory limits of concentration.

2. Material and methods

Water samples were taken along the entire course of the Ham Luong R. from the sea to the Tien R. at stations 1–6 (Figure 1) in November–December 2022. Samples at each station were taken on the cross section of the channel at 3 points (near each bank and in the center of the river channel) in 2 replicates. Thus, for each station, the average value of the concentration of trace elements in surface water was determined from three sampling points. Bottom water was sampled only in the center of the riverbed. Sampling was carried out at high tide as a rule. At station 1, samples were taken at low tide and high tide. The results of the analysis of water samples for the determination of hydrocarbons, including oil hydrocarbons, are presented for st. 1–5. The location of the stations was chosen in order to study possible zones of salinization of the waters of the Ham Luong R. (seaward part) and freshwater areas, as well as taking into account the location of large industrial and urban facilities along its banks (Figure 1).

2.1. Hydrocarbon determination method

The determination of the total content of hydrocarbons in suspended matter and the concentration of oil hydrocarbons in filtered river water was performed. To obtain

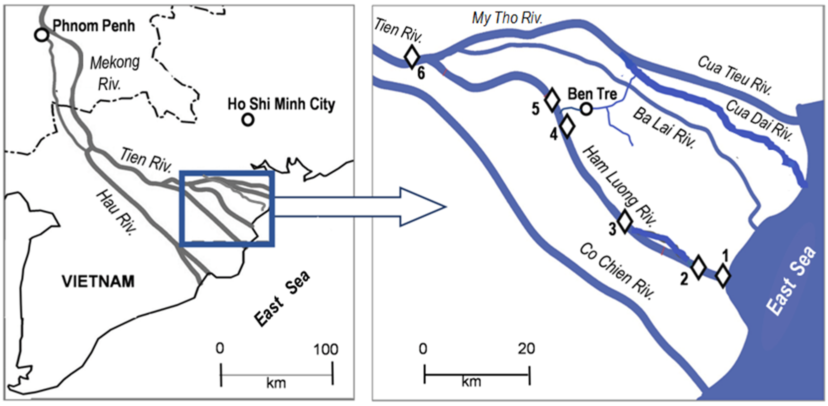

Figure 1. Study areas. Location of sampling sites on the Ham Luong River in the Mekong Delta, where the stations are marked with rhombs (the location of cross sections from three points on the riverbed).

a suspended matter, vacuum filtration was carried out using a vacuum pump, a Bunsen flask, a filter unit, and nitrocellulose membrane filters with a pore size of 0.45 µm. The volume of filtered river water varied depending on the concentration of suspended matter in water and was taken into account when recalculating the content of hydrocarbons in suspended matter. The filters were dried in natural conditions and stored in a desiccator and transported in sealed zip-lock bags.

Pretreatment of water samples was fulfilled under laboratory conditions by extraction with n-hexane according to the procedure [*Barabashin*, 2018].

Determination of hydrocarbons was made by chromatography on a chromatograph "Crystal 5000.2". Quantitative determination of their content was carried out by absolute calibration of the FID with a hydrocarbon's mixture (standard sample ASTMD2887 Reference Gas Oil (SUPELCO, USA). To process the results of determining the hydrocarbons concentrations, the Chromatek Analytic 3.0 software was used (the method of absolute calibration and percentage normalization). Correlation analysis ($p = 0.05$) was performed using the Microsoft Excel 2010 analysis package.

2.2. Heavy metals and metalloids determination method in water

In surface and near-bottom water, 15 trace elements were determined – heavy metals and metalloids (Be, V, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Sb, Tl, Pb) in dissolved form. They included some of the most toxic elements recommended for monitoring in natural waters, as well as a list of elements determined by the capabilities of the analytical method used for the chemical quantitative determination of the trace element composition of waters [*Gidrometeoizdat*, 1993; *Mirzoeva et al.*, 2020]. To define the dissolved form of trace elements in water, the samples of river water were filtered through nitrocellulose membrane filters with a pore size of 0.45 µm. Filtered water was processed in the laboratory according to the guidance document [*Gidrometeoizdat*, 1993], with subsequent measurement of trace elements in the prepared acid extracts from samples on a mass spectrometer with inductively coupled plasma (ICP-MS) PlasmaQuant MS Elite (Analytik Jena AG) in accordance with [*Analytik Jena AG*, 2014; *Mirzoeva et al.*, 2020; *SS R 56219-2014*, 2015]. The mass spectrometer was calibrated using the standard solution "Multi-element calibration standard IV-28, HNO3/HF, 125 ml" (Inorganic Ventures). The calculation and presentation of the measurement results were performed in accordance with the regulatory documents [*Gidrometeoizdat*, 1993; *SS R 56219-2014*, 2015]. The average relative error in the determination of trace elements was no more than ±10% for all studied heavy metals and metalloids in samples of natural river water.

Measurement of hydrocarbons and trace elements was made on equipment of the Scientific and Educational Center for Collective Use "Spectrometry and Chromatography" of the IBSS.

The assessment of the chemoecological state of the river water was fulfilled by comparing the obtained levels of trace element concentrations with the standard regulatory limits – maximum permissible concentration (MPC) and target value for surface water (TV). National standard values – MPC_V – from the National Technical Regulation for Surface Water Quality in Vietnam (NTR) [*NTR-2015*, 2015] were used as well. For comparative analysis, the standard values of concentrations accepted in other countries were also used: MPC_{FP} – for waters of reservoirs for fishery purposes (Russian Federation) [*Kostyleva and Racheva*, 2016], as well as TV_N (the limit of safe concentration, the non-exceeding of which ensures the absence of a negative impact on biota) and MPC_N (the limit of permissible concentration, the excess of which leads to a significant negative impact of pollutants on biota) (Netherlands) [*Warmer and van Dokkum*, 2002]. According to the Regulations of Vietnam, standard values were used for surface water sources of category A1 – sources for household use and conservation of flora and fauna [*NTR-2015*, 2015].

The obtained concentrations of oil hydrocarbons in water were compared with the sanitary standard for fishery reservoirs (MPC = 0.05 mg/l) in Russia [*SanPIN 1.2.3685-21*, 2021] and Vietnam national standard for domestic supply water (0.1 mg/l). [*TCVN5502:2003*, 2003] as well as MPC for surface water of category A – 0.3–0.5 mg/l [*NTR-2015*, 2015].

Determination of station metadata and measurement of some physical and chemical characteristics of water (temperature, salinity S, pH, Eh, TDS, concentration of dissolved oxygen) were performed using a ProDSS–Professional Digital Sampling System (YSI, USA) multi-parameter measuring instrument (measurement errors did not exceed: pH ± 0.01; Eh ± 0.5 mV; TDS ± 1 mg/l; S ± 0.01 PES, DO ± 0.001 mg/l; T ± 0.15 °C) with built-in GPS navigator to determine the location of sampling stations – equipment of the Environmental Analysis Laboratory of Southern Branch of Joint Vietnam-Russia Tropical Science and Technology Research Center, Ho Chi Minh City.

3. Results and discussion

3.1. Physicochemical parameters of water in the Ham Luong River in rainy season

Measurement of the physicochemical parameters of the river water was carried out to characterize them as independent indicators of water quality, the deviation of which from the standard regulatory limits can lead to negative consequences for hydrobionts and affect the quality of water and other natural resources of rivers. In addition, these measurements were performed in order to study the degree of water salinization, its magnitude and distance of spreading along the riverbed of the Ham Luong R., as well as possible impact of salinization on the levels of technogenic substances concentrations.

Average values of measured physicochemical parameters of water in investigated areas of the Ham Luong R. present in Table 1.

Bold type in the Table 1 indicates the values of the studied parameters that did not comply with the NTR of Vietnam for surface water of category A1.

One of the normalized water quality parameters is the concentration of dissolved oxygen in water (DO). During the rainy season in November-December 2022 in the Mekong Delta, the concentrations of DO in surface water of Ham Luong R. were below the standard for water of category A1 (≥6 mg/l) at almost all stations. Only at the st. 1 – the closest station to the sea – concentrations of DO higher than 6 mg/l were observed during a high tide (Table 1). The hydrogen index (pH) in the water at all the stations studied did not go beyond the range of standard values, according to the NTR. Water salinization was observed during high tide at all points of st. 1. It changed from 6 PSU in surface water to 14 PSU in bottom water. At low tide, salinity increased much less than at high tide: from 0.4 PSU in surface water to 0.8 PSU in bottom water. With distance from the sea, increased water salinity was noted only at st. 2 in bottom water in a high tide, at other stations in Ham Luong R. the levels of salinity values corresponded to fresh water (Table 1). The DO

Table 1. Average values of physicochemical characteristics in November-December 2022 in surface and measured values in near-bottom (B) waters in the Ham Luong River in Mekong Delta where: LT is a low tide period; HT – a high tide period, DO – dissolved oxygen.

Station no	DO, mg/l	S, PSU	TDS, mg/l	T, °C	Eh, mV	pH
1-LT	5.8	0.41	540	28.8	10.2	7.58
1-LT-B	—*	0.80	—	29.0	—	6.90
1-HT	6.38	6.25	9117	28.9	10.1	7.66
1-HT- B	—	13.90	—	—	—	6.40
2-HT	5.58	0.15	203	29.0	12.2	7.57
2-HT-B	—	5.40	—	29.0	—	6.20
3-HT	5.14	0.08	122	28.9	15.7	7.49
3-HT-B	—	0.0	—	29.0	—	6.08
4-HT	5.27	0.08	109	29.0	11.1	7.42
4-HT-B	—	0.0	—	29.2	—	6.80
5-LT	5.19	0.08	108	29.3	9.9	7.38
5-LT-B	—	0.0	—	29.6	—	6.80
6-LT	4.78	0.07	97	29.4	21.2	7.22
6-LT-B	—	0.0	—	29.5	—	7.00

* no data.

concentrations were higher and salinity values – lower in the rainy season in 2022 in Ham Luong R. compared to those in the dry season in May 2021. In the dry season at station 4, the DO concentration was below 4 mg/l, and a salinity of 13 PSU was observed even at station 3 [*Russian-Vietnamese Tropical Center*, 2023].

3.2. Hydrocarbons in the Ham Luong River water and suspended matter

Oil hydrocarbon's content in the water of the investigated branch – the Ham Luong R. – ranged from 0.042 to 0.076 mg/l, averaging 0.061 ± 0.019 mg/l (Figure 2). These concentrations were quite high, in some cases they exceeded the sanitary standard for fishery reservoirs (MPC = 0.05 mg/l) [*SanPIN 1.2.3685-21*, 2021], in other cases they approached its value. Since the river studied is used both for fishing and for aquaculture, these values of concentrations characterize the state of its waters as unsatisfactory. On the other hand, the level of oil hydrocarbon concentration in water of the Ham Luong R. from this study was significantly lower compared to values reported in some regions including Buffalo R. of South Africa [*Abdullah et al.*, 1996; *Adeniji et al.*, 2017; *Li et al.*, 2010]. The observed levels were also lower than Vietnam Quality requirements for domestic supply water – 0.1 mg/l [*TCVN5502:2003*, 2003] as well as than MPC for surface water of category A – 0.3–0.5 mg/l [*NTR-2015*, 2015].

The obtained concentrations of hydrocarbons depended on the presence of the source of their input. Near the settlements and when approaching the seawater area, the values increased and corresponded to a similar pattern of concentration changing in other water bodies. For example, in Don R., where concentrations in the range of 0.03–0.04 mg/l were recorded in its waters far from settlements, near the large settlements content in water increased to 0.10 mg/l. In Don R. water in the area of the port of Ust-Donetsk, the highest concentrations were noted – up to 0.122 mg/l [*Stepanyan and Kharkovsky*, 2020].

The hydrocarbons content in suspended matter was in the range of 0.011–0.37 mg/l, averaging 0.019 ± 0.009 mg/l (Figure 2). The hydrocarbons total content in suspended matter was in the range of 0.011–0.037 mg/l, averaging 0.019 ± 0.009 mg/l (Figure 2). It should be noted the increase in the content of hydrocarbons in the suspended phase in the water at area of st. 1 compared to upstream sections of the river. This fact may be associated with the transition of substances from a dissolved to a suspended state with an increase of water salinity in the river-sea mixing zone (Table 1), as it was observed earlier in the zone of geochemical barriers in other regions of the oceans [*Nemirovskaya*, 2004].

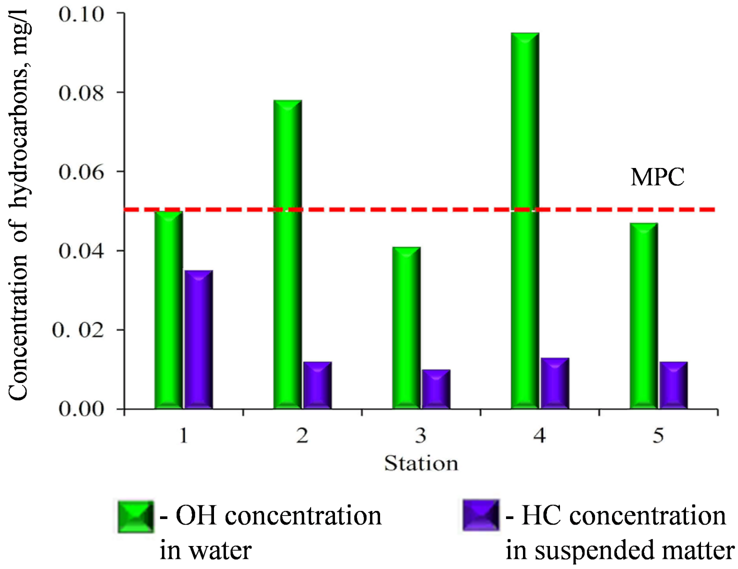

Figure 2. Concentrations of hydrocarbons at stations of the Ham Luong River in Delta Mekong, where OH – oil hydrocarbons in water; HC – hydrocarbons total content in suspended matter and MPC – maximum permissible concentration for fishery reservoirs [*SanPIN 1.2.3685-21*, 2021].

The share of hydrocarbons in suspended matter accounted from 20 to 75% (average 34±21%) from the total content of hydrocarbons in water. That is, the range of values was quite wide.

3.3. Heavy metals and metalloids

The obtained results on the determination of the dissolved form of trace elements concentration in the surface water of the Ham Luong R. are presented in Table 2, which shows the mean concentrations of trace elements at the stations.

Analysis of the elements concentrations presented in Table 2 showed that in general for most trace elements (Ni, Co, V, Cu, Se, Ag, Be, Sb) their concentrations were characterized by limited variability, differing from each other at the studied stations by 2–3 times within the same order of magnitude. For another group of the investigated trace elements (Fe, Pb, As, Zn, Cd, As, Tl), the variability was more pronounced and the concentration values at individual stations exceeded those at other stations by an order of magnitude. It was noted that for Fe, Cd, Tl, Pb, and Zn, the highest concentrations were found at station 6 in the riverbed of the Tien R. This indicated the inflow of an increased amount of these elements from the upstream sections of the catchment basin of the Mekong R. Comparison of the heavy metals and metalloids concentrations at stations 3 and 4, showed that significant trace element pollution of the surface waters of the Ham Luong R. did not flow from the city of Ben Tre.

This is obviously, because the agricultural sector of the economy is mainly developed in the province and industry in it occupies about 30% of the city's economy. In addition, the confectionery and clothing industries are predominantly developed there [*Map of Vietnam*, 2008].

As well, the bottom waters were examined for the content of trace elements. The results of determining the trace elements concentration in the bottom water layer of the Ham Luong R. are presented in Table 3.

Table 2. Levels of heavy metals and metalloids concentrations in the surface water of the Ham Luong R. in November-December 2022 mainly at high tide during the wet season, where DL – detection limit.

Station no	Concentrations of trace elements in the surface water, µg/l				
	V	Fe	Co	Ni	Cu
	DL = 0.01	DL = 0.1	DL = 0.001	DL = 0.01	DL = 0.01
1	0.37 ± 0.03	2.6 ± 0.5	0.013 ± 0.003	0.60 ± 0.06	0.91 ± 0.08
2	0.28 ± 0.02	7.7 ± 1.0	0.285 ± 0.028	0.58 ± 0.06	0.86 ± 0.07
3	0.23 ± 0.02	11.8 ± 1.5	0.053 ± 0.006	0.68 ± 0.07	0.77 ± 0.08
4	0.29 ± 0.02	14.7 ± 1.6	0.049 ± 0.005	0.43 ± 0.04	0.75 ± 0.07
5	0.26 ± 0.02	16.4 ± 1.8	0.021 ± 0.003	0.51 ± 0.05	0.79 ± 0.06
6	0.18 ± 0.02	30.0 ± 2.3	0.011 ± 0.003	1.31 ± 0.09	0.72 ± 0.05
Station no	Zn	As	Se	Mo	Ag
	DL = 0.1	DL = 0.001	DL = 0.01	DL = 0.01	DL = 0.001
1	1.71 ± 0.29	0.135 ± 0.016	0.032 ± 0.028	0.100 ± 0.012	0.027 ± 0.020
2	2.86 ± 0.33	0.075 ± 0.011	<0.01	0.026 ± 0.004	<0.001
3	6.67 ± 0.57	0.053 ± 0.010	0.027 ± 0.017	0.068 ± 0.008	0.006 ± 0.004
4	3.08 ± 0.37	0.125 ± 0.014	0.031 ± 0.026	0.071 ± 0.008	0.021 ± 0.006
5	1.64 ± 0.20	0.129 ± 0.013	<0.01	0.068 ± 0.008	0.012 ± 0.004
6	17.71 ± 0.96	0.057 ± 0.009	0.021 ± 0.011	0.053 ± 0.007	0.005 ± 0.003
Station no	Cd	Sb	Tl	Pb	Be
	DL = 0.001	DL = 0.0001	DL = 0.0001	DL = 0.01	DL = 0.003
1	0.012 ± 0.003	0.004 ± 0.001	0.0036 ± 0.0012	0.03 ± 0.02	<0.003
2	0.007 ± 0.004	0.004 ± 0.001	0.0028 ± 0.0006	0.07 ± 0.02	<0.003
3	0.005 ± 0.002	0.006 ± 0.001	0.0031 ± 0.0005	0.04 ± 0.01	<0.003
4	0.007 ± 0.001	0.004 ± 0.001	0.0036 ± 0.0008	0.04 ± 0.01	<0.003
5	0.004 ± 0.003	0.003 ± 0.001	0.0038 ± 0.0009	0.04 ± 0.01	<0.003
6	0.022 ± 0.004	0.005 ± 0.001	0.0126 ± 0.0017	0.53 ± 0.10	<0.003

In general, the concentrations of trace elements in the bottom layer between stations varied within a narrower range than the concentrations in surface water, with the exception of Fe, whose concentration at st. 6 was an order of magnitude higher than that at st. 1.

At the same time, the concentrations in the bottom water layer exceeded the concentrations in the surface layer for such elements as Zn, Cd, Ni, Co, Mo, Tl, and vice versa for As and Pb, higher concentrations were determined in the surface water layer (Table 2, 3).

Consideration of the levels of trace elements concentrations at st. 1 during high and low tide indicates that the concentration of a number of elements (V, Co, Pb, Tl, Sb, Mo) was higher during the high tide, especially in the bottom layer, which indicates salty seawaters, moving along the bottom of the riverbed during high tide. Therefore, seawater can be considered as the source of introduction of these elements into the Ham Luong R. water (Figure 3).

Table 3. Levels of trace elements concentrations in the bottom water of the Ham Luong R. in November-December 2022 during the rainy season mainly at high tide, where DL – detection limit.

Station no	Concentrations of trace elements in the bottom water, μg/l				
	V	Fe	Co	Ni	Cu
	DL = 0.01	DL = 0.1	DL = 0.001	DL = 0.01	DL = 0.01
1	0.32 ± 0.01	2.5 ± 0.3	0.003 ± 0.002	0.98 ± 0.05	0.95 ± 0.04
2	0.21 ± 0.01	2.4 ± 0.3	0.013 ± 0.002	0.75 ± 0.04	0.78 ± 0.03
3	0.22 ± 0.01	5.1 ± 0.5	0.013 ± 0.002	0.89 ± 0.04	0.79 ± 0.04
4	0.30 ± 0.01	16.0 ± 1.1	0.016 ± 0.002	0.77 ± 0.04	1.03 ± 0.05
5	0.29 ± 0.01	14.4 ± 0.9	< 0.001	0.98 ± 0.04	0.80 ± 0.04
6	0.13 ± 0.01	27.0 ± 1.2	0.007 ± 0.001	1.28 ± 0.05	1.17 ± 0.05
Station no	Zn	As	Se	Mo	Ag
	DL = 0.1	DL = 0.001	DL = 0.01	DL = 0.01	DL = 0.001
1	3.01 ± 0.17	0.033 ± 0.006	0.039 ± 0.003	0.160 ± 0.008	0.018 ± 0.008
2	2.57 ± 0.19	0.011 ± 0.006	<0.01	0.267 ± 0.014	0.012 ± 0.004
3	11.00 ± 0.52	0.043 ± 0.005	<0.01	0.074 ± 0.003	<0.001
4	3.40 ± 0.18	0.073 ± 0.007	<0.01	0.059 ± 0.003	<0.001
5	2.16 ± 0.10	0.239 ± 0.012	<0.01	0.077 ± 0.004	<0.001
6	16.40 ± 0.62	0.042 ± 0.005	<0.01	0.040 ± 0.003	0.006 ± 0.003
Station no	Cd	Sb	Tl	Pb	Be
	DL = 0.001	DL = 0.0001	DL = 0.0001	DL = 0.01	DL = 0.003
1	0.006 ± 0.002	0.0037 ± 0.0009	0.0053 ± 0.0006	0.018 ± 0.006	<0.003
2	0.013 ± 0.002	0.0030 ± 0.0007	0.0041 ± 0.0005	0.022 ± 0.006	<0.003
3	<0.001	0.0062 ± 0.0008	0.0024 ± 0.0002	0.010 ± 0.005	<0.003
4	<0.001	0.0037 ± 0.0006	0.0038 ± 0.0005	0.045 ± 0.008	<0.003
5	<0.001	0.0035 ± 0.0006	0.0039 ± 0.0004	0.014 ± 0.006	<0.003
6	0.016 ± 0.002	0.0041 ± 0.0007	0.0029 ± 0.0004	0.054 ± 0.007	<0.003

For Zn and As at high tide, higher concentrations were observed only in the bottom layer.

For Be and Se, the concentrations at high and low tide were the same, and for Fe, Ni, Cd, Cu, Ag, the concentrations were lower at high tide (Figure 4).

The obtained levels of trace elements concentrations showed that according to the NTR, which regulates 6 elements: Pb, Zn, Cu, As, Cd, Ni, Fe in the surface water of the Ham Luong R., the established normative values (MPC_V) of concentrations for water sources of category A1 were not exceeded. It should be noted that the normative values of NTR are from 2 to 10 times higher than the standards adopted in other countries. Moreover, for the eight studied trace elements, the standard regulatory limit values in the NTR of Vietnam have not been established. In this regard, a comparison of the results obtained with the accepted regulatory limits of concentration in other countries was carried out. It was found that these standards (TV_N, MPC_N and MPC_{FP}) were exceeded for individual trace elements. The concentrations of nine trace elements among the studied ones (Ni, Fe, V, As, Se, Be, Cd, Sb, Tl) did not exceed any of the considered normative indicators. But for six elements, the found concentrations were above the normative values (Table 4).

The highest excess of the MPC_N was determined for Zn. Its concentration at station 6 was more than 3 time higher the MPC_N and more than 10 times the TV_N. In addition to

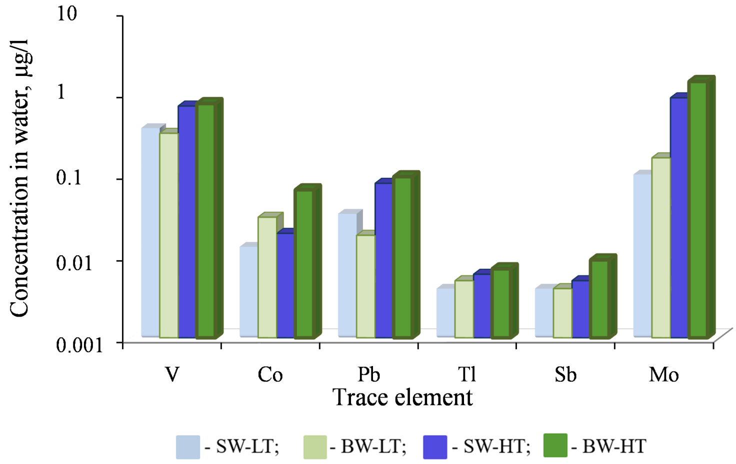

Figure 3. Concentrations of trace elements in the surface and bottom water at station 1 of the Ham Luong River during low tide and high tide, where SW – surface water, BW – bottom water, LT – low tide, HT – high tide.

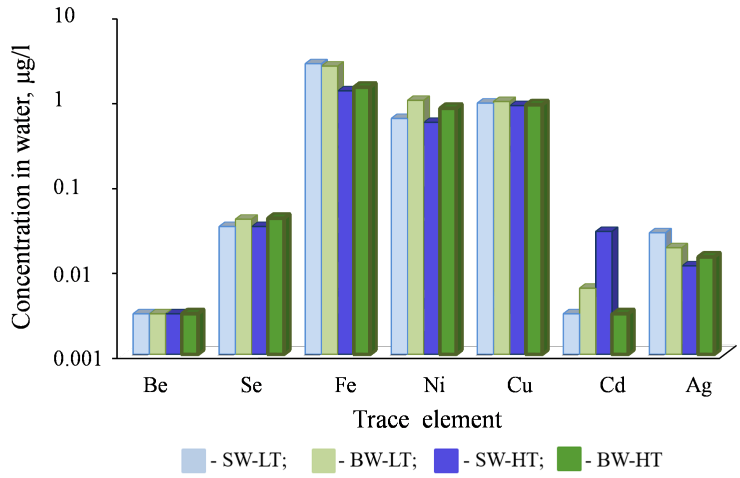

Figure 4. Concentrations of trace elements in the surface and bottom water at station 1 of the Ham Luong River during low tide and high tide, where SW – surface water, BW – bottom water, LT – low tide, HT – high tide.

Zn, at station 6, the TV_N exceeded the concentrations of Cu and Pb. Exceeding the TV_N for Zn and Cu was noted at all six stations studied. The excess of TV_N for Ag was recorded at four stations (st. 1, 2, 4, 5), and for Co – only at one station – 3 (Table 4). Exceeding the permissible concentration for fishery reservoirs – MPC_{FP} – was observed only in relation to Mo.

4. Conclusion

The use of modern techniques of mass spectrometry and chromatography has made it possible to obtain new data on the concentrations of a wider range of heavy metals and metalloids in water than previously studied, as well as oil hydrocarbons in water and total hydrocarbon content in suspended matter in the Ham Luong River. Based on the results obtained, a chemoecological reconnaissance analysis of the state of the quality of waters was carried out in one of the most full-flowing branches in the lower part of the Mekong Delta – the Ham Luong River.

The results obtained indicate that the levels of concentrations of some pollutants were more related to the inflow from the catchment basin of the river, while others enter the water of the river with seawater and suspended matter during high tides. The level of water salinity, as well as the deficiency of dissolved oxygen in the Ham Luong water, is much

Table 4. Range of trace elements concentrations in water (Cw) in the Ham Luong R. compared to the standard regulatory limits of concentration in surface waters (the bold type indicates the data exceeding one of the regulatory limits and the standard values being exceeded); n.d. – no data.

Element Trace	Range of Cw Value for 6 station, µg/l	MPC_{FP}, µg/l (station number with increased concentration Cw)	MPC_N, µg/l (station number with increased concentration Cw)	TV_N, µg/l (station number with increased concentration Cw)	MPC_V for sources of category A1, µg/l
Pb	0.10–1.333	10	11	0.3 (st. 6)	20
Cu	0.68–1.17	5	1.5	0.5 (st. 1–6)	100
Zn	1.01–8.07–31.61	50	9.4 (st. 6)	2.9 (st. 1-5)	500
Ni	0.39–1.28	10	5.1	3.3	100
Co	0.002–0.482	10	2.8	0.2 (st. 3)	n.d.
V	0.13–0.87	1	4.3	0.9	n.d.
As	0.007–0.255	10	25	1.0	10
Ag	0.012–0.043	n.d.	1.2	0.01 (st. 1,2,4,5)	n.d.
Mo	0.014–1.383	1	290	4.3	n.d.
Cd	< 0.002–0.061	10	0.4	0.08	5
Se	< 0.002–0.042	2	5.3	0.09	n.d.
Sb	0.0024–0.0088	n.d.	6.5	0.4	n.d.
Fe	0.46–32.35	100	n.d.	n.d.	500
Be	<0.003	0.3	0.2	0.02	n.d.
Tl	0.0024–0.0070	n.d.	1.6	0.06	n.d.

higher in the dry season of the year compared to the rainy season. Therefore, monitoring studies of river water quality should cover different seasons of the year.

It is shown that the excess of the installed regulatory limits of concentration was observed only in relation to a part of trace elements and oil hydrocarbons in the water, and the concentration of dissolved oxygen was below the standard value at all stations of the river, with the exception of the seaward st. 1 in rainy season.

Critical pollutants include Zn, Mo and oil hydrocarbons, the concentrations of which exceed the established MPCs, can have a significant negative impact on living organisms and therefore they are subject to priority attention. Potentially critical substances include trace elements (*Pb*, *Co*, *Cu*, *Ag*), whose concentrations exceeded the safe concentration limit (TV_N), the non-exceeding of which ensures the absence of a negative impact on biota, and therefore they are subject to monitoring as well.

With regard to critical pollutants, it is necessary to carry out primary regular monitoring and take measures to identify the main sources of pollutant entry and reduce their entry into the riverbed of Ham Luong R. to reduce the levels of modern concentrations of these substances. Potentially critical elements require periodic monitoring to track further changes in their concentration levels in river waters. It is important to take timely measures to improve the chemoecological state of the waters to ensure the proper quality of the river water itself and the biological resources of the river, which are widely used as food and food raw materials both to meet the country's domestic needs and to export products.

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