Vietnam Journal of Marine Science and Technology 2022, 22(3) 285–298

Vietnam Academy of Science and Technology

Vietnam Journal of Marine Science and Technology

journal homepage: vjs.ac.vn/index.php/jmst

Marine sediment quality at coastal monitoring stations in Vietnam 2016–2020

Duong Thanh Nghi[1,*], Le Van Nam[1], Nguyen Thi Thu Ha[1], Nguyen Thi Mai Luu[1], Dinh Hai Ngoc[1], Dang Hoai Nhon[1], Hoang Thi Chien[1], Pham Thi Minh Hanh[2], Vu Tuan Anh[3]

[1]*Institute of Marine Environment and Resources, VAST, Vietnam*
[2]*Institute of Mechanics, VAST, Vietnam*
[3]*Institute of Oceanography, VAST, Vietnam*

Received: 8 March 2022; Accepted: 25 June 2022

ABSTRACT

Marine sediment quality at Vietnam's coastal monitoring stations in 2020 has an average ecological risk impact, with an average SQG-Q index of 0.16. 4-Four out of 24 stations have sediment quality with zero ecological risk impact, including Bach Long Vi, Thuan An, Phan Thiet, and Sa Huynh stations. The remaining stations (20/24 stations) have sediment quality with moderate ecological risk impact. The SQG-Q indices in 2020 and 2019 tend to decrease compared to 2018 and 2017.

Keywords: Sediment quality, Vietnam coastal zone, SQG-Q index.

[*]Corresponding author at: Institute of Marine Environment and Resources, 246 Da Nang, Ngo Quyen, Hai Phong, Vietnam. *E-mail addresses:* nghidt@imer.vast.vn

https://doi.org/10.15625/1859-3097/16975

INTRODUCTION

Sediment in different water bodies from continent to the ocean, has been an object of concern. In sediment basin studies, environmental conditions are assessed through sediment because of their environmental imprints over time. The sediment quality is also a consequence of the interaction among causes, activities, and results, containing signals of the deposition process such as environmental dynamics, material origin, human impacts causing environmental pollution, etc., that have been paid attention to the economic development purpose. According to human imprints over time of the sediment layers from young to ancient sediments, they contain signals to identify the environment. Environmental evolution over time and space can be identified based on assessing sediments' physical and chemical properties [1].

In Vietnam, the national coastal environment quality monitoring network managed by the Vietnam Environment Administration has been established since 1996, including the Northern coastal monitoring station, the Central coastal monitoring station, and the Southern coastal monitoring station.

Locations of the Northern coastal monitoring station: Tra Co, Cua Luc, Do Son, Ba Lat, Sam Son, Cua Lo, Co To island, and Bach Long Vi island.

Locations of the Central coastal monitoring station: Deo Ngang, Dong Hoi, Con Co, Cua Viet, Thuan An, Da Nang, Dung Quat, Sa Huynh, and Quy Nhon.

Locations of the Southern coastal monitoring station: Nha Trang, Phan Thiet, Ganh Rai, Dinh An, Song Doc, Rach Gia, and Ha Tien.

This paper presents the marine sediment quality assessment results at the Vietnam coastal monitoring stations from 2016 to 2020. Those results have played an important role in the national task in the planning sector, making desicions for a coastal exploitation, and so on.

MATERIALS AND METHODS

Materials

The paper uses the results monitored at monitoring stations from 2016 to 2020. The results were collected by the northern coastal monitoring station, the central coastal monitoring station, and the southern coastal monitoring station. Marine sediment samples were collected in dry and rainy seasons every year. The locations of monitoring points of the Northern, the Central and the Southern coastal monitoring and analysis stations are shown in Table 1 and Figure 1.

Table 1. Coordinate of stations

No.	Stations	Coordinates	Depth at sampling points (m)
1	Tra Co	21°27'31.7''N - 108°0'36,9''E	6
2	Cua Luc	20°56'59.6''N - 107°03'57,4''E	15
3	Do Son	20°39'57.4''N - 106°48'47,1''E	7
4	Ba Lat	20°14'15,3''N - 106°35'38''E	5
5	Sam Son	19°45'12.7''N - 105°55'7,5''E	12
6	Cua Lo	18°49'55.4''N - 105°43'16,8''E	8
7	Co To island	20°58'34,9''N - 107°44'54,8''E	15
8	Bach Long Vi island	20°7'8,6''N - 107°43'27,1''E	20
9	Deo Ngang	17°54'42"N - 106°34'30"E	11,5
10	Dong Hoi	17°30'36" N - 107°31'30"E	12
11	Con Co	17°05'00"N - 107°20'00"E	36
12	Cua Viet	16°55'00"N - 107°12'00"E	12
13	Thuan An	16°35'18"N - 107°38'00"E	12
14	Da Nang	16°11'54"N - 108°15'00"E	13
15	Dung Quat	15°28'48"N - 108°47'36"E	13

No.	Stations	Coordinates	Depth at sampling points (m)
16	Sa Huynh	14°39’42”N - 109°04’45”E	13
17	Quy Nhon	13°45’24”N - 109°18’54”E	13
18	Nha Trang	12°12’45”N - 109°13’12”E	20
19	Phan Thiet	10°54’10”N - 108°06’37”E	8
20	Ganh Rai	10°23’27”N - 107°01’05”E	10
21	Dinh An	9°31’51”N - 106°20’54”E	8
22	Song Doc	9°02’05”N - 104°47’45”E	5
23	Rach Gia	9°58’24’’N - 105°04’07”E	3
24	Ha Tien	10°21’47”N - 104°28’13”E	4

Figure 1. Location of monitoring stations

Sampling and analytical methods of sea water samples

Sediment samples were collectd by a Petersen grab that is 5,000 cm^3 volume and made of stainless steel. Sediment samples were collected according to the guidance of the Circular 24/2017/TT-BTNMT (Environmental monitoring and technical regulations) (Circular 24/2017/TT-BTNMT) [2] and TCVN 6663-15: 2004 (Guidance on preservation and handling of sludge and sediment samples) [3]. Sediment parameters were analyzed according to the current Vietnamese and International standards (Table 2).

Table 2. Methods of analyzing sediment samples in the laboratory

No.	Parameter	Analytical methods
1	Copper (Cu)	TCVN 6649:2000; APHA Part 300-3125 B (ICP-MS), 2012
2	Chromium (Cr)	TCVN 6649: 000; APHA Part 300-3125 B (ICP-MS), 2012
3	Zinc (Zn)	TCVN 6649:2000; APHA Part 300-3125 B (ICP-MS), 2012
4	Lead (Pb)	TCVN 6649:2000; APHA Part 300-3125 B (ICP-MS), 2012
5	Mercury (Hg)	TCVN 6649:2000; APHA Part 300-3125 B (ICP-MS), 2012
6	Cadmium (Cd)	TCVN 6649: 000; APHA Part 300-3125 B (ICP-MS), 2012
7	Arsenic (As)	TCVN 6649: 000; APHA Part 300-3125 B (ICP-MS), 2012
8	PCBs	TCVN 8061: 2009
9	Organic Chlorinated Pesticides (OCPs)	EPA 8081A
10	Organic carbon	EPA Method 9071B
11	PAHs	TCVN 9318:2012

The study applied the Vietnams National technical regulations about sediment quality (the QCVN 43:2017/BTNMT-Ministry of Natural Resources and Environment, 2017) [4] to assess the quality of the sediment environment.

Assess the possibility of heavy metal pollution (Table 1) in sediments according to the *Q* coefficient. The *Q* coefficient is calculated as a ratio between the observed heavy metal concentration and corresponding limit values of the national technical regulations about sediment quality (QCVN43:2017/BTNMT).

Using unweighted average sediment quality index [5–7].

$$SQG - Q = \frac{\sum_{i=1}^{n} PEL - Q_i}{n};\ PEL - Q_i = \frac{C_i}{PEL}$$

in which: PEL: permissible exposure limit (using the QCVN 43:2012); $PEL - Q_i$: impact coefficient of pollutant *i*; *n:* number of pollutant parameters used in the formula; C_i: monitored concentration of pollutant *i*.

Assessment of sediment quality on ecological risks:

$SQG - Q \leq 0,1$: no impact;

$0,1 < SGQ - Q < 1$: moderate impact;

$SQG - Q \geq 1$: high impact.

RESULTS AND DISCUSSION

Sediment quality evolution at the Northern coastal monitoring station

Organic carbon

The annual average organic carbon concentration in sediments at monitoring stations ranges from 25,11 mg/kg dry (BLV station in 2017) to 1,671.08 mg/kg dry (Cua

Luc station in 2019) during the period 2016–2020. The sedimentary characteristics at Bach Long Vi station are mainly sand grain composition and low organic matter concentration. The organic matter concentrations in the sediments at the monitoring stations are relatively stable and less variant (Table 3).

Table 3. Total organic concentration (mg/kg dry) in marine sediment at the Northern coastal monitoring stations 2016–2020 [8]

No.	Stations	2020	2019	2018	2017	2016
1	Tra Co	675.96	651.67	494.31	445.97	440.69
2	Cua Luc	995.18	1671.08	1580.7	1587.43	1242.01
3	Do Son	795.89	819.81	716.41	636.8	517.49
4	Ba Lat	723.24	794.43	856.15	841.53	689.33
5	Sam Son	364.62	368.06	400.89	339.82	202.94
6	Cua Lo	788.13	878.04	835.36	826.78	696.56
7	Co To	506.12	284.67	330.22	26.33	KQT
8	Bach Long Vi	214.98	195.2	219.81	25.11	KQT
The coastal in average		*633.01*	*707.87*	*679.23*	*591.22*	*631.50*

Notes: KQT: no observation.

Heavy metal

The results of monitored heavy metal concentrations (Cr, Cu, Pb, Zn, Cd, As, and Hg) in sediment at the Northern coastal monitoring stations in 2020 showed that Cr concentration ranged from 6.80 mg/kg dry (Bach Long Vi) to 42.85 mg/kg dry (Cua Lo), with the average value of 26.88 mg/kg dry; Cu concentration ranged from 4.36 mg/kg dry (Bach Long Vi) to 49.14 mg/kg dry (Ba Lat), average 22.37 mg/kg dry; Pb concentration ranged from 9.89 mg/kg dry (Bach Long Vi) to 39.91 mg/kg dry (Ba Lat), average 21.80 mg/kg dry; Zn concentration ranged from 31.19 mg/kg dry (Bach Long Vi) to 79.57 mg/kg dry (Ba Lat), average 56.95 mg/kg dry; Cd concentration ranged from 0.15 mg/kg dry (Bach Long Vi) to 0.34 mg/kg dry (Ba Lat), average 0.21 mg/kg dry; As concentration ranged from 2.14 mg/kg dry (Bach Long Vi) to 11.09 mg/kg dry (Ba Lat), average 6.53 mg/kg dry; Hg concentration ranged from 0.04 mg/kg dry (Bach Long Vi) to 0.33 mg/kg dry (Cua Luc), average 0.15 mg/kg dry.

Table 4. The concentrations of Cu, Pb, Zn, Cd, As, Hg in sediment (mg/kg dry) at the Northern coastal monitoring stations 2016–2020 [8]

No.	Stations	Heavy metal concentrations (mg/kg dry)						
		Cr	Cu	Pb	Zn	Cd	As	Hg
1	Tra Co	23.01	12.57	15.02	40.61	0.15	2.70	0.07
2	Cua Luc	21.28	18.53	20.21	61.49	0.17	5.92	0.33
3	Do Son	31.78	34.98	32.54	69.13	0.24	10.50	0.26
4	Ba Lat	41.25	49.14	39.91	79.57	0.34	11.09	0.16
5	Sam Son	27.98	22.38	22.59	69.57	0.19	7.85	0.14
6	Cua Lo	42.85	28.65	22.08	60.65	0.22	9.23	0.14
7	Co To	20.09	8.37	12.15	43.41	0.20	2.85	0.07
8	Bach Long Vi	6.80	4.36	9.89	31.19	0.15	2.14	0.04
Average 2020		*26.88*	*22.37*	*21.80*	*56.95*	*0.21*	*6.53*	*0.15*
Average 2019		*27.24*	*23.79*	*25.18*	*61.59*	*0.16*	*7.53*	*0.16*
Average 2018			*28.44*	*38.19*	*69.17*	*0.27*	*0.45*	*0.33*
Average 2017			*20.45*	*24.65*	*102.79*	*0.09*	*7.17*	*0.25*
Avergae 2016			*30.06*	*24.84*	*64.17*	*0.18*	*6.41*	*0.10*
QCVN43:2017/BTNMT		160	108	112	271	4.2	41.6	0.7

The heavy metal concentrations (Cr, Cu, Pb, Zn, Cd, As, and Hg) in sediment at the monitoring stations (2016–2020) are relatively stable, less variant, and lower than the allowable limits according to QCVN 43:2017/BTNMT (Table 4).

Plant protection chemicals (OCPs)

Table 5. OCPs concentration (ng/g dry) in sediment at the Northern coastal monitoring stations 2016–2020 [8]

No.	Stations	2020	2019	2018	2016
1	Tra Co	12.97	4.52	0.14	42.89
2	Cua Luc	21.99	3.30	0.44	1.05
3	Do Son	115.42	2.38	0.28	1.39
4	Ba Lat	10.68	1.00	0.18	1.66
5	Sam Son	14.22	17.53	0.20	0.97
6	Cua Lo	26.49	3.75	0.25	0.68
7	Co To	7.25	1.03	0.09	KQT
8	Bach Long Vi	1.31	0.59	0.03	KQT
The coastal in average		*26.29*	*4.26*	*0.20*	*8.10*

Note: KQT: no observation.

The concentration of OCPs in sediment at the Northern coastal monitoring stations (2016–2020) was relatively low and lower than the allowable limit according to QCVN 43:2012/BTNMT. The average concentration of total OCPs in sediment from 2018–2020 tended to increase (the concentration of total OCPs in 2020 increased 6.17 times compared to 2019 and 131.05 times compared to 2018 (Table 5).

PCBs

Table 6. PCBs concentration (ng/g dry) in sediment at the Northern coastal monitoring stations 2016–2020 [8]

No.	Stations	2020	2019	2018	2016
1	Tra Co	43.40	27.15	21.96	17.94
2	Cua Luc	22.59	34.37	18.55	30.40
3	Do Son	60.96	49.81	23.52	44.72
4	Ba Lat	26.03	41.82	3.05	15.18
5	Sam Son	27.58	39.45	21.55	33.03
6	Cua Lo	43.20	32.56	6.42	27.49
7	Co To	24.53	34.11	KQT	KQT
8	Bach Long Vi	1.90	27.72	0.22	KQT
The coastal in average		*31.27*	*35.87*	*13.61*	*28.13*

Note: KQT: no observation.

Observed typical PCBs compounds in the environment include PCB28, PCB52, PCB101, PCB138, PCB153, PCB180. The average PCBs concentration in sediment at the Northern coastal monitoring stations (2016–2020) ranged from 0.22 ng/g dry to 60.96 ng/g dry, lower than the allowable limit according to QCVN 43:2017/BTNMT. The average concentrations of PCBs in sediment in 2019 and 2020 were higher than those in 2018 and 2016 (Table 6).

PAHs (Polycyclic Aromatic Hydrocarbons)

The analysis results of PAHs concentration in sediment at 8 monitoring stations in 2020 showed that 6 PAHs components were detected in sediment samples, including Phenanthrene, Flouranthene, Perylene, Benzo[a] anthracene, Triphenylene, and Benzo (a) pyrene; Two components Benzo (e) pyrene and pyrene were not detected in sediment samples.

The average concentration of PAHs in sediment at the northern coastal monitoring stations (2016–2020) ranged from 2.26 µg/kg to 106.16 µg/kg dry, lower than the allowable limit according to QCVN 43:2017/BTNMT. The average concentration of PAHs in sediment decreased from 2016 to 2020 (Table 7).

Table 7. PAHs concentration (µg/kg dry) in sediment at the Northern coastal monitoring stations 2016–2020 [8]

No.	Stations	2020	2019	2018	2017	2016
1	Tra Co	53.13	88.36	88.27	39.36	40.14
2	Cua Luc	16.56	20.87	23.35	92.84	94.48
3	Do Son	14.35	21.03	32.32	33.57	34.00
4	Ba Lat	23.93	27.46	27.13	34.02	33.87
5	Sam Son	24.74	26.09	41.63	37.54	38.43
6	Cua Lo	52.73	86.23	99.54	106.16	105.63
7	Co To	10.50	9.29	10.02	11.11	KQT
8	Bach Long Vi	2.26	2.66	3.75	4.28	KQT
The coastal in average		*24.77*	*35.25*	*40.75*	*44.86*	*57.76*

Note: KQT: no observation.

The Central coastal monitoring station

Organochlorine plant protection chemicals

The analysis results of sediment samples at monitoring stations showed undetectable values (< 0.001 mg/kg) for all 18 monitoring parameters, including Alfa-BHC, Gama-BHC, Beta-BHC, Delta-BHC, Heptachlor, Aldrine, Heptachlorepoxide, Chlordan, 4.4’-DDE’, Endosunfan 1, Diedrine, Endrine, 4.4’-DDD, Endosunfan 2, 4.4’-DDT, Methoxylchlor, Endrin aldehyde, and Endosunfal sulfate.

Heavy metals, oil, and cyanide

Table 8. The concentrations of oil, heavy metals, and xyanide (mg/kg dry) in sediment at the Central coastal monitoring stations 2016–2020 [9]

Years	Values	Oil	Xyanide	Zn	Cu	Pb	Cd	As	Hg	Fe	Cr
2020	Min	4.3	< 0.1	4.13	2.6	1.8	0.01	1.8	0.01	2.13	2.4
	Max	11.3		84.96	42.3	54	0.22	25.2	0.04	39.31	90.5
	Average	*7.8*	< 0.1	*44.55*	*22.45*	*27.9*	*0.12*	*13.5*	*0.03*	*20.72*	*46.45*
2019	Min	5.4	< 0.1	5.6	1.7	1.12	0.01	1.22	0.01	1.15	7.2
	Max	15.4			54.7	17.97	0.27	35.23	0.05	28.57	75.9
	Average	*10.4*	< 0.1	*2.8*	*28.2*	*9.55*	*0.14*	*18.23*	*0.03*	*14.86*	*41.55*
2018	Min	6.5	< 0.1	12.1	1.9	2.2	0.1	1.5	0.1	1.18	4.3
	Max	16.3		132.2	29.1	50.7	3.6	16.9	0.2	36.37	87.6
	Average	*11.4*	< 0.1	*72.15*	*15.5*	*26.45*	*1.85*	*9.2*	*0.15*	*18.78*	*45.95*
2017	Min	8.6	< 0.1	7.2	5.2	1.4	< 0.01	2.9	< 0.01	8	6.5
	Max	23.4		73.4	29.1	30.9		17		25.2	35.2
	Average	*16*	< 0.1	*40.3*	*17.15*	*16.15*	*0.01*	*9.95*	*0.01*	*16.6*	*20.85*
2016	Min	6.5	< 0.1	11.5	5.1	3.8	< 0.01	3.8	<0.01	KQT	4.8
	Max	22.1		85.3	33.3	36.6		19			14.3
	Average	*14.3*	< 0.1	*48.4*	*19.2*	*20.2*	*0.01*	*11.4*	*0.01*		*9.55*
QCVN 43:2017/BTNMT		*100*	*0.1*	*271*	*108*	*112*	*4.2*	*41.6*	*0.7*	*20*	*160*

Note: KQT: no observation.

The concentrations of oil and other heavy metals (Cu, Pb, Zn, As, Cr) in sediment did not change during the year as well as over the years and were much smaller than the allowable limit according to QCVN 43:2017/BTNMT.

As a result, all sediment samples illustrated that cyanide concentrations were below the detection limit (< 0.1 mg/kg).

Fe concentration was the highest among the observed heavy metals. The analysis results of sediment samples collected in 2020 showed that in 4 sampling periods, Fe concentration in Dong Hoi and Da Nang exceeded the allowable limit; 3/4 of the number of samples in Con Co and Deo Ngang as well as 1/4 of the number of samples in Cua Viet exceeded the permissible limit. In 2019, some samples collected at Deo Ngang, Dong Hoi, and Da Nang also exceeded the allowable limits. The average Fe concentration among measurement periods did not change.

Comparing the mean value of Fe concentrations in sediment at observed points from 2017–2020 showed that there was no difference in these values between Deo Ngang, Dong Hoi, Con Co, and Da Nang, while the concentrations of Fe observed at these points were higher than those of the remaining observed points, including Cua Viet, Thuan An, Dung Quat, Sa Huynh, and Quy Nhon (Table 8).

PCBs và PAHs

The analysis results of PCBs concentration showed that in the sediment samples with more sand grain was lower than in the samples with more clay and mud composition. The amount of PCBs concentration varied from KHP (under the detection threshold of the method: < 0.05 μg/kg) to 7.62 μg/kg, many times smaller than GHPC (QCVN 43:2017/BTNMT: with total PCBs of 189 μg/kg). At the measurement points (Cua Viet, Thuan An, Dung Quat, and Sa Huynh) in 2020, there were no PCBs detected in sediment samples. Comparing between the measurement periods showed that most of the measuring points, except Dong Hoi, could not detect PCBs in sediment samples in May. The average PCBs concentration in sediment did not change much over the remaining measurement periods.

Similar to PCBs concentrations in sediment, the analysis results showed that PAHs concentration in sediment tended to be higher in samples with clay composition collected at Con Co and Da Nang as well as than in other samples with predominant sand composition collected at Cua Viet, Thuan An, Dung Quat, and Sa Huynh. Comparing the content of PAHs with marine sediment standards shows that this value is many times lower than the allowable limit, from a few to several hundred times lower.

The Southern coastal monitoring station

The concentrations of metals in sediment at the stations have the following order value as Zn > Cr > Pb ≈ Cu > As > Cd > Hg, and there is no significant difference in these values between sampling periods, lower than the allowable limit according to QCVN 43:2012/BTNMT. The concentration of organochlorine plant protection chemicals in sediments is lower than the permissible limit; however, it is noteworthy that Lindan often exceeds the allowable limit at stations. The concentrations of PCBs and PAHs at the stations are lower than the allowable limit. The concentration of total hydrocarbons in sediments is less variant, consistently exceeding the allowable limit.

The concentrations of some heavy metals, PCBs, PAHs, organochlorine plant protection chemicals and total hydrocarbons in the sediments at the Southern coastal monitoring station (2016–2020) tend to vary unclearly (Table 9).

Table 9. The concentrations of heavy metals and total hydrocarbon (mg/kg) in sediment at the Southern coastal monitoring station 2016–2020 [10]

Stations	Years	Zn	Cu	Pb	As	Cd	Hg	Cr	Hydrocarbon
Nha Trang	2020	59.7	30.2	21.4	2.68	0.28	0.13	50.6	102
	2019	60.4	18.1	19.5	2.8	0.47	0.12	34.5	110
	2018	58.3	23.6	18.8	3.25	0.56	0.14	44.1	129
	2017	80.5	27.8	31.2	4.9	1.37	0.21	14.7	113
Phan Thiet	2020	14.3	7.1	5.55	2.4	0.19	0.12	13.6	86.5
	2019	15.4	6.8	5.77	2.37	0.19	0.13	13.7	98.3
	2018	15.4	5.95	7.6	3.25	0.28	0.09	14.5	116
	2017	17.8	8.3	8.5	2.75	0.55	0.20	7.6	101
Ganh Rai	2020	61.6	27.8	23.3	3.8	0.39	0.14	54.2	112
	2019	58.7	24.6	16.9	4.6	0.47	0.12	41.6	116
	2018	62.5	24.3	18	4.9	0.55	0.11	46.2	147
	2017	78.3	34.7	26	4.25	1.08	0.22	51	130
Dinh An	2020	52.1	26.4	23.3	4.3	0.27	0.14	42.4	115
	2019	58.2	22.5	19.2	4.57	0.38	0.14	38.4	116
	2018	57	20.6	19.3	5.7	0.55	0.12	47.3	127
	2017	71.9	35.7	28.8	6.4	1.09	0.25	30.2	109
Rach Gia	2020	50	25.3	20.1	4.3	0.25	0.11	40.8	111
	2019	57.1	18	21.1	3.43	0.19	0.11	32.5	116
	2018	55.6	23.7	24.5	3.95	0.42	0.11	42.9	122
	2017	71.6	23.9	25.3	5.75	0.75	0.19	28.1	107

Assessment of sediment quality on ecological risk

SQG – Q index indicates that the quality of sediment at Vietnam's coastal monitoring stations in 2020 has an average ecological risk impact, with an average *SQG – Q* index of 0.16 (Table 10).

The stations (4/24 stations) that had sediment quality with zero ecological risk impact were Bach Long Vi, Thuan An, Sa Huynh, and Phan Thiet. The remaining stations (20/24 stations) had sediment quality with moderate ecological risk impact (Table 10). The *SQG – Q* index of sediment at offshore stations tended to be lower than that of nearshore stations because the offshore stations are less affected by pollutant discharge sources than the nearshore stations. The average *SQG – Q* index during the period 2016–2020 is higher than 0.1 (moderate ecological risk impact); the *SQG – Q* index in 2020 and 2019 tended to decrease compared to 2018 and 2017. Those *SQG – Q* indices showed that many human development activities in the coastal areas are not controlled more and more (Figures 2–3).

Marine pollution from rivers and coastal industrial activities is considered the primary pollution source for coastal waters. The sources of marine pollution are associated with marine space exploitation activities and urbanization. Socio-economic development (industrial-urban zones, aquaculture, expansion of seaports, increase in activities of ships at sea, etc.) has increased the pollution risk of marine sediments, causing negative impacts in both short and long terms on the marine environment. Therefore, it is necessary to establish an urban wastewater treatment system before discharging directly into the environment, build solid waste treatment factories, and reinforce the barrier system of landfills, etc.

Comparison of the *SQG – Q* index of sedimentary environment at Vietnam's coastal monitoring stations with some other areas shows that the *SQG – Q* indexes in the study areas are similar (Table 11).

Table 10. SQG – Q index of sedimentary environment at the coastal monitoring stations 2016–2020

No.	Stations	2020	2019	2018	2017	2016
1	Tra Co	0.11	0.10	0.19	0.11	0.21
2	Cua Luc	0.19	0.21	0.23	0.22	0.1
3	Do Son	0.25	0.27	0.41	0.30	0.15
4	Ba Lat	0.28	0.30	0.34	0.54	0.19
5	Sam Son	0.18	0.20	0.24	0.25	0.09
6	Cua Lo	0.20	0.21	0.27	0.24	0.09
7	Co To	0.10	0.13	0.15	0.09	-
8	Bach Long Vi	0.06	0.06	0.04	0.03	-
9	Deo Ngang	0.20	0.21	0.23	0.24	0.21
10	Dong Hoi	0.24	0.23	0.25	0.26	0.28
11	Con Co	0.22	0.21	0.23	0.27	0.24
12	Cua Viet	0.18	0.17	0.14	0.16	0.15
13	Thuan An	0.11	0.09	0.08	0.07	0.08
14	Da Nang	0.26	0.27	0.27	0.26	0.26
15	Dung Quat	0.19	0.20	0.17	0.19	0.19
16	Sa Huynh	0.10	0.09	0.08	0.07	0.07
17	Quy Nhon	0.15	0.13	0.12	0.13	0.12
18	Nha Trang	0.12	0.13	0.17	0.17	0.18
19	Phan Thiet	0.06	0.06	0.08	0.08	0.07
20	Ganh Rai	0.12	0.21	0.17	0.18	0.19
21	Dinh An	0.11	0.12	0.17	0.15	0.15
22	Song Đoc	0.10	0.12	0.14	0.13	0.11
23	Rach Gia	0.11	0.13	0.17	0.16	0.14
24	Ha Tien	0.12	0.10	0.12	0.12	0.13
The coastal in average		*0.16*	*0.16*	*0.19*	*0.18*	*0.15*

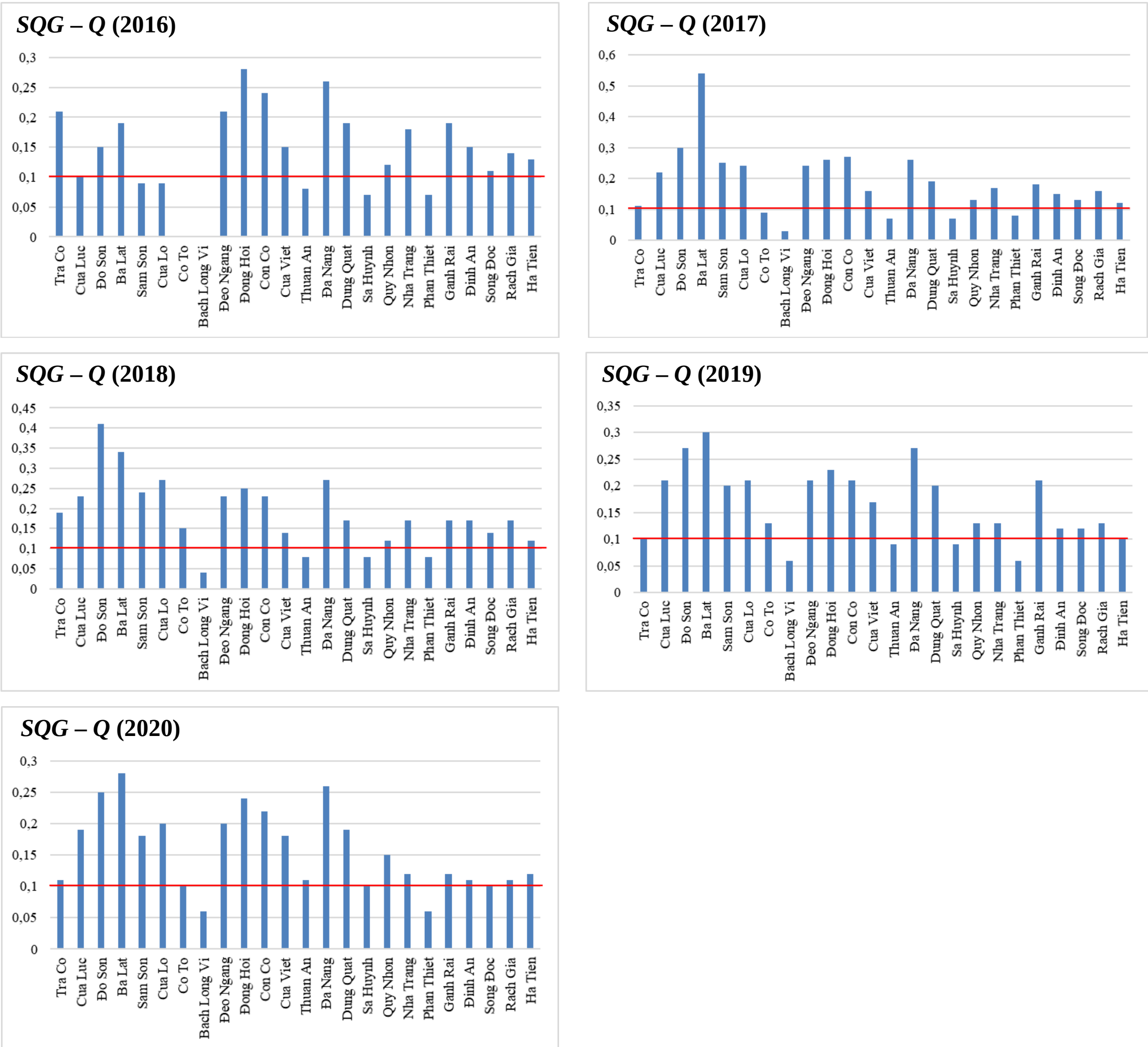

Figure 2. The fluctuation of *SQG – Q* index of sedimentary environmet at coastal monitoring stations 2016–2020

Table 11. Comparison of the *SQG – Q* index of the sedimentary environment at the Vietnam’s coastal monitoring stations with some other areas

No.	Stations	*SQG – Q*	References
1	The coastal monitoring stations (Vietnam)	0.06–0.28 (*n* = 24)	In this study
2	Masan Bay (Korea)	0.04–0.20 (*n* = 21)	[11]
3	West Coast of Peninsular Malaysia	0.17–0.70 (*n* = 6)	[12]
4	Lampung Bay, Indonesia	0.06–0.22 (*n* = 13)	[13]
5	Kramat Kebo Estuary, West Java, Indonesia	0.09–0.22 (*n* = 9)	[14]
6	Jiaozhou Bay (China)	0.27–0.68 (*n* = 8)	[15]
7	Gajah Mungkur Reservoir, Indonesia	0.28–0.45 (*n* = 8)	[16]

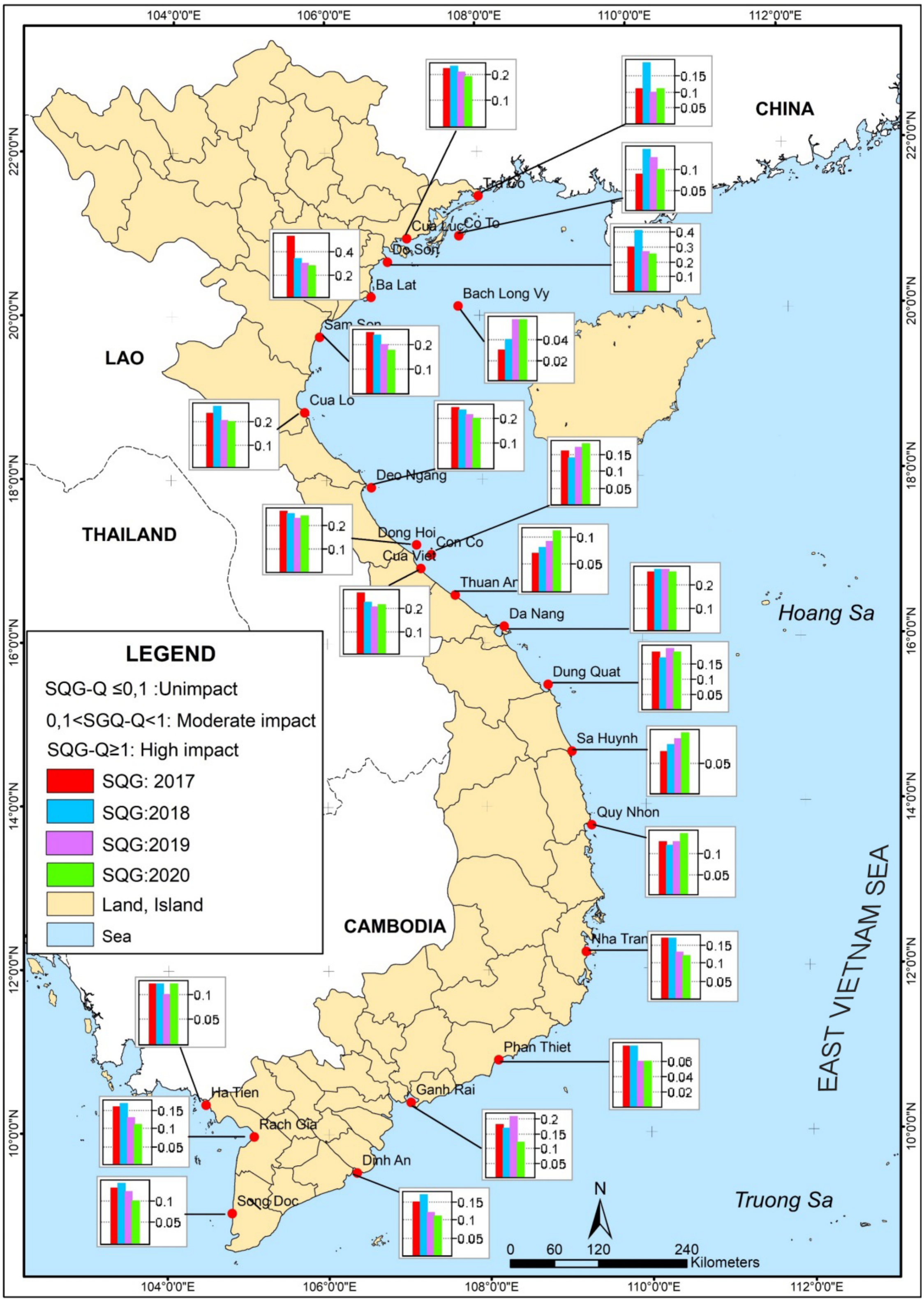

Figure 3. SQG – Q index of sedimentary environment at monitoring stations in 2017–2020

CONCLUSIONS

The marine sediment at Vietnam's coastal monitoring stations has not shown any signs of contamination by plant protection chemicals, heavy metals, PCBs, and PAHs. The *SQG – Q* index shows that the quality of marine sediment at Vietnam’s coastal monitoring stations in 2020 had an average ecological risk impact, with an average *SQG – Q* index of 0.16 (in a range of 0.06–0.28). At the southern monitoring stations, the total hydrocarbon concentration in sediment exceeded the allowable limit.

Four stations with good environmental quality with zero ecological risk were Bach Long Vi, Thuan An, Sa Huynh, and Phan Thiet. Twenty stations left had a sediment quality with moderate ecological risk impact.

The *SQG – Q* index in 2020 and 2019 decreased compared to 2018 and 2017.

Acknowledgments: The authors gratefully acknowledge the Northern coastal monitoring station, the middle coastal monitoring station, and the southern coastal monitoring station for their kind cooperation.

REFERENCES

[1] Thanh Loan, B. T., Hoang, N. H., Luu, N. M., Nam, L. V., Dung, P. T. Ve, N. D., Sieu, L. N., Nhon, D. H., and Thanh, T. D., 2022. Some Sedimentary Environment Characteristics in the Mong Cai Coastal Area, Quang Ninh Province, Vietnam. *VNU Journal of Science: Earth and Environmental Sciences*, *38*(1), 57–70. (in Vietnamese).

[2] Circular 24/2017/TT-BTNMT, September 1, 2017. Regulations on environmental monitoring techniques. (in Vietnamese).

[3] TCVN 6663-15:2004. Water quality - Sampling - Part 15: Guidance on preservation and handling of sludge and sediment samples. (in Vietnamese).

[4] Ministry of Natural Resources and Environment, 2012. National technical regulation on sediment quality: QCVN 43:2012/BTNMT. Ministry of Natural Resources and Environment. (in Vietnamese).

[5] Ramli, I., and Lestari, M. R., 2020. Water and Sediment Quality Index Due To Gold Mining in The Krueng Kluet Hilir Watershed, Aceh Selatan Regency. *Aceh International Journal of Science and Technology*, *9*(1), 29–39. https://doi.org/10.13170/aijst.9.1.15267

[6] Long, E. R., and MacDonald, D. D., 1998. Recommended uses of empirically derived, sediment quality guidelines for marine and estuarine ecosystems. *Human and Ecological Risk Assessment*, *4*(5), 1019–1039. https://doi.org/10.1080/10807039891284956

[7] Caeiro, S., Costa, M. H., Ramos, T. B., Fernandes, F., Silveira, N., Coimbra, A., Medeiros, G., and Painho, M., 2005. Assessing heavy metal contamination in Sado Estuary sediment: an index analysis approach. *Ecological Indicators*, *5*(2), 151–169. https://doi.org/10.1016/j.ecolind.2005.02.001

[8] Northern Coastal Monitoring Station, 2020. Report on marine environment monitoring results in 2016, 2017, 2018, 2019, 2020. Report stored at the Institute of Marine Environment and Resources. (in Vietnamese).

[9] Central Coastal Monitoring Station, 2020. Report on marine environment monitoring results in 2016, 2017, 2018, 2019, 2020. Report stored at the Institute of Mechanics. (in Vietnamese).

[10] Southern Coastal Monitoring Station, 2020. Report on marine environment monitoring results in 2016, 2017, 2018, 2019, 2020. Report stored at the Institute of Oceanography.

[11] Shim, W. J., and Hong, S. H., 2007. Application of a Sediment Quality Index to the Masan Bay, Korea. *Ocean and Polar Research*, *29*(4), 367–378. doi: 10.4217/OPR.2007.29.4.367

[12] Buhari, T. R. I., and Ismail, A., 2016. Heavy metals pollution and ecological risk assessment in surface sediments of

west coast of Peninsular Malaysia. *International Journal of Environmental Science and Development*, *7*(10), 750. doi: 10.18178/ijesd.2016.7.10.874

[13] Budiyanto, F., 2015. The assessment of sediment contamination level in the Lampung bay, Indonesia: heavy metal perspective. *Jurnal Segara*, *11*(1), 71–78. http://dx.doi.org/10.15578/segara.v11i1.9085

[14] Puspitasari, R., and Lestari, L., 2018. Heavy metal condition in Kramat Kebo Estuary, West Java, Indonesia as Habitat of Oryzias javanicus. *Jurnal Segara*, *14*(2), 79–85. http://dx.doi.org/10.15578/segara.v14i2.6643

[15] Lin, Y., Liu, Q., Meng, F., Lin, Y., and Du, Y., 2018. Integrated toxicity evaluation of metals in sediments of Jiaozhou bay (China): Based on biomarkers responses in clam R*uditapes philippinarum* exposed to sediment extracts. *Marine Pollution Bulletin*, *131*, 180–190. https://doi.org/10.1016/j.marpolbul.2018.04.024

[16] Pujiastuti, P., Putri, R. J., and Suseno, S., 2021. Determination of the tropical status of floating net cage water based on the distribution of nitrogen, phosphorus and chlorophyll-a. *BIOLINK (Jurnal Biologi Lingkungan Industri Kesehatan)*, *7*(2), 172–184. doi: 10.31289/biolink.v7i2.3902