

# Accumulation of Persistent Organic Pollutants in Sediment on Tidal Flats in the North of Vietnam

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**Abstract:** Tidal flats in the North of Vietnam extend from Móng Cái – Quảng Ninh to Kim Sơn - Ninh Bình are studied sedimentation rates by <sup>210</sup>Pb and <sup>226</sup>Ra on CRS model, accumulation of pollutants include organochlorine pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons.

On the tidal flats there are two sedimentary processes, which are accretion and erosion. The accretion process is most on the top of tidal flats, sedimentation rates are range from 0.04-15.83 cm/year, highest sedimentation rates are on deltaic tidal flats, the next is on estuary tidal flats, and smallest sedimentation rate is embayment tidal flats. The erosion process are showed on 20-40cm at Ba Lạt tidal flat and some layers from 20 cm until end of cores on Cửa Đáy tidal flats.

Accumulation of persistent organic pollutants in sediment on the tidal flats show two trends, the first trend is increasing on the tidal flats in recently years which are PCBs and PAHs, the second trend is decreasing in recently years is organochlorine pesticides. The deltaic tidal flats have not clearly trend of PAHs in sediments. The compounds of organic pollutants over ISQGs level are 4,4'-DDT, phenanthrene, flouranthrene, benzo [a] anthracene.

**Keywords:** Tidal flat, <sup>210</sup>Pb, sedimentation rate, persistent organic pollutants, North of Vietnam.

## 1. Introduction

The coast of the North of Vietnam extends from Mong Cai, Quang Ninh to Kim Son, Ninh Binh provinces. They are divided into three areas base on tidal ranges, geomorphology and sediments by which there are three type environments: deltaic environments, estuary environments and embayment environments,

thereby also tidal flats are divided into three types as are: deltaic tidal flat, estuary tidal flat and embayment tidal flat [1,2].

On the tidal flats distribute much resources as biotic and abiotic resources, along coastal of the North of Vietnam there are some ecosystems as mangrove, coral reef, estuaries, embayment ecosystems with high biodiversity and rich biotic resources. Today people from coastal provinces and mainland do development plan, extract coastal resources make risks to

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coastal environments. Many activities of human in mainland in the North of Vietnam increase in recently bring pollutants to coast, pollutants in sediments are showed that increasing by time [3-5], pollutants in coastal sediment relationship with increasing of industrial areas more ten recently years [6]. During with developing of industrial areas, wastes and environmental remediation is incomplete [7], these reason high concentration pollutant in coastal area.

Accumulation of persistent organic pollutants in aquatic environment by used  $^{210}\text{Pb}$  and other radiotracer are usefully in tracking environment change, they help us to know sources, pathway, time and sedimentary processes in coastal water body [8], sedimentation rates and accumulation of pollutants in coastal area are important information in climate change, sea level rise and human activities. This paper use  $^{210}\text{Pb}$  and persistent organic pollutants (organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs)) in sediments to understand, estimate sedimentary processes, impacts from human activities from mainland to tidal flats in the North of Vietnam.

## 2. Material and methods

Seven sediment cores on the tidal flats are collected in 2012 on fig. 1, the length of cores are ranges 0-90cm in depth: on the Mong Cai tidal flat (MC 0-90cm), Dong Rui tidal flat (DR 0-60cm), Cua Luc tidal flat (CL 0-57cm), Cua Cam tidal flat (HP 0-90cm), Thai Binh tidal flat (TB 0-90cm), Ba Lat tidal flat (BL 0-90cm) and Cua Day tidal flat (KS 0-90 cm). During sampling, choose the positions to avoid effects of human activities and mixing disturbance of nature, usually outside of mangrove forest and

inside sand bars where is quiet place for deposition processes occurs.

Sediment cores were cut into 2 cm slices, which were kept at  $4^{\circ}\text{C}$  until reaching laboratory. In the laboratory samples were dry by air-conditioner at  $16^{\circ}\text{C}$ , used agate mortar and pestle for grinding for analysis  $^{210}\text{Pb}$  and persistent organic pollutants.

Grain sizes were analyzed by sieves and particle size analyzer CILAS 990 after removed salts and organic matters by distilled water and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) 10 percent. Sediment classification is according to Lisitzin [9].

The content of  $^{210}\text{Pb}$  is determined through it's daughter radionuclide  $^{210}\text{Po}$  with the assumption of secular equilibrium. After digestion of the sample, polonium is extracted with 0.1% DDTC in chloroform from HCl solution and then deposited on silver disc.  $^{209}\text{Po}$  is used as a tracer in the separation for chemical recovery. Radionuclide  $^{210}\text{Po}$  is analyzed using PIPS detectors with  $600\text{ mm}^2$  active area. Unsupported  $^{210}\text{Pb}$  then can be calculated by subtraction of  $^{226}\text{Ra}$  from the total  $^{210}\text{Pb}$  activity [10].  $^{226}\text{Ra}$  in sediments was measured directly by gamma spectrometry.

The constant rate supply (CRS) model is used to calculate chronology of sediment layers (1), and sedimentation rates (2). This model was suggested by Krishnaswami [11], later have been modified [12-14]. Nowadays this CRS model is used very common for calculating sedimentation rate in coastal and estuaries.

$$t = \frac{1}{\lambda} \ln \left( \frac{A(0)}{A(x)} \right) \quad (1)$$

t: year.

$\lambda$ : constant = 0.03114;

A (0) is the total integrated  $^{210}\text{Pb}_{\text{excess}}$  in sediment core ( $^{210}\text{Pb}_{\text{excess}} = ^{210}\text{Pb}_{\text{activity}} - ^{226}\text{Ra}$ )

A(x) is the integrated  $^{210}\text{Pb}_{\text{excess}}$  below depth x.

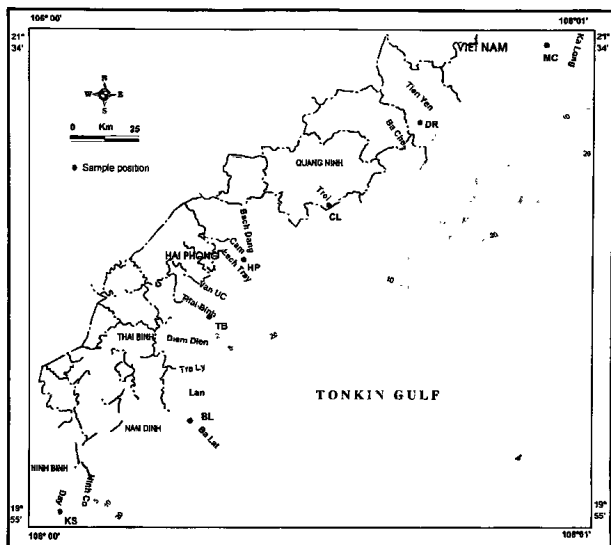


Fig.1. Local sampling collected

Sedimentation rate was calculated by (2)

$$S = \frac{l}{t_n - t_{n-1}} \quad (2)$$

S: sedimentation rate (cm/year)

l: thickness of layer

$t_n$  and  $t_{n-1}$ : are the age (year) of the n and n-1 layers calculated by (1).

Organochlorine pesticides (OCPs) analysis by weight 20-100g dry sediment, use n-hexane and soxhlet extractor drag OCPs out of

sediments, after that remove substance interfere by pure copper, then clean up on the floisil column, final analysis on gas chromatography with electron capture detector (GC - ECD). Total OCPs (lindan+ aldrin + endrin + 4,4'DDE + 4,4'DDD+4,4'DDT)

Polychlorinated biphenyls (PCBs) analysis by weight 20-100g dry sediment, use n-hexane to extract PCBs of sediments under microwave extractor, after that remove substance interfere by pure copper, then clean up on the silicagen column, final analysis on Gas chromatography

with electron capture detector (GC-ECD). Total 6 PCB = (PCB28 + PCB52 + PCB101 + PCB138 + PCB153 + PCB180), total PCBs =  $A \cdot (\text{PCB28} + \text{PCB52} + \text{PCB101} + \text{PCB138} + \text{PCB153} + \text{PCB180})$  with A is coefficient range from 3.5-8 [15].

Polycyclic aromatic hydrocarbons (PAHs) analysis by weight 20-100g dry sediment, use dichloromethane to extract PAH of sediments under microwave extractor, remove substance interfere by pure copper, then clean up on the silicagen column, use mix solvent n-hexane and dichloromethane with volume ratio 3:1 rinse silicagen column, final analysis on gas chromatography with flame ionization detector (GC-FID). Total PAHs=(phenanthrene+flouranthrene+perylene+benzo[a]anthracene+benzo[a]pyrene+pyrene+triphenylene+benzo[e]pyrene).

### 3. Results

#### 3.1. The characteristic sediments on the tidal flats

In fig.2 and tab.1, the mean diameters (Md) of sediments in the tidal flats change in depths, reflect sedimentary environmental conditions with time. At MC core on the Mong Cai tidal flat distribute three sediment types which are

coarse aleurites, fine sand and coarse sands. At CL core on the Cua Luc tidal flat with two types of sediments which are coarse aleurites and fine sands. At HP core on the Cua Cam tidal flat there are three sediment types, distribution on the top of tidal flat is fine-aleurites muds, in the middle and bottom layers in the tidal flat distribute coarse aleurites and aleuritic-pelitic muds. At TB core on the Thai Binh tidal flat, there are two sediment types, which are most of coarse aleurites, there are some layers fine-aleurites muds. At BL core on the Ba Lat tidal flat, most layers sediment on tidal flat are coarse aleurites. At KS core on the Cua Day tidal flat, most of layers are coarse aleurites.

Sorting parameter ( $S_0$ ) reflects sedimentary conditions, follows Track divided into three states [16], well sorted ( $S_0$  1.20-1.58), moderately ( $S_0$  = 1.58 - 2.20) to poorly sorted ( $S_0$  > 2.20). On the tidal flats sediments has well sorted and moderately sorted appear same with coarse sand, fine sand and coarse aleurites, they reflect strong conditions. The poor sorted are belong fine-aleurites muds and aleuritic-pelitic mud sediment, the sediments have poor sorted relationship with weak conditions. On the each tidal flat, it ranges from well to poor sorted, it indicates for change of sedimentary environment by time (fig.2).

Tab. 1. Statistical sedimentary parameters on tidal flats

Cores	Md (mm)				$S_0$			
	Minimum	Maximum	Average	Standard deviation	Minimum	Maximum	Average	Standard deviation
MC	0.052	0.725	0.224	0.119	1.297	6.381	2.280	1.497
CL	0.080	0.181	0.130	0.021	1.531	4.047	1.887	0.654
HP	0.008	0.057	0.024	0.015	2.284	3.988	3.262	0.380
TB	0.022	0.063	0.048	0.012	1.740	3.557	2.991	0.408
BL	0.054	0.102	0.065	0.008	1.255	3.635	2.119	0.810
KS	0.051	0.084	0.066	0.007	1.233	3.588	2.108	0.848

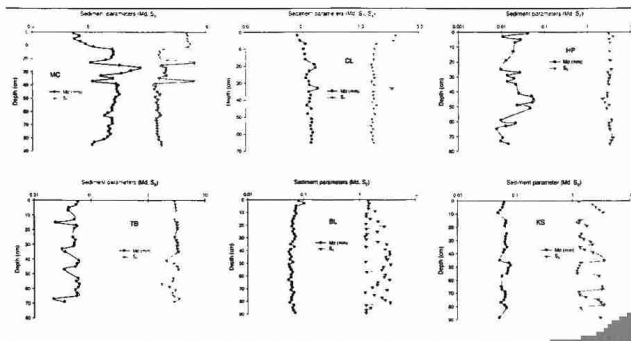


Fig.2. Distribution of sedimentary parameters on the tidal flats

Tab.2. Sedimentation rates on the tidal flats

N <sup>o</sup>	Levels	Sedimentation rates (cm/year)					
		DR	CL	HP	TB	BL	KS
1	Minimum	0.11	0.04	0.19	0.17	0.06	0.14
2	Maximum	1.31	0.34	2.35	14.42	15.83	0.64
3	Average	0.82	0.14	1.40	2.08	3.04	0.34
4	Standard deviation	0.37	0.11	0.65	3.105	5.27	0.15

From tab.1 we see at the Hai Phong tidal flat where is quiet, diameter of sediment (Md) is smallest, dynamic environment effect small on sediment, most core positions were collected in quiet so impacts from environment to sediment small, they also reflect by sorting of sediments from moderately to poorly at tops of core, but some layers in deeper of tidal flats we see well sorted that is in the past tidal flats affect by strong condition, and there are no deposition in these time.

### 3.2. Sedimentation rates on the tidal flats

Most of tidal flats at the time collect samples show that are accretion, highest

sedimentation rate are on Ba Lat tidal flat (BL), the next are on the Cua Cam tidal flat and Thai Binh tidal flat (TB) (tab. 2 and fig. 3). In the lower layers on tidal flats show that there is erosion states in cores of Ba Lat and Kim Son tidal flats (fig. 4). The states of accretion with suddenly high sedimentation rates are seeing in TB during 2005 and BL 2010, events high sedimentation rate suddenly are shown by results of  $^{210}\text{Pb}_{\text{activity}}$  subtract  $^{226}\text{Ra}$  at same slice is small (fig.3), they are also shown by mean diameter of sediments at that time is smaller in the sediment cores (fig.2)

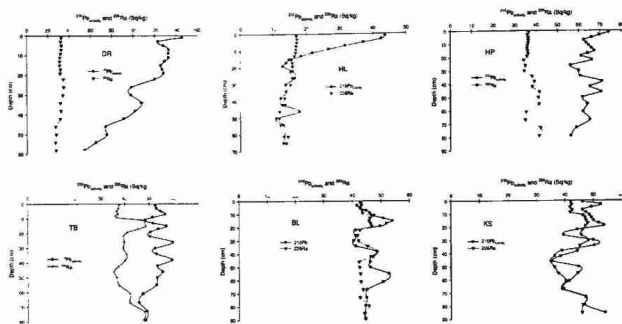


Fig.3. Distribution of  $^{210}\text{Pb}$  activity and  $^{226}\text{Ra}$  on the tidal flats.

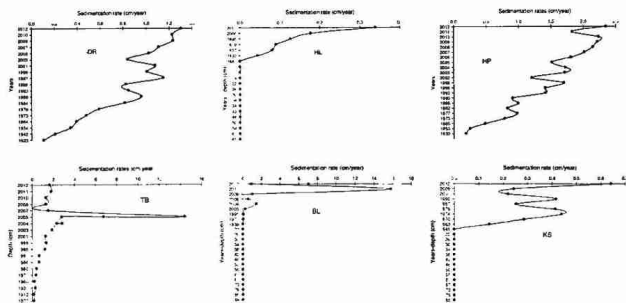


Fig.4. Distribution sedimentation rates on the tidal flats.

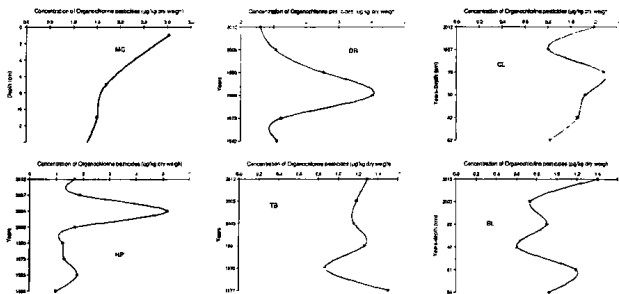
### 3.3. Organochlorine pesticides in sediment on tidal flats

In tab.3 and fig.5 the concentration of total organochlorine pesticides (OCPs) show two trends, the first trend of OCPs is increasing in recently years on Mong Cai tidal flats (MC) and Ba Lat tidal flat (BL), the second trend of OCPs is decreasing in during time seeing on DR, HP, CL, KS tidal flats. The highest of OCPs in

sediment is on Cua Cam tidal flat (HP), the next are Mong Cai (MC) and Dong Rui (DR) tidal flats, lowest of OCPs is on Ba Lat (BL) tidal flat. The compound of OCPs highest is 4,4'DDT, there are some layers in past time with 4,4'DDT over ISQG level of Canadian quality sediment guide [17]. The other compounds are always lower than ISQG levels (tab.3).

Tab.3. The concentration ( $\mu\text{g}/\text{kg}$  dry weight) of OCPs in sediment

Core	Total OCPs	Lindan	Aldrin	Endrin	4,4'DDE	4,4'DDD	4,4'DDT
KS	$1.69 \pm 1.24$	$0.11 \pm 0.04$	$0.05 \pm 0.00$	$0.65 \pm 0.51$	$0.14 \pm 0.05$	$0.16 \pm 0.08$	$0.77 \pm 0.58$
BL	$0.97 \pm 0.30$	$0.12 \pm 0.00$	$0.06 \pm 0.00$	$0.31 \pm 0.09$	$0.11 \pm 0.02$	$0.15 \pm 0.07$	$0.44 \pm 0.12$
TB	$1.21 \pm 0.21$	$0.10 \pm 0.01$	$0.05 \pm 0.00$	$0.44 \pm 0.12$	$0.14 \pm 0.00$	$0.15 \pm 0.03$	$0.51 \pm 0.12$
HP	$1.98 \pm 1.33$	$0.10 \pm 0.02$	$0.05 \pm 0.01$	$0.58 \pm 0.18$	$0.11 \pm 0.02$	$0.13 \pm 0.07$	$1.03 \pm 1.06$
CL	$1.05 \pm 0.20$	$0.09 \pm 0.01$	$0.05 \pm 0.01$	$0.36 \pm 0.08$	$0.10 \pm 0.00$	$0.11 \pm 0.02$	$0.43 \pm 0.12$
DR	$1.78 \pm 1.29$	$0.10 \pm 0.02$	$0.05 \pm 0.01$	$0.59 \pm 0.30$	$0.11 \pm 0.01$	$0.16 \pm 0.08$	$1.12 \pm 1.29$
MC	$1.86 \pm 0.81$	$0.10 \pm 0.01$	$0.05 \pm 0.00$	$0.58 \pm 0.23$	$0.11 \pm 0.01$	$0.28 \pm 0.30$	$0.76 \pm 0.29$
ISQG		0.32	-	2.67	2.07	1.22	1.19



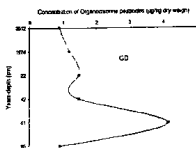


Fig.5. Distribution of total OCPs in sediments.

Tab.4. The concentration ( $\mu\text{g}/\text{kg}$  dry weight) of PAH in sediments

Cores	PAHs	Phenanthrene	Flouranthrene	Perylene	Benzo [a]-anthracene	Benzo [a]-Pyrene	Pyrene
KS	93.73 $\pm$ 31.63	61.77 $\pm$ 24.76	14.74 $\pm$ 9.80	5.79 $\pm$ 2.47	8.15 $\pm$ 2.13	1.42 $\pm$ 1.52	0.78 $\pm$ 0.08
BL	92.73 $\pm$ 35.11	58.51 $\pm$ 26.43	18.90 $\pm$ 5.62	4.60 $\pm$ 0.82	10.36 $\pm$ 4.70	0.60 $\pm$ 0.00	0.67 $\pm$ 0.08
TB	112.27 $\pm$ 24.12	68.73 $\pm$ 22.64	26.44 $\pm$ 26.50	5.86 $\pm$ 2.32	10.85 $\pm$ 3.05	0.60 $\pm$ 0.00	0.80 $\pm$ 0.32
HP	79.19 $\pm$ 34.89	68.73 $\pm$ 22.64	26.44 $\pm$ 26.49	4.78 $\pm$ 1.93	7.57 $\pm$ 7.91	0.60 $\pm$ 0.00	0.77 $\pm$ 0.10
CL	216.88 $\pm$ 139.27	82.20 $\pm$ 26.66	51.87 $\pm$ 23.96	10.55 $\pm$ 4.75	70.68 $\pm$ 128.64	1.20 $\pm$ 4.50	0.96 $\pm$ 0.23
DR	475.01 $\pm$ 511.22	251.56 $\pm$ 277.83	140.72 $\pm$ 161.14	30.00 $\pm$ 37.99	35.03 $\pm$ 40.25	14.50 $\pm$ 34.05	3.70 $\pm$ 4.36
MC	106.54 $\pm$ 39.86	61.75 $\pm$ 21.85	28.95 $\pm$ 34.29	8.19 $\pm$ 2.47	7.64 $\pm$ 4.15	0.60 $\pm$ 0.00	0.60 $\pm$ 0.00
ISQG		86.70	113.00	-	74.80	88.80	153.00

### 3.4. Polycyclic aromatic hydrocarbons on tidal flats

Polycyclic aromatic hydrocarbons (PAHs) in sediments are showed in tab.4 and fig.6, there are two trends concentration of PAHs. The first trend of PAHs shows clearly increasing by time seeing from Cua Cam (HP) tidal flat to Mong Cai (MC) tidal flat. The second trend is not clear from Thai Binh (TB) to Cua Day (KS) tidal flats. These compounds of PAHs have high concentration over ISQG levels are phenanthrene, flouranthrene, benzo [a] anthracene, other compounds are lower than ISQG levels. Two PAH which are triphenylene

and benzo [e] pyrene are equal or lower than limited detection ( $0.6 \mu\text{g}/\text{kg}$ ).

### 3.5. Distribution of polychlorinated biphenyls in sediment on tidal flats

The concentration of polychlorinated biphenyls (PCBs) in tidal flat sediment is low, it is lower than  $21.5 \mu\text{g}/\text{kg}$  dry weight (ISQG level) (tab.5). On all tidal flats, PCBs in sediments are increasing during the time (fig.7), and with PCB appear frequency common are PCB 28, PCB52 and PCB 101 in layers of tidal flats, other PCB include of PCB 138, PCB 152 and PCB 180 appear in sediment layers is not frequency common.



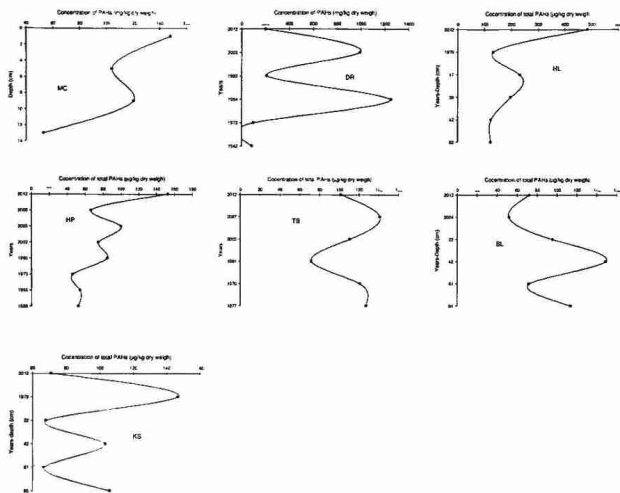


Fig.6. Distribution of total PAHs in sediments.

Tab.5. The concentration ( $\mu\text{g}/\text{kg}$  dry weight) of PCBs in sediments

Core	6PCB	PCBs	PCB28	PCB52	PCB101	PCB138	PCB 153	PCB 180
KS	0.16±0.06	1.19±0.49	0.04±0.06	0.10±0.03	0.01±0.01	0.01±0.00	0.02±0.01	
BL	0.16±0.03	1.18±0.36	0.03±0.02	0.10±0.02	0.02±0.00	0.01±0.00	0.01±0.01	
TB	0.19±0.06	1.40±0.53	0.07±0.08	0.10±0.03	0.02±0.01	0.01±0.00	0.01±0.01	
HP	0.15±0.13	1.03±0.96	0.03±0.04	0.08±0.07	0.09±0.03	0.02±0.01	0.02±0.02	
CL	0.28±0.22	2.00±1.67	0.07±0.13	0.09±0.04	0.02±0.01	0.02±0.01	0.03±0.03	0.04±0.09
DR	0.14±0.06	1.00±0.40	0.03±0.02	0.09±0.03	0.01±0.01	0.01±0.01		
MC	0.22±0.13	1.52±0.93	0.03±0.02	0.14±0.08	0.01±0.00	0.01±0.01	0.03±0.02	0.01±0.01
ISQG	-	21.5	-	-	-	-	-	-

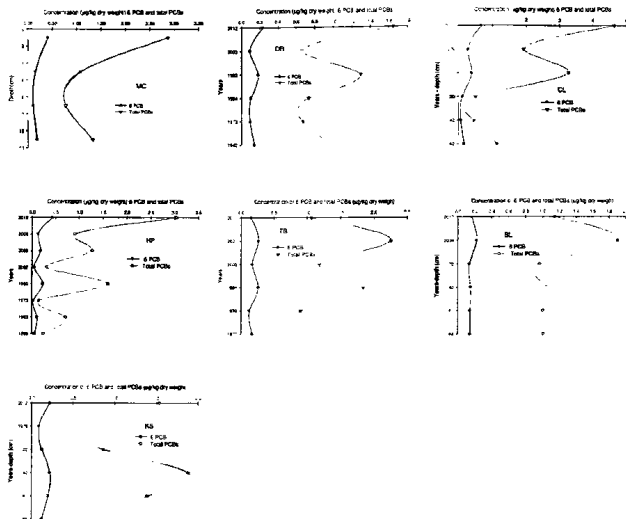


Fig.7. Distribution of PCBs in sediment.

#### 4. Discussion

Sedimentary processes on the tidal flats show two states, accretion and erosion. Erosion is showed on 20 - 40cm, 80-90 cm in depth on Ba Lat (BL) and Cua Day (KS) tidal flats, they rely on imbalance between radioactivity of  $^{226}\text{Ra}$  and  $^{210}\text{Pb}_{\text{activity}}$  in same slice with time is less than 150 years, for erosion states show base on radioactivity of  $^{226}\text{Ra}$  higher than radioactivity of  $^{210}\text{Pb}_{\text{activity}}$ , and mean diameter

(Md) of sediments bigger than accretion states. Accretion states are the most in top of tidal flats, there are some states with high sedimentation rates suddenly in short time 2005 in Thai Binh tidal flat and 2010 at Ba Lat tidal flat, if we compare the sedimentation rates on the tidal flats in areas, the deltaic tidal flats are higher than estuary and embayment tidal flats. Erosion is cause of discontinuation of calculate chronology of sediment on tidal flats in some layers.

Accumulation of persistent organic pollutants in sediments on tidal flats in the North of Vietnam are increasing by time show clearly with PAHs and PCBs, OCPs is show both increasing and decreasing by time. Increasing of PCBs, PAHs maybe relationship with developing of industrial activities in mainland, they are evidence by value of industrial products in coastal provinces are continuing increase during the time (Fig.8), source of PCBs only by human activities, but sources of PAHs in environment are complexes include from nature and human activities [18], for diagnostic ratio understand source PAHs though Flouranthrene/(Flouranthrene + Pyrene). If it is in a range  $< 0.4$ , PAHs source come from petrogenic; if it is in a range  $0.4 - 0.5$ , PAH

source come from fossil fuel (petroleum) combustion; if it range  $> 0.5$ , PAHs source come from grass, wood, coal combustion [19], these ratio Flouranthrene/(Flouranthrene + Pyrene) in sediments on the tidal flat in the North of Vietnam range from 0.56 to 0.99. Source of OCPs in sediment come only human activity on the farm in agriculture, decrease trend over time of OCPs in sediments is seeing on tidal flats, convention banning use persistent organic pollutants are effect on wide area from 2001, but until now we have been seen used OCPs in agriculture farm in mainland [20], these are reasons explain increasing trend by time of OCPs at Ba Lat and Mong Cai tidal flats.

Tab. 6. Diagnostic ratios in sediment on tidal flats in the North of Vietnam

Diagnostic ratios	Cores						
	MC	DR	HL	HP	TB	BL	CD
Flouranthrene / (Flouranthrene + Pyrene)	0.86-0.99	0.95-0.99	0.95-0.99	0.90-0.98	0.89-0.99	0.95-0.98	0.56-0.98

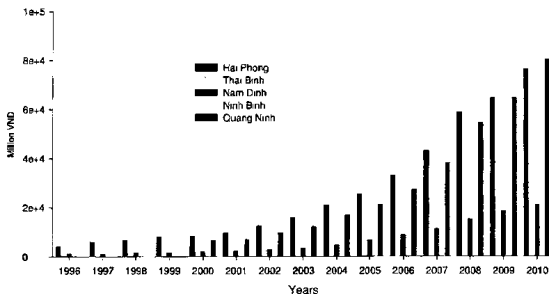


Fig.8. Value of industrial products of coastal provinces in the North of Vietnam [21].

## 5. Conclusion

On tidal flats in the North of Vietnam at the sediment cores are collected, two sedimentary processes are recorded erosion and accretion, erosion is seen in past, accretion is seen on all tidal flat at the time to collect samples. Sedimentation rates range from 0.04 to 15.83 cm/year, highest sedimentation rates on deltaic tidal flats then estuarine tidal flats, embayment tidal flats is lowest.

Accumulation of OCPs in sediment on the tidal flats have layers under surface higher than ISQGs are 4,4-DDT in concentration at Cua Cam and Dong Rui tidal flats. Trend increasing by time are shown in the Ba Lat, Mong Cai tidal flats, other tidal flats are shown decreasing by time. Accumulation of PCBs in sediment are shown increasing by time clearly at all tidal flats, but they are lower than ISQGs. PAH have some compounds are higher than ISQG, the trends increasing of PAHs in sediments by time are shown clearly from Hai Phong to Quang Ninh provinces. Sources of PCBs and OCPs are only relationship with human activities, source of PAHs in tidal sediments comes from combustion of coal, grass, wood are indicated clearly.

Accumulation of organic persistent pollutants in tidal flats are shown increasing in recently years, they are need to monitoring in near future and plan to protect environment for sustainable development of tidal flats in the North of Vietnam.

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## Tích lũy các chất ô nhiễm hữu cơ bền trong trầm tích bãi triều Miền Bắc Việt Nam

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**Tóm tắt:** Bãi triều Miền Bắc Việt Nam trải dài từ Móng Cái – Quảng Ninh tới Kim Sơn – Ninh Bình được nghiên cứu tốc độ lắng đọng trầm tích bằng  $^{210}\text{Pb}$  và  $^{226}\text{Ra}$  trên mô hình CRS, tích lũy của các chất ô nhiễm bao gồm hóa chất bảo vệ thực vật gốc clo (OCPs), polychlorinated biphenyls (PCBs) và hydrocarbon thơm đa vòng (PAHs).

Trên bãi triều có 2 hai quá trình trầm tích là bồi tụ và xói mòn. Quá trình bồi tụ là hầu hết trên đỉnh bề mặt bãi triều, tốc độ lắng đọng dao động 0,04-15,83 cm/năm, tốc độ lắng đọng cao nhất là trên bãi

triều châu thổ, tiếp đến trên bãi triều cửa sông hình phiểu và tốc độ lắng đọng nhỏ nhất trên bãi triều vũng vịnh. Quá trình xói mòn quan sát thấy ở độ sâu 20-40cm trên bãi triều Ba Lạt và một vài lớp từ 20cm cho đến đáy cột khoan ở bãi triều cửa Đáy.

Tích lũy của các chất hữu cơ bền trong trầm tích trên bãi triều thể hiện hai xu hướng, xu hướng thứ nhất là tăng lên trong những năm gần đây trên bãi triều là PCBs và PAHs, xu hướng thứ hai là giảm đi trong những năm gần đây là hóa chất bảo vệ thực vật gốc clo. Bãi triều châu thổ có xu thế không rõ ràng của hydrocarbon thơm đa vòng trong trầm tích. Một số hợp chất ô nhiễm hữu cơ bền vượt quá ngưỡng ISQGs là 4,4'-DDT, phenanthrene, flouranthrene, benzo [a] anthracene.

*Từ khóa:* Bãi triều,  $^{210}\text{Pb}$ , tốc độ lắng đọng trầm tích, các chất ô nhiễm hữu cơ bền, Miền Bắc Việt Nam.