Heavy Metal Concentrations in Hard Clam *Meretrix lyrata* and the Coastal Environment of Tien River Estuary, Mekong Delta

Viet Tuan Tran, Phuoc-Dan Nguyen, Quoc-Tuc Dinh, Huu-Viet Nguyen, Emilie Strady, and Sunghee Han

***Abstract*—The coastal area surrounding Mekong Delta-Vietnam (MDV) is one of the largest clam farming sites in Vietnam. Furthermore, previous studies showed that the rapid growth of urbanization, industrialization, and agriculture lead to the contamination of heavy metals in MDV. Therefore, this study is aimed to evaluate the presence of cadmium (Cd), cooper (Cu), lead (Pb) and zinc (Zn) in sea water, sediment, as well as hard clam (*Meretrix lyrata*) around coastal area of Tien River Estuary named Tan Thanh. The results showed that all studied metals' concentrations in sediment were lower than the limits of marine sediment quality guidelines, except Zn. The levels of studied metals in clam samples were less than the maximum values of metals in food which regulated by Commission Regulation 1881/2006 and some countries. Concentrations of Cd, Cu, Pb and Zn in the clam flesh were ranging between 0.01 and 1.34 mg kg^{-1}, 1.1 and 15.8 mg kg^{-1}, not detected and 0.6 mg kg^{-1}, as well as 9.9 and 192.5 mg kg^{-1}, respectively. Among the studied metals, Cd is considered as the most influential parameter for the health risk assessment of local clam consumers. According to this study, the daily intake of 100 g clam flesh (wet weight) is recommended as the largest amount of clam for local consumers.**

***Index Terms*—Heavy metals, safe daily intake, sediment, white hard clam, *Meretrix lyrata*.**

I. Introduction

Mekong Delta, Vietnam (MDV) plays an important role in the economic development of Vietnam. The rapid growth of urbanization, industry, and agriculture in MDV during the recent years has resulted in the presence of high concentrations of trace metals as well as other contaminants in the aquatic habitat and organisms [1]. Some previous studies reported that water in the urban areas and the estuaries of Tien and Hau Rivers, which are the two distributaries of Mekong River in MDV, was contaminated with organic, nitrogen, and trace metals [2]–[7]. Indeed, sediment in the river estuary can significantly contain trace metals [8]–[10]. The Cu, Pb and Cr concentrations in the sediment in Tien River estuary were presented to exceed the thresholds of the Canadian Interim Sediment Quality Guidelines (ISQG) and the Probable Effect Level (PEL) of US National Oceanic and Atmospheric Administration (NOAA) [4], [5]. The levels of trace metals in both soluble and particulate phases can influence the concentrations of these elements in the tissue of organisms [8], [11], [12]. Ikemoto *et al*. claimed that concentrations of Se, Rb, and Hg were found in the aquatic animals through an increase of the trophic level at one sampling site of Hau River. That study also revealed that high concentrations of Mn, Cu, Zn, As, Sr, Mo, Ag, Cd, Sb, Cs, Ba, Tl and Pb had occurred in crustaceans, while fish contained high levels of Cr, Rb and Hg [7].

At the estuary areas, the complicated interaction between fluvial and marine processes act as a geochemical filter. The entrapment and adsorption of metals on the fine-grained sediment and clay particles could be increased because of salinity variation at the estuary areas [13]. In addition, fishery, industrial, transportation and recreational activities surrounding the river estuaries may increase the trace metals contamination in aquatic environment [14]. As a result, organisms such as oyster or hard clam, which live around the estuarine areas may be exposed to trace metals at a high level. Higher metal concentrations in hard clam flesh were found in comparison with those in their living habitat [15]–[17]. In other studies, high average concentrations of Cu, Ni, Cd, Zn, Fe, Pb, and Mg were observed in mollusks living in the coastal area [12], [15], [18], [19]. The concentrations of Fe, Cu, and Cd in clams collected at Loreto, Gulf of California were 572, 181, and 4.6 mg kg^{-1} in dry weight, respectively [15]. Furthermore, several families of bivalve mollusks such as mussels and clams were suggested using as biomonitors for metallic monitoring in the environment [19], [20].

Some metals, such as Pb and Hg, have not involved into biological functions [21]. Therefore, their existence in seafood is considered as a potential risk to human health [22], [23]. Thusly, the Commission Regulation (EC) has issued the maximum levels (MLs) of trace metals in seafood, such as Cd (1 mg kg^{-1}) and Pb (1.5 mg kg^{-1}) in bivalve mollusks, and Hg (0.5 mg kg^{-1}) in seafood [24]. Until now, the European Union (EU) has not issued MLs of As, Ni, and Cr in food. However, the European Food Safety Agency (EFSA) has provided the provisional tolerable weekly intake (PTWI) of As (15 mg kg^{-1} body weight) in 2009 [25], the tolerable daily intake (TDI) of Cr(III) (300 mg kg^{-1} body weight) in 2014 [26] and Ni (2.8 mg kg^{-1} body weight) in 2015 [27]. Besides, the US.EPA [28] suggested the hazard quotient (HQ) and hazard index (HI) could be used to estimate the risk of each single toxicant to human health via a single pathway like ingestion.

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Hard clam is a high economic value species that have been cultured in the coastal areas of Vietnam. Vietnam Association of Seafood Exporters and Producers (VASEP) reported that Vietnam was the second biggest supplier for the processed clams in the world [29]. An average of 2,300 hectares in MDV coastal area are used as hard clam farms. About 20,000-40,000 tons of hard clam are produced each year and most of them (up to 17,000 tons) are exported [30]. In 2019, only in Tan Thanh, 2,200 hectares of hard clam farm were established [31].

Therefore, this study is aimed to (1) determine Cu, Zn, Pb, and Cd concentrations in hard clam (*Meretrix lyrata*) and its habitat including water and sediment at clam farms; and (2) to assess the potential health risk of these metals to local clam consumers.

II. Materials and Methods

A. Study Area

During the dry and wet seasons in 2014 and 2015, sea water, sediment, and *Meretrix lyrata* samples were collected at the hard clam farm (10^{o}17’25.46” N and 106^{o} 47’20.1” E) which were located in Tan Thanh area. This place is about 3-5 km away from the Tieu Estuary, Tien River, Mekong Delta (Fig. 1).

Fig. 1. Sampling area.

B. Sampling and Preparation Methods

About 30 *M. lyrata* individuals were collected during low tide to make one composite sample. In this study, only the hard clam from 8 to 12 months-old were chosen for sampling. In the laboratory (Centre Asiatique de Recherche sur l’Eau (CARE) Laboratory), mud and debris were removed from the hard clam by washing them with tap water and MilliQ water (Fig. 2a). Subsequently, the clam flesh was removed from its shell using a sterile stainless-steel knife [32] (Fig. 2b). The flesh was dried using an oven at 60 ℃ for 72 h [33]. An amount of 1 g of dried clam flesh was ground into fine powder using a porcelain pestle and mortar. Homogenized sample was stored in an air-tight zip bag for the next step.

During low tide, around the *M. lyrata* sampling areas, about 200 g of surface sediment at three points was collected for one composite sample using a Ponar sediment grab sampler. All samples were immediately stored in an icebox during the transportation from the sampling site to the laboratory within 12 h. The sediment samples were dried in an oven at 60^{o}C for about 5-6 h until their weight were stabilized. Then they were milled to powder before the digestion process and metals analysis.

During high tide, sea water was measured on-site the physico-chemical parameters including temperature, pH, dissolved oxygen (DO), salinity and electronic conductivity (EC) using a multi-parameter probe (WTW 3420). Then, the sea water was collected at 10-50 cm below the water surface using a Niskin non-metallic water sampling bottle (General Oceanics®). One aliquot of water sample was filtered immediately using 0.45 μm Whatman® cellulose acetate (WCA) filter paper. The filtrate was acidified at pH less than 2.0 using HNO_3 solution (Normapur HNO_3) and then stored in acid pre-cleaned PP bottle for metals analysis. Another aliquot of water sample was stored in 5 L PE bottles for other parameter analysis in the laboratory including hardness, alkalinity, chloride, sulphate, nitrogen and phosphorous. All samples were preserved in an ice box (~ 4 ℃) and transported to the laboratory.

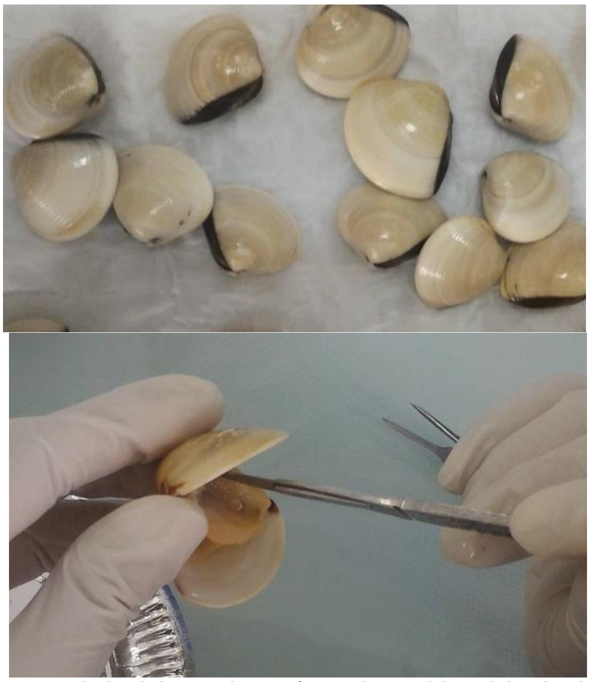

Fig. 2. (a) The hard clams *M.lyrata* after washing in lab; and (b) The clam flesh was removing from its shell.

C. Digestion of the Samples

Firstly, a mixture of 2 ml perchloric acid and nitric acid (HNO_3:$HClO_4$ 1:1 v/v) and then 5 ml of concentrated sulfuric acid (H_2SO_4) were added into the dried sediment and hard clam samples (NovaWave SCP Sciences®, CARE $HClO_4$, HNO_3, H_2SO_4; Trace Metal grade Fisher®). Secondly, samples with the acid solution reflux were digested at 200 ℃ for 30 minutes in a clean fume chamber. Then, the completely digested samples were cooled down to room temperature before they were filtered using 0.45 μm WCA filter papers. Finally, the filtrate was diluted to 50 ml in volumetric flasks with 2% HNO_3 solution [34].

D. Determination of Heavy Metals

Heavy metals (Cd, Cu, Pb, and Zn) in sea water, *M. lyrata* and sediment samples were analyzed according to US EPA method 200.7 by ICP - OES [35] at the CARE laboratory in Ho Chi Minh City University of Technology. Replicate analyses were conducted for 10% of the samples to evaluate precision of the analytical techniques. Each sample of water, sediment and hard clam was analyzed three times.

E. Risk Assessment

In this study, the hazard quotient (HQ) was used to determine the health risk to local people consuming metal-contaminated hard clams. The HQ was calculated by the equation (1) as follows [28]:

$$HQ = \frac{EDI}{RfD} = \frac{C_{bivalve} * \frac{dc_{bivalve}}{bw}}{RfD} \quad (1)$$

where *bw* is body weight (kg). The average body weight of local people was 60 kg, which similar with the Asian body weight of 57.7 kg in 2005 [36]; *EDI* is the estimated daily intake (μg kg^{-1} bw per day); $C_{bivalve}$ is metal concentration in hard clam (μg g^{-1} wet weight); $dc_{bivalve}$ is daily consumption of 4.97 g clam per capita per day. This value was estimated by FAO for Vietnamese people [37]; *RfD* is equivalent to tolerable daily intake (*TDI*) and it is determined from provisional tolerable monthly intake (*PTMI*).

F. Statistical Analysis

The correlation between the concentrations of the four heavy metals (Cu, Zn, Pb and Cd) in samples was evaluated using the Pearson correlation (p<0.05). All statistical analysis and graphs were done using Microsoft Excel.

III. Results and Discussion

A. Sea Water Quality

The quality of sea water is presented in Table I. The sea water temperature at Tan Thanh in wet season was lower than that it in the dry season about 1.0-2.0 °C. This is similar to the previous research of Noh et al. [3], who showed that water temperatures at Cua Tieu estuary were 30.5±0.7 °C in March and 28.0±0.3 °C in September. The insignificant temperature change illustrates that the study area is much favorable for clam culture. Salinity in the wet season was lower than that it in the dry season. However, the salinity of both seasons was less than the normal sea water salinity, about 35‰ [38]. The low salinity might be caused by the dilution of freshwater from Tien River at Cua Tieu stuary. Salinity of the sea water at the sampling site in 2014 ranged from 19 to 23‰, which is suitable for hard clam growth. However, during sampling time in wet season 2015, the salinity decreased to an incredibly low value 6.2±0.25‰, which might influence to hard clams. In comparison to the dry season, the lower pH and DO values in the wet season may be influenced by the strong growth of phytoplankton during this time. Similarly, Noh et al. [3] found that the average pH at Cua Tieu estuary was slightly higher in March (7.67±0.31) than in September (7.07±0.15) and the average DO in March (6.08±1.15) was somewhat higher than it in September (5.04±1.05). During the studied time, the results presented high nutrient concentrations at the sampling sites that might have originated from high nutrient loads of the Tien River discharge. However, high nitrogen and phosphorous concentrations in the sea water could promote growth of phytoplankton, which fed the surrounding clams.

TABLE I: Sea Water Quality in Different Seasons in 2014-2015 at Clam Farms in Tan Thanh Beach

Parameter	2014				2015	
	Dry season		Wet season		Dry season	Wet season
	March	April	June	October	March	September
T (°C)	31.8±3.8	34.4±2.3	33.5±1.2	33±2.1	31.2±1.8	29±1.2
pH	8.41±0.08	8.19±0.14	8.03±0.09	7.4±0.06	8.2±0.09	6.24±0.08
DO (mg L^{-1})	NA	6.18±0.81	5.58±0.49	NA	8.2±0.6	5.4±0.55
Salinity (‰)	21±0.71	16.5±0.17	15.6±0.17	19.8±0.19	27.1±0.31	6.2±0.25
EC (mS/cm)	33.7±1.4	26.8±0.6	25.4 ±0.3	15.3±0.2	42.5±1.8	10.1±0.8
Hardness, (mg L^{-1}) as $CaCO_3$	4,834±110	5,580±218	10,000±223	1,472±75	NA	NA
Alkalinity, (mg L^{-1}) as $CaCO_3$	84±2	107±4	76±1	144±6	NA	NA
Cl^- (mg L^{-1})	NA	12,375±850	22,693±753	973±95	NA	NA
SO_4^{2-} (mg L^{-1})	816±19	447±36	795±18	175±23	1,372±21	610±15
TP (mg L^{-1})	2.06±0.05	5.50±0.80	6.64±1.53	2.1±0.3	2.6±0.08	2.38±0.09
NO_2^--N (mg L^{-1})	0.03±0.00	1.60±0.1	0.06±0.01	0.01	0.01±0.0	0.21±0.01
NO_3^--N (mg L^{-1})	0.58±0.08	10.8±11.7	3.68±4.69	0.70±0.1	0.8±0.5	0.31±0.41
NH_4^+-N (mg L^{-1})	NA	0.60±0.10	0.87±0.19	0.21±0.02	0.04±0.02	0.03±0.01
TKN (mg L^{-1})	4.14±0.16	20.5±2.70	20.5±2.60	3.8±0.2	8.4±1.8	17.1±2.5

NA: Not available.

B. Heavy Metals in Sea Water

In estuaries, the increase of salinity may lead to the desorption of trace metals from sediment [39]. In brackish and sea water, trace metal ions were replaced with alkalinity and alkaline earth cations [40]. The concentrations of heavy metals in sea water samples in Table II shows that all values were less than the limits of the Vietnamese coastal water quality standards QCVN 10-MT:2015/BTNMT (Zn ≤ 500 μg L^{-1}; Cu ≤ 200 μg L^{-1}, Cd ≤ 5 μg L^{-1}, Pb ≤ 50 μg L^{-1}). These results are the same as the previous study of Nguyen et al. [4], who presented that Zn, Cu, Cd and Pb concentrations in the brackish water of Tien River were 22-166 μg L^{-1}, 53-82 μg L^{-1}, 0-2 μg L^{-1} and 0-27 μg L^{-1}, respectively.

TABLE II: CONCENTRATION OF HEAVY METALS IN SEA WATER (μG L^{-1}) IN DRY AND WET SEASONS AT CLAM FARMS IN TAN THANH BEACH

Metals	**LODs**	**2014**				**2015**	
		Dry season		**Wet season**		**Dry season**	**Wet season**
		March	**April**	**June**	**August**	**March**	**September**
Zn	3	6 ±1	34 ±11	207 ±21	240 ±34	317 ±29	130 ±9
Cu	2	2 ±1	< LOD	7 ±1	< LOD	70 ±8	2 ±0.5
Cd	1	< LOD	< LOD	5 ±3	< LOD	2 ±1	< LOD
Pb	1	< LOD	3 ±1	10 ±6	1 ±0.5	15 ±2	2 ±1

Note: Values represent mean value ±SD from three replicates; LOD: Limit of detection

C. Heavy Metals in Sediment

Fig. 3 shows the heavy metals' concentrations in sediment at the sampling station during 2014-2015. In comparison to the sediment quality guidelines (Table III), all the concentrations of metals in sediment at the hard clam farms met the limits, except Zn in dry season in 2015. In the previous research, Nguyen et al. [4] presented that the mean contents of Cu and Cr in the brackish zone of Tien River (10-20 km far from the sampling station in this study) were higher than the limits of Canadian marine sediment quality guideline and effect range medium of NOAA. Tien River receives a huge amount of surface runoff from agricultural areas where fungicides or herbicides contenting Cu and other metals may be widely used [41]. Thus, the lower values of metals' concentrations in coastal sediment might be influenced due to the dilution of sea water and active condition of semidiurnal tide in this study area. These results were similar with other studies on trace metals in sediment of Mekong and Saigon - Dong Nai Rivers [2], [9]. Another study around this area has also suggested that the change of metal concentrations in sediment might be influenced by seasonal change of sea current at river estuary [42].

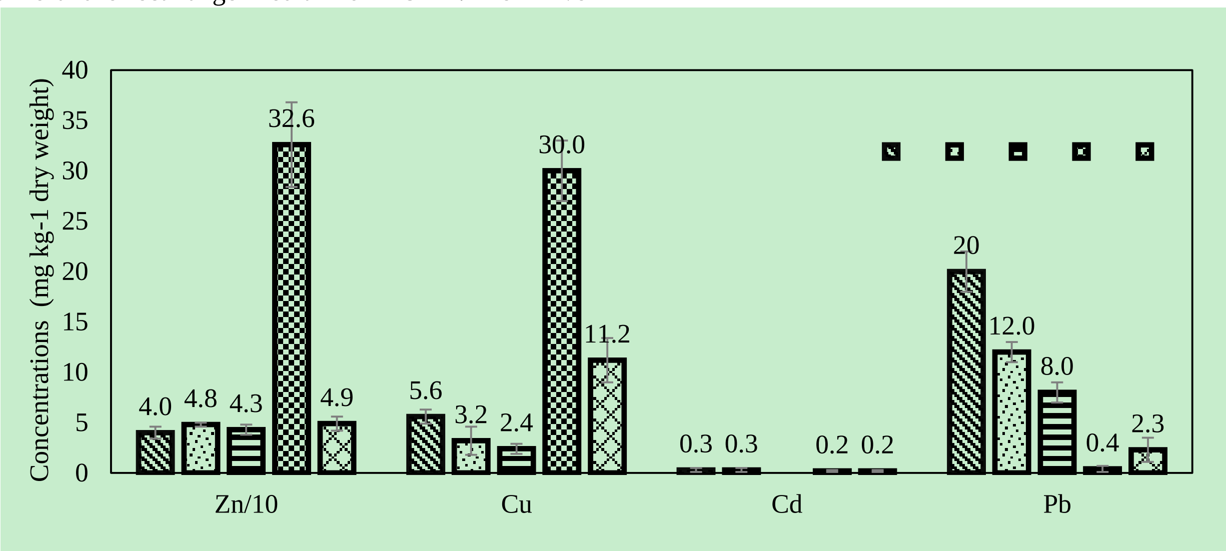

Fig. 3. Metals content in sediment at Tan Thanh area during 2014-2015.

TABLE III: GUIDELINE LEVELS OF HEAVY METALS IN MARINE SEDIMENT AND MEAN CONCENTRATIONS OF HEAVY METALS IN SEDIMENT IN THE STUDY AREA DURING 2014 - 2015

Guideline	**Zn**	**Cu**	**Pb**	**Cd**	**Remark**
	Heavy metal content in sediment (mg kg^{-1} dry weight)				
Canadian SQR:					[43]
ISQG	-	35.7	35	0.6	
PEL	-	197	91.3	3.5	
NOAA:					[44]
PEL	-	108	112	4.2	
PEC	-	149	128	5	
ERM	410	270	218	9.6	
ERL	150	34	40	1.0	
This study					The range of mean values from Table 3
2014 (in range)	40-49	2-6	9.6-16	0.30-0.32	
2015 (in range)	48.5-326	11.2-29.9	0.4-2.3	0.16-0.19	

Note:

-: No data

CCME: Canadian Council of Ministers of the Environment.

NOAA: National Oceanic and Atmospheric Administration.

ISQG: Interim marine sediment quality guidelines.

PEL: Probable effects level.

PEC: Probable effects concentration.

ERM: Effect range medium.

ERL: Effect range low.

D. Heavy Metals in Hard Clams

Fig. 4 shows the concentrations of 4 studied heavy metals in *M. lyrata* at Tan Thanh coastal area. The results presented that all metals concentrations in *M. lyrata* samples met the limits for food in some countries (Table IV). The similar results were also found in the research of Mesndez et al. [45], who showed that the Zn, Cu, and Cd concentrations in chocolate clam (*Megapitaria squalida*) in a bay within Gulf of California ranged from 47 - 65, 5.4-18.7 and 1.5-11 mg kg^{-1} dry weight, respectively. One year later, another study at Tan Thanh and other area near Sai gon – Dong nai River Estuary showed that some metals, such as Cd, could be accumulated in one specific organ of *M. lyrata*. According to that research, the metals content in gills or digestion glands were significantly higher than in other organs or in whole body of hard clams [42].

The first metal in this study was Cu which is an essential micronutrient for marine organisms. It is difficult to identify a correlation between Cu content in soft tissues of marine organisms and adverse biological effects [46]. The Cu concentrations in the hard clam flesh at Tan Thanh were not much different with those (5.2-12.4 mg kg^{-1}) in commercial Razoe clams in Moyan and Serpan, Malaysia [47]. They also met the limit of food quality standards or health standards of some countries (Table 6). Health standards for Cu in fishery products for human consumption varied from one country to other, ranging between 50 and 500 mg kg^{-1} dry weight [46]. Secondly, the Zn concentration in hard clam *M. lyrata* at Tan Thanh ranged from 53±12 to 193±21 mg kg^{-1} dry weight (Table 5). Those values were higher than Zn in clam *Galatea paradoxa* at the Volta estuary in Ghana, which were ranging between 16 and 49 mg kg^{-1} [48]. Zn was an similar essential metal to Cu, it is naturally concentrated by living organisms [49]. Thus, the bio-concentration factor for zinc normally has no correlation with toxicity. On the other hand, Pb and Cd are toxicants for organisms. The high Cd contents in grill of *Tegillarca granosa* clam might negatively affect the osmotic function, nerve system as well as energy metabolism [50]. Fortunately, Table IV presents that Cd contents (in dry weight) in all *M. lyrata* samples were small and met the limit of food regulations of some countries. These values were also lower than those in the study of Nur and Long [51], who reported that Cd concentrations in *P. expansa*, *M. meretrix*, *S. regularis* at Estuary Area of Sarawak River, Malaysia were 1.15±0.50 mg kg^{-1}, 2.15±1.38 mg kg^{-1}, 2.35±0.01 mg kg^{-1}, respectively. Finally, this study showed that the Pb concentrations in all clam samples were met the limit value of WHO guideline of 0.3 mg kg^{-1} [52], the ML regulated by the EU (1.5 mg kg^{-1}) [25], and the aqua-food quality regulations in some countries (Table IV).

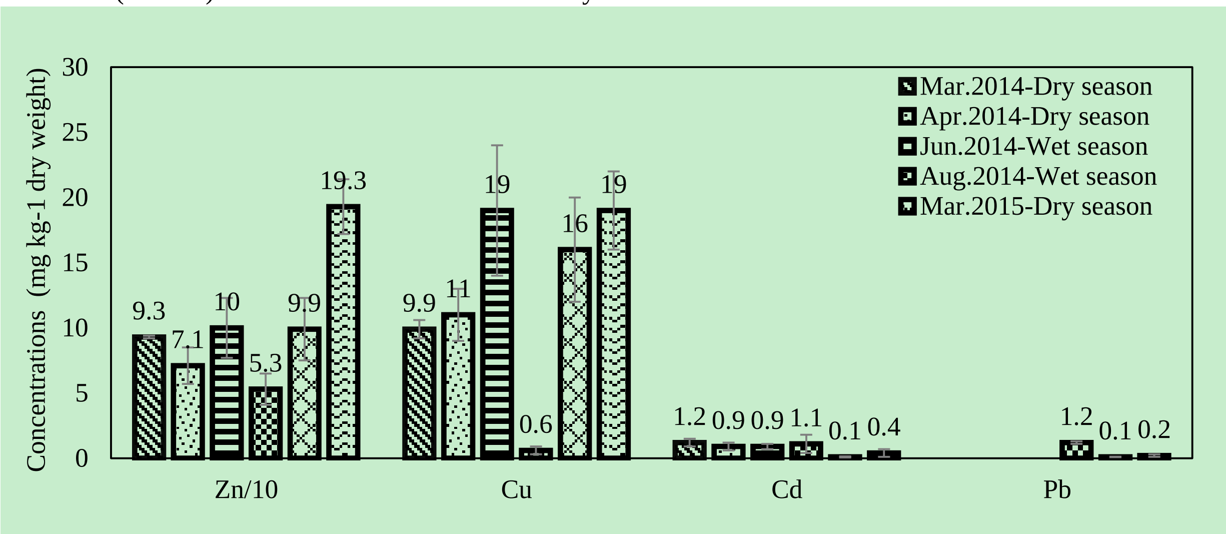

Fig. 4. Metals content in *M.lyrata* clam at Tan Thanh area during 2014-2015.

TABLE IV: COMPARISON BETWEEN CONTENT OF HEAVY METALS IN CLAM FLESH IN THIS STUDY WITH LIMITS OF FOOD REGULATION IN OTHER COUNTRIES

Country	Basic weight	Cd	Cu	Pb	Zn
		Limit values (mg kg^{-1})			
Malaysia(1)	Wet	1.0	30	2.0	100
Brazil(2)	Dry	5.0	150	10	250
Thailand(3)	Dry	-	133	6.67	667
Australia(4)	Dry	10	350	-	750
MIS(5)	Wet	0.05-2.0	10-100	0.5-10	40-100
Vietnam(6)	Wet	1.0	-	1.0	-
This study	Dry	*Metal content (mg kg^{-1} dry weight) in the clam flesh*			
2014 (Range)		0.12-1.34	1.1-10	< LOD-0.6	9.9-83
2015 (Range)		0.01-0.38	1.9-16	0.01-0.2	11.8-193

Note:

1) *Malaysian food regulation* [53]
2) *Maximum permissible levels established by Brazilian Ministry of Health* [54]
3) *Permissible limit set by Ministry of Public Health, Thailand* [55]
4) *Australian Legal Requirements* [56]
5) *Median International Standards (MIS) for metals in shellfish compiled by the Food and Agricultural Organization of the United Actions, California (RWQCB, 2006).*
6) *Vietnamese regulation for quality of exported mollusks foods* [57]

E. Daily Intake and Total Hazard Index

Table V shows that the HQ values were found in decreasing order of Cd (0.013) > Pb (0.0061) > Zn (0.0015) > Cu (0.00037) and the THI was 0.021 (lower than 1.0). It indicates that a negligible health hazard could derive from the ingestion of clam flesh. These results were same as HQs for people who consumed *Ruditapes philippinarum* in China [58], and smaller than the HQs for clam *Tapes decussatus* and mussel *Mytilus galloprovincialis* in Homa Lagoon (Eastern Aegean Sea) [59]. Among all studied metals in this research, Cd is considered as the most important parameter to evaluate the human health risk for *M. lyrata* consumers. The similar suggestion about Cd also was presented in another study with total 11 elements in hard clam at Tan Thanh and Can Gio area one year later [42].

Based on this study, the maximum tolerable daily intake for a sixty-kg person is 500 g of wet clam flesh (Table V). However, FAO recommended that consumption of clams for Vietnamese should be less than 100 g wet weight capita^{-1} day^{-1} [60]. Therefore, 100 g should be considered to recommend as the maximum of clam flesh per capita.

TABLE V: MAXIMUM DAILY OF FRESH CLAM FLESH BASED ON USFDA LEVELS OF CONCERN AND HAZARD QUOTIENT

Heavy metal	**USFDA (1) levels of concern,** µg person^{-1} day^{-1} (*) **[a]**	**USFDA (1) background level,** µg person^{-1} day^{-1} (*) **[b]**	**Maximum tolerable daily intake,** µg kg^{-1} (body weight) day^{-1} **[c]**	**Average metal content in dried clam flesh** mg kg^{-1} **[d]**	**Maximum tolerable daily intake for wet clam flesh,** g person^{-1} day^{-1}		**Hazard quotient**	**Total hazard index**
					USFDA(1) [e] (**)	**FAO/WHO(2) [f] (***)**		
Zn	50,000	1,000	1,000 (3)	101	4,040	4,950	0.0015	0.021
Cu	10,000	500	500 (3)	12.3	6,440	20,320	0.00037	
Cd	55	10	1.0 (2)	0.75	500	667	0.013	
Pb	75	5-10	3.5 (2)	0.49	1,190	3,570	0.0061	

Note:

- *For a sixty-kg person.*
- $[e] = \frac{[a]-[b]}{[d]\times 12\%}$ *where 12% = mean total dried solids of clam flesh 12±0.3% which were analyzed in this study.*
- $[f] = \frac{[c]\times 60}{[d]\times 12\%}$

1) USFDA - *Food* and Drug Administration of the United States [61]
2) FAO/*WHO* – The joint Food and Agriculture Organization and World Health Organization [52].
3) [62]

IV. CONCLUSIONS

The present study showed that all metals were detected in the water and sediment in clam farms at Tan Thanh coastal area, MDV. The concentrations of Cd, Pb and Cu in sediment samples were lower than the limits of marine sediment quality guidelines, while Zn in dry season in 2015 was higher. Although Pb was not detected or was an extremely low concentration in *M. lyrata*, it was found in the sediment and water. All studied metal concentrations in *M. lyrata* clam samples were below the maximum level regulated by Commission Regulation (EC) 1881/2006 and to aqua-food quality regulation of some countries. This study indicates that the health risk for local clam consumer is not significant in case of the toxicity of Cd, Pb, Cu and Zn in *M. lyrata*. However, a maximum consumption of clam flesh is necessary for safety reasons. The daily intake of about 100 g (wet weight) of clam flesh is recommended as the largest amount of clam for local adults.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Phuoc-Dan Nguyen and Sunghee Han designed the research; Viet Tuan Tran, Emilie Strady and Huu-Viet Nguyen conducted the study and analyzed the data; Quoc-Tuc Dinh wrote the draft of the paper; and all authors had adjusted and edited the paper before approved the final version.

REFERENCES

[1] M. P. Cajaraville, M. J. Bebianno, J. Blasco, C. Porte, C. Sarasquete, and A. Viarengo, "The use of biomarkers to assess the impact of pollution in coastal environments of the Iberian Peninsula: A practical approach," *Science of The Total Environment*, vol. 247, no. 2–3, pp. 295–311, Mar. 2000, doi: 10.1016/S0048-9697(99)00499-4.

[2] E. Strady *et al*., "Spatial variation and risk assessment of trace metals in water and sediment of the Mekong Delta," *Chemosphere*, vol. 179, no. March, pp. 367–378, Jul. 2017, doi: 10.1016/j.chemosphere.2017.03.105.

[3] S. Noh *et al*., "Influence of salinity intrusion on the speciation and partitioning of mercury in the Mekong River Delta," *Geochimica et Cosmochimica Acta*, vol. 106, pp. 379–390, Apr. 2013, doi: 10.1016/j.gca.2012.12.018.

[4] P. D. Nguyen, S. Han, V. H. Duong, V. B. H. Dang, and V. S. H. Dang, "Survey on the presence of typical heavy metals in the brackish water ecosystem of Tien river, Vietnam," Project Report — Environmental Challenges for Urban City, 2013.

[5] P. D. Nguyen, S. Han, S. Bang, X. T. Bui, and T. P. Nguyen, "Monitoring of water and sediment quality in Tien river — Mekong Delta in Vietnam," 2010.

[6] R. M. Cenci and J.-M. Martin, "Concentration and fate of trace metals in Mekong River Delta," *Science of The Total Environment*, vol. 332, no. 1–3, pp. 167–182, Oct. 2004, doi: 10.1016/j.scitotenv.2004.01.018.

[7] T. Ikemoto *et al*., "Biomagnification of trace elements in the aquatic food web in the Mekong Delta, South Vietnam using stable carbon and nitrogen isotope analysis," *Archives of Environmental Contamination and Toxicology*, vol. 54, no. 3, pp. 504–515, Apr. 2008, doi: 10.1007/s00244-007-9058-5.

[8] N. Thanh-Nho, E. Strady, T. Nhu-Trang, F. David, and C. Marchand, "Trace metals partitioning between particulate and dissolved phases along a tropical mangrove estuary (Can Gio, Vietnam)," *Chemosphere*, vol. 196, pp. 311–322, 2018, doi: 10.1016/j.chemosphere.2017.12.189.

[9] E. Strady *et al*., "Baseline seasonal investigation of nutrients and trace metals in surface waters and sediments along the Saigon River basin

impacted by the megacity of Ho Chi Minh (Vietnam)," *Environmental Science and Pollution Research*, vol. 24, no. 4, pp. 3226–3243, Feb. 2017, doi: 10.1007/s11356-016-7660-7.

[10] W. C. Renfro, "Transfer of 65Zn from sediments by marine polychaete worms," *Marine Biology*, vol. 21, no. 4, pp. 305–316, 1973, doi: 10.1007/BF00381087.

[11] E. E. R. Philipp and D. Abele, "Masters of longevity: Lessons from long-lived bivalves — A mini-review," *Gerontology*, vol. 56, no. 1, pp. 55–65, 2010, doi: 10.1159/000221004.

[12] C. Vodopivez, A. Curtosi, E. Villaamil, P. Smichowski, E. Pelletier, and W. P. Mac Cormack, "Heavy metals in sediments and soft tissues of the Antarctic clam Laternula elliptica: More evidence as a ? Possible biomonitor of coastal marine pollution at high latitudes?" *Science of the Total Environment*, vol. 502, no. October 2014, pp. 375–384, 2015, doi: 10.1016/j.scitotenv.2014.09.031.

[13] M. B. Fernandes, M.-A. Sicre, A. Boireau, and J. Tronczynski, "Aquatic hydrocarbon distributions in the seine estuary: Biogenic polyaromatics and n-alkanes," *Estuaries*, vol. 20, no. 2, p. 281, Jun. 1997, doi: 10.2307/1352343.

[14] P. Lei, H. Zhang, B. Shan, S. Lv, and W. Tang, "Heavy metals in estuarine surface sediments of the Hai River Basin, variation characteristics, chemical speciation and ecological risk," *Environmental Science and Pollution Research*, vol. 23, no. 8, pp. 7869–7879, Apr. 2016, doi: 10.1007/s11356-016-6059-9.

[15] L. Cadena-Cárdenas, L. Méndez-Rodríguez, T. Zenteno-Savín, J. García-Hernández, and B. Acosta-Vargas, "Heavy metal levels in marine mollusks from areas with, or without, mining activities along the Gulf of California, Mexico," *Archives of Environmental Contamination and Toxicology*, vol. 57, no. 1, pp. 96–102, Jul. 2009, doi: 10.1007/s00244-008-9236-0.

[16] H. A. Madkour, K. A. Obirikorang, S. Amisah, F. A. Otchere, and D. Adjei-Boateng, "Relationship between heavy metal concentrations in bottom sediments and the clam, galatea paradoxa (born 1778) from the Volta Estuary, Ghana," *Journal of Environmental Protection*, vol. 02, no. 06, pp. 720–728, 2011, doi: 10.4236/jep.2011.26083.

[17] Z.-Q. Fang, R. Y. H. Cheung, and M. H. Wong, "Heavy metals in oysters, mussels and clams collected from coastal sites along the Pearl River Delta, South China," *J Environ Sci (China)*, vol. 15, no. 1, pp. 9–24, Jan. 2003.

[18] J. Kahle and G.-P. Zauke, "Bioaccumulation of trace metals in the Antarctic amphipod Orchomene plebs: Evaluation of toxicokinetic models," *Marine Environmental Research*, vol. 55, no. 5, pp. 359–384, Jun. 2003, doi: 10.1016/S0141-1136(02)00288-X.

[19] P. Szefer, A. A. Ali, A. A. Ba-Haroon, A. A. Rajeh, J. Geładon, and M. Nabrzyski, "Distribution and relationships of selected trace metals in molluscs and associated sediments from the Gulf of Aden, Yemen," *Environ Pollut*, vol. 106, no. 3, pp. 299–314, Sep. 1999.

[20] C. K. Yap, M. Sharifinia, W. H. Cheng, S. A. Al-Shami, K. W. Wong, and K. A. Al-Mutairi, "A commentary on the use of bivalve mollusks in monitoring metal pollution levels," *International Journal of Environmental Research and Public Health*, vol. 18, no. 7, Apr. 01, 2021. doi: 10.3390/ijerph18073386.

[21] S. Chiesa, P. Chainho, Â. Almeida, E. Figueira, A. M. V. M. Soares, and R. Freitas, "Metals and as content in sediments and Manila clam Ruditapes philippinarum in the Tagus estuary (Portugal): Impacts and risk for human consumption," *Marine Pollution Bulletin*, vol. 126, pp. 281–292, Jan. 2018, doi: 10.1016/j.marpolbul.2017.10.088.

[22] G. Lozano, E. Herraiz, A. Hardisson, A. J. Gutiérrez, D. González-Weller, and C. Rubio, "Heavy and trace metal concentrations in three rockpool shrimp species (Palaemon elegans, Palaemon adspersus and Palaemon serratus) from Tenerife (Canary Islands)," *Environmental Monitoring and Assessment*, vol. 168, no. 1–4, pp. 451–460, Sep. 2010, doi: 10.1007/s10661-009-1126-z.

[23] S. Squadrone *et al*., "Presence of trace metals in aquaculture marine ecosystems of the northwestern Mediterranean Sea (Italy)," *Environmental Pollution*, vol. 215, pp. 77–83, Aug. 2016, doi: 10.1016/j.envpol.2016.04.096.

[24] EC, "Commission Regulation (EC) No. 1881/2006 setting maximum levels for certain contaminants in foodstuffs," *Off. J. Eur. Union L 364*, pp. 5–24, 2006.

[25] (European Food Safety Authority) EFSA, "Scientific opinion on arsenic in food," *EFSA J.*, pp. 199–351, 2009.

[26] (European Food Safety Authority) EFSA, "Scientific opinion on the risks to public health related to the presence of chromium in food and drinking water," *EFSA J.*, pp. 11–25, 2014.

[27] (European Food Safety Authority) EFSA, "Scientific opinion on the risks to public health related to the presence of nickel in food and drinking water," *EFSA J.*, pp. 4002–4203, 2015.

[28] U.S. EPA, "Exposure factors handbook 2011 edition (final report)," Washington, DC, 2011.

[29] VASEP. (2015). Vietnam Association of Seafood Exporters and Producers. [Online]. Available: http://seafood.vasep.com.vn/seafood/53_10931/vietnam-maintains-as-a-leading-exporter-of-processed-clams-to-italy.htm

[30] VASEP. (2014). Vietnam Association of Seafood Exporters and Producers. [Online]. Available: http://vasep.com.vn/Tin-Tuc/1214_37101/Nghe-nuoi-ngheu-ven-bien-Go-Cong-Nguoi-nuoi-con-gap-kho.htm, accessed August 2014

[31] Tieng Giang Province Office, "Tien Giang: Establish 2,200 ha of hard clam farms at Tan Thanh," 2019.

[32] S. T. Chiu, F. S. Lam, W. L. Tze, C. W. Chau, and D. Y. Ye, "Trace metals in mussels from mariculture zones, Hong Kong," *Chemosphere*, vol. 41, no. 1–2, pp. 101–108, 2000, doi: 10.1016/S0045-6535(99)00395-1.

[33] A. G. Ferreira, A. L. dos S. Machado, and I. R. Zalmon, "Temporal and spatial variation on heavy metal concentrations in the bivalve Perna perna (LINNAEUS, 1758) on the northern coast of Rio de Janeiro State, Brazil," *Brazilian Archives of Biology and Technology*, vol. 47, no. 2, pp. 319–327, Jun. 2004, doi: 10.1590/S1516-89132004000200020.

[34] A. O. Fred, "Heavy metals concentrations and burden in the bivalves (Anadara (Senilia) senilis, Crassostrea tulipa and Perna perna) from lagoons in Ghana: Model to describe mechanism of accumulation/excretion," *African Journal of Biotechnology*, vol. 2, no. 9, pp. 280–287, Sep. 2003, doi: 10.5897/AJB2003.000-1057.

[35] T. D. Martin, C. A. Brockhoff, J. T. Creed, and EMMC, "Method 200.7, Revision 4.4: Determination of metals and trace elements in water and wastes by inductively coupled plasma-atomic emission spectrometry," 1994.

[36] S. C. Walpole, D. Prieto-Merino, P. Edwards, J. Cleland, G. Stevens, and I. Roberts, "The weight of nations: an estimation of adult human biomass," *BMC Public Health*, vol. 12, no. 1, p. 439, Dec. 2012, doi: 10.1186/1471-2458-12-439.

[37] FAOSTAT. (2017). Food Supply — Livestock and Fish Primary Equivalent. [Online]. Available: http://www.fao.org/faostat/en/#data/CL

[38] F. Culkin and N. Smith, "Determination of the concentration of potassium chloride solution having the same electrical conductivity, at 15°C and infinite frequency, as standard seawater of salinity 35.0000 ‰ (Chlorinity 19.37394 ‰)," *IEEE Journal of Oceanic Engineering*, vol. 5, no. 1, pp. 22–23, Jan. 1980, doi: 10.1109/JOE.1980.1145443.

[39] G. R. Helz, R. J. Huggett, and J. M. Hill, "Behavior of Mn, Fe, Cu, Zn, Cd and Pb discharged from a wastewater treatment plant into an estuarine environment," *Water Research*, vol. 9, no. 7, pp. 631–636, Jul. 1975, doi: 10.1016/0043-1354(75)90168-2.

[40] M. Slimak, M. Callahan, and C. Fowler, *Water-Related Environmental Fate of 129 Priority Pollutants Volume I Introduction and Technical Background Metals and Inorganics Pesticides and PCBs*, Springfiel. National government publication, 1979.

[41] P. M. Nirel and F. Pasquini, "Differentiation of copper pollution origin : agricultural and urban sources," in *Proc. Novatech 2010 - 7th International Conference on Sustainable Techniques and Strategies for Urban Water Management*, 2010, pp. 1–7.

[42] V. T. Tran, P.-D. Nguyen, and E. Strady, "Bioaccumulation of trace elements in the hard clam, Meretrix lyrata, reared downstream of a developing megacity, the Saigon-Dongnai River Estuary, Vietnam," *Environmental Monitoring and Assessment*, vol. 192, no. 9, 2020, doi: 10.1007/s10661-020-08502-z.

[43] CCME, "Canadian sediment quality guidelines for the protection of aquatic life," *Canadian Council of Ministers of the Environment*, 2017.

[44] M. F. Buchman, "NOAA screening quick reference tables," Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, Seattle WA, 2008.

[45] L. Méndez, E. Palacios, B. Acosta, P. Monsalvo-Spencer, and T. Alvarez-Castañeda, "Heavy metals in the Clam Megapitaria squalida collected from wild and phosphorite mine-impacted sites in Baja California, Mexico: Considerations for human health effects," *Biological Trace Element Research*, vol. 110, no. 3, pp. 275–288, 2006, doi: 10.1385/BTER:110:3:275.

[46] J. M. Neff, *Bioaccumulation in Marine Organisms — Effect of Contaminants from Oil Well Produced Water*, Elsevier, 2002.

[47] D. Kanakaraju, F. Ibrahim, and M. N. Berseli, "Comparative study of heavy metal concentrations in razor clam (solen regularis) in Moyan and Serpan, Sarawak," *Global Journal of Environmental Research*, vol. 2, no. 2, pp. 87-91, 2008.

[48] S. Amisah, D. Adjei-Boateng, K. a Obirikorang, and K. K. Quagrainie, "Effects of clam size on heavy metal accumulation in whole soft tissues of Galatea paradoxa (born, 1778) from the Volta estuary, Ghana," *International Journal of Fisheries and Aquaculture*, vol. 1, no. 2, pp. 14–21, 2009.

[49] B. Simon-Hettich, A. Wibbertmann, D. Wagner, L. Tomaska, and H. Malcolm, "Environmental health criteria 221 — Zinc," *Geneva*, 2001.
[50] Y. Bao *et al*., "Identification of a regulation network in response to cadmium toxicity using blood clam Tegillarca granosa as model," Scientific Reports, vol. 6, no. 1, p. 35704, Dec. 2016, doi: 10.1038/srep35704.
[51] N. A. M. Yusoff and S. M. Long, "Comparative bioaccumulation of heavy metals (Fe, Zn, Cu, Cd, Cr, Pb) in different edible mollusk collected from the Estuary area of Sarawak River," *Empowering Science, Technology and Innovation Towards a Better Tomorrow*, 2011, pp. 806–811.
[52] FAO/WHO, "Evaluation of certain food additives and the contaminants mercury, lead, and cadmium," p. 33, 1972.
[53] Malaysia, "Food regulations 1985," Malaysia, 1985.
[54] ABIA, "Atos do Ministerio da Sa ude: Compendio da Legislacao de Ali-mentos." Associacao Brasileira das Industrias de Alimentacao (Brazilian Ministry of Health), 1991.
[55] MPHT, "Residues in foods," Ministry of Public Health, Thailand, 1986.
[56] NHMRC, "National food standard A 12: Metal and contaminants in food," National Health and Medical Research Council, Australia Government Publishing Services, Canberra, Australia, 1987.
[57] T. M. Pham and B. Petlock, "Vietnam — Food and agricultural import regulations and standards — Narrative," 2017.
[58] F. Yang, L. Zhao, X. Yan, and Y. Wang, "Bioaccumulation of trace elements in ruditapes philippinarum from China: Public health risk assessment implications," *International Journal of Environmental Research and Public Health*, vol. 10, no. 4, pp. 1392–1405, Apr. 2013, doi: 10.3390/ijerph10041392.
[59] M. Bilgin and E. Uluturhan-Suzer, "Assessment of trace metal concentrations and human health risk in clam (Tapes decussatus) and mussel (Mytilus galloprovincialis) from the Homa Lagoon (Eastern Aegean Sea)," *Environmental Science and Pollution Research*, vol. 24, no. 4, pp. 4174–4184, Feb. 2017, doi: 10.1007/s11356-016-8163-2.
[60] N. Wanner, C. Cafiero, N. Troubat, and P. Conforti, "Refinements to the FAO methodology for estimating the prevalence of undernourishment indicator," *Rome*, 2014.
[61] USFDA, "Guide for the control of molluscan shellfish 2019 revision," *National Shellfish Sanitation Program*, U. S. Food and Drug Administration, 2019.
[62] FAO/WHO, "Twenty-sixth report of the joint FAO/WHO expert committee on food additives (JECFA)," *Geneva*, 1982.

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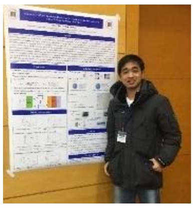

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