Coastal Sea Water Quality of Nha Trang Bay, Khanh Hoa, Viet Nam

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Abstract: Nha Trang Bay is famous not only because of its beauty, but also of the biodiversity values, especially coral reefs. Thus, the sea water quality monitoring systems are necessary for effective and available managements to protect the ecosystems and for sustainable development. There have been several monitoring systems here but they have been done separately and unconnectedly. This research was done to take an overview and access the status and changes of water quality from 2007-2014. The data obtained rainy seasons over the years showed a quite good environment here. The environment changes were also monitored and there were some changes between seasons and over years, decreasing, increasing, or unobvious trends. However, the difference was not so much; and there was not the sign of environmental degradation in the bay from 2007 to 2014. Besides, the stoichiometric nutrients limitations were initially assessed. Since Si ratios here were always higher compared to N and P, there was not increased potential for non-diatom algal blooms. Together with the recorded nutrients concentration data, it can be said that there was no evidence of eutrophication in the bay. Although there was partial contamination of some parameters at few moments, the sea water quality of Nha Trang bay was still in a good condition (according to Vietnamese and ASEAN criteria).

Key words: Nha Trang bay, sea water quality, environmental trend, nutrients limitations.

1. Rationale

Nha Trang Bay, a well-known tourism site in the south of the central region, is famous not only because of its beauty, but also of the biodiversity values. However, the economic activities here have caused certain impacts to the ecosystems, especially coral reefs. The increased development of tourism in recent years creates more and more stress to the environmental quality here. Besides, thousands of cubic meters of waste water is discharged every day from residential quarters; there are five sewers through which waste water goes directly to the sea from the city, and some others to Cai river in the north (basin square around 3,000 km², discharge around 5.6 m³/s in dry and 78 m³/s in rainy season) and Tac river in the south (basin square around 120 km², discharge around 0.6 m³/s in dry and 2.6 m³/s in rainy season) [1]. All of these have made the Nha Trang Bay more and more polluted. For these reasons, the water quality monitoring is necessary for effective and available management to protect the ecosystems here and for sustainable development. Since 1990s, monitoring programs in Nha Trang Bay are conducted regularly. The data from 2007 to 2014 [2] is quite adequate, continuous and timely to have an overview of the situation and changes in sea water quality.

The objective of this research is to assess and take an overview of status and changes of sea water quality of Nha Trang Bay.

2. Materials and Methods

The water samples were collected at surface and bottom layers, using 5 L plastic vertical water sampler at selected sites (Fig. 1); totally, 308 samples had been collected in rainy and dry seasons through 6 years 2007 and 2010-2014. The environmental basic parameters (pH, TSS, DO, BOD5), nutrient concentrations (NH₃, ₄-N, NO₂-N, NO₃-N, PO₄-P, SiO₂-Si), heavy metals (Zn, Cu, Pb, Fe) and hydrocarbon
were selected for statistic and comparison. The samples were treated and analyzed following the methods in APHA [5] and FAO [6]. Vietnam National Technical Regulation on Coastal Water Quality and Asian Marine Water Quality Criteria for Aquatic Life Protection were used as references for accessing the environmental quality.

Statistic and comparison methods, using Microsoft Excel software, were applied to compare and estimate the trend of changes.

3. Results and Discussions

3.1 Status of Water Quality

3.1.1 Water Quality in Dry Seasons

For the basic and nutrient parameters, the data in dry seasons showed that most of values of these parameters were in the controlled level (Table 1). The high silicate concentration showed the effect of fresh water from rivers on Nha Trang bay, even in dry seasons. Especially, the Cai River had a marked effect on the northern area.

At few moments, there were partial contaminations of some nutrient parameters (TSS, NH$_3$-N, NO$_3$-N, PO$_4$-P). However, generally, the sea water quality in the entire bay in dry seasons was pretty good; most of the values of nutrient parameters were much lower than the standard.

For heavy metals parameters, the data from Table 2 shows that heavy metals contents were very low, except Fe. The metals such as Zn, Cu and Pb had the values much lower; meanwhile Iron content was always higher than the standard. However, compared to other sea areas in Vietnam, this Fe content is not higher (even much lower than some) [7]. It might be explained that, the Iron from natural sources processes, which is major compared to the human activities sources [8, 9], and the standard here is unrealistic when skipping this.
Table 1  Values of some basic and nutrient parameters in dry season in 2014.

| Areas          | n   | pH  | TSS (mg/l) | DO (mg/l) | BOD₅ (mg/l) | NH₃-N (µg/l) | NO₂-N (µg/l) | NO₃-N (µg/l) | PO₄-P (µg/l) | SiO₃-Si (µg/l) |
|----------------|-----|-----|------------|-----------|-------------|--------------|--------------|--------------|--------------|----------------|
| Cairiver mouth 2 | 7.96 | 6.76 | 1.04       | 2.0       | 8.8         | 2.7          | 39           | 7.7          | 426          |
| Tre Island      4  | 8.03 | 6.87 | 1.09       | 1.7       | 0           | 1.8          | 33           | 10.1         | 204          |
| Tam Island      4  | 8.12 | 6.85 | 0.87       | 2.7       | 0           | 0            | 34           | 7.1          | 196          |
| Mun Island      8  | 8.10 | 6.75 | 1.03       | 7.4       | 4.3         | 0.6          | 34           | 7.7          | 189          |
| Tacriver mouth  2 | 8.08 | 6.82 | 0.97       | 5.2       | 0           | 0            | 35           | 7.5          | 162          |
| Reference site  2 | 8.03 | 6.88 | 0.99       | 2.5       | 10.8        | 3.1          | 31           | 5.7          | 375          |
| Season mean     22 | 8.04 | 7.6  | 6.26       | 0.81      | 3.3         | 1.1          | 34           | 7.8          | 229          |
| Standard        6.5-8.5* 50* | ≥5 | - | 100*       | 55**       | 60**        | 15**         | -            |              |              |

* Vietnam National Technical Regulation on Coastal Water Quality [3].
** Asean Marine Water Quality Criteria for Aquatic Life Protection [4].
0 values mean under limit of detection.

Table 2  Values of heavy metal and hydrocarbon parameters in dry season in 2014.

| Areas          | n   | Zn (µg/l) | Cu (µg/l) | Pb (µg/l) | Fe (µg/l) | HC (µg/l) |
|----------------|-----|-----------|-----------|-----------|-----------|-----------|
| Cairiver mouth 2 | 6.1  | 3.0       | 2.2       | 53        | 439       |
| Tre Island      4  | 6.3  | 2.6       | 2.1       | 61        | 384       |
| Tam Island      4  | 8.1  | 2.5       | 2.4       | 257       | 468       |
| Mun Island      8  | 7.2  | 2.8       | 2.1       | 280       | 359       |
| Tacriver mouth  2 | 7.9  | 2.4       | 2.1       | 256       | 497       |
| Reference site  2 | 6.8  | 2.4       | 2.1       | 485       | 299       |
| Season mean     22 | 7.1  | 2.6       | 2.1       | 232       | 398       |
| Standard        50* | ≥5   | - | 100*       | 55**       |            |            |

* Vietnam National Technical Regulation on Coastal Water Quality.
** Asean Marine Water Quality Criteria for Aquatic Life Protection.

Table 3  Values of some basic and nutrient parameters in rainy season in 2014.

| Areas          | n   | pH  | TSS (mg/l) | DO (mg/l) | BOD₅ (mg/l) | NH₃-N (µg/l) | NO₂-N (µg/l) | NO₃-N (µg/l) | PO₄-P (µg/l) | SiO₃-Si (µg/l) |
|----------------|-----|-----|------------|-----------|-------------|--------------|--------------|--------------|--------------|----------------|
| Cairiver mouth 2 | 7.61 | 7.16 | 3.90       | 5.2       | 14          | 0            | 41           | 7.5          | 745          |
| Tre Island      4  | 7.74 | 6.56 | 2.09       | 3.9       | 2           | 0            | 38           | 7.6          | 272          |
| Tam Island      4  | 8.06 | 6.87 | 1.97       | 6.6       | 5           | 0            | 35           | 7.5          | 223          |
| Mun Island      8  | 8.09 | 6.75 | 2.30       | 5.1       | 4           | 0            | 34           | 6.7          | 211          |
| Tacriver mouth  2 | 7.48 | 7.31 | 2.55       | 6.6       | 2           | 0            | 42           | 7.8          | 361          |
| Reference site  2 | 7.81 | 6.68 | 1.49       | 4.6       | 0           | 0            | 34           | 7.2          | 335          |
| Season mean     22 | 7.90 | 6.8  | 2.30       | 5.2       | 4.1         | 0            | 36           | 7.2          | 297          |
| Standard        6.5-8.5* 50* | ≥5 | - | 100*       | 55**       | 60**        | 15**         | -            |              |              |

* Vietnam National Technical Regulation on Coastal Water Quality.
** Asean Marine Water Quality Criteria for Aquatic Life Protection.
0 values mean under limit of detection.

3.1.2 Water Quality in Rainy Seasons

In rainy seasons, the effect of river water was more obvious (the raw data showed that it even has effect on the reference station at some moments). There were more partial contaminations of Nitrate and Phosphate parameters. Surprisingly, there was no Ammonia partial contamination like dry seasons. The TSS (total suspended solid) content sometimes exceeded the standard. The heavy metals parameters were in same status as dry seasons (Table 3 and 4).

Generally, although a bit worse than in dry seasons, the water quality in rainy seasons was still in the
controlled level. However, there were some unusual notable things from the data on sea water quality:

Ammonia concentrations in the rainy season 2011 were recorded quite high, while Nitrite levels were very low compared to the same periods of 2007 and 2010;

In 11/2012, Nitrate and Phosphate concentrations were not much different to other years. However, Ammonia and Nitrite concentration were almost fully absent;

3.1.3 Water Quality at Coral Reefs

Besides the data of sea water quality in the entire bay above, there were two surveys taken to assess the water quality at some coral reefs in Nha Trang bay.

There was no deep difference of the values of some parameters such as pH, DO and NO₂-N between the surveys in August 2010 and August 2013. However, the TSS, NH₃,₄, and HC parameters had changed significantly between the surveys, even the NH₃,₄ concentration was almost absent in 8/2013 survey.

Generally, water quality in the reef coral was good for coral reef conservation and aquatic life protection [7].

3.2 The Changes of Water Quality in the Entire Bay

Over the years, the values of DO, BOD₅, SiO₂-Si, NO₂-N, and Fe were higher in the rainy seasons while pH and NH₃,₄-N were lower. The comparisons are showed in Fig. 2. Similar to the environmental status in 2014, the water quality from 2007 had the situation better in rainy seasons, a bit worse in dry seasons, and in the controlled level in both.

There were some changes of the parameters in dry seasons. Some parameters such as BOD₅, Cu and Pb had increasing trends; TSS, NH₃,₄-N and HC had been decreasing; meanwhile the others were in unobvious trends (Fig. 3). However, these changes were not significantly.

Unlike dry seasons, in rainy seasons, the changes of the parameters were in wider range. Most of the parameters changed unobviously. However, it was

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**Table 4 Values of heavy metal and hydrocarbon parameters in rainy season in 2014.**

| Areas            | n | Zn (µg/l) | Cu (µg/l) | Pb (µg/l) | Fe (µg/l) | HC (µg/l) |
|------------------|---|-----------|-----------|-----------|-----------|-----------|
| Cairiver mouth   | 2 | 6.1       | 3.0       | 2.2       | 53        | 439       |
| Tre Island       | 4 | 6.3       | 2.6       | 2.1       | 61        | 384       |
| Tam Island       | 4 | 8.1       | 2.5       | 2.4       | 257       | 468       |
| Mun Island       | 8 | 7.2       | 2.8       | 2.1       | 280       | 359       |
| Tacriver mouth   | 2 | 7.9       | 2.4       | 2.1       | 256       | 497       |
| Reference site   | 2 | 6.8       | 2.4       | 2.1       | 485       | 299       |
| Season mean      | 22| 7.1       | 2.6       | 2.1       | 232       | 398       |
| Standard         |   | 50*       | ≥5        |           | 100*      | 55**      |

*Vietnam National Technical Regulation on Coastal Water Quality.

**Asien Marine Water Quality Criteria for Aquatic Life Protection.

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**Fig. 2 Comparisons of mean values of the parameters in dry and rainy seasons from 2007 to 2014.**
quite clear (the $R^2$ of graphs, 0.77 and higher) to see that five parameters $\text{NO}_2$-$\text{N}$, TSS, Fe and HC had decreasing trends, only Cu changed increasingly (Fig. 4).

According to Le Thi Vinh et al. [10] and together with the data and figures above, it can be seen that
although there were some changes in seasons through the years, the differences were not so much. All the parameters were still in controlled level, and there was not the sign of environmental degradation in the bay till 2014.

3.3 Nutrient Structure in the Entire Bay

According to Dortch and Whitledge [11], the stoichiometric limitations can be assessed by calculating ambient nutrient ratios for each nutrient and applied the following criteria: P limitation if Si:P > 22 and DIN:P > 22; N limitation if DIN:P < 10 and Si:DIN > 1; Si limitation if Si:P < 10 and Si:DIN < 1. Therefore, through the data, most values of DIN:DIP ratios were from 6.76 to 9.97, only the year 2007 and the dry season in 2010 had the values a bit higher than 10, we can see a very slight N limitation.

Pristine rivers generally deliver Si to the coastal ocean in great stoichiometric excess over N and P, relative to the nutrient requirements of diatoms (Si:N:P = 16:16:1) [12], and it could be assumed, through the data from table 5, that the rivers which have effects on Nha Trang bay were still in good condition.

The data also showed that the Si:DIN and Si:DIP ratios were always higher than 3.5 and 30, while the replete nutrient levels for diatom growth are Si:N~1 and Si:P~16. This showed that the productivity of diatoms has approached closely the upper level set by the N and P availability. Thus, it might not cause a shift in dominance from diatoms to non-siliceous forms in this area. There were several researches presented that “during periods of decreasing Si:DIP ratios, significant blooms of non-siliceous algae have increased in frequency. Often, these “novel” phytoplankton blooms included noxious and toxic forms, which replaced diatoms as the dominant biomass group [12, 13].

Table 5 Concentrations and atomic ratios of DIN, DIP and Si in the entire bay.

| Time     | DIN (µM) | DIP (µM) | Si (µM) | DIN:DIP | Si:DIN  | Si:DIP  |
|----------|----------|----------|---------|---------|---------|---------|
|          | 5/2007 (n = 36) | 3.51   | 0.42    | 12.61   | 8.4     | 3.6     | 30.0    |
|          | 11/2007 (n = 36) | 3.57   | 0.36    | 25.14   | 9.9     | 7.0     | 69.8    |
| Avg. 2007 | 3.54   | 0.39    | 18.88   | 9.1     | 5.3     | 48.4    |
| 4/2010 (n = 26) | 2.98   | 0.23    | 15.46   | 13.0    | 5.2     | 67.2    |
| 11/2010 (n = 26) | 3.69   | 0.36    | 32.50   | 10.3    | 8.8     | 90.3    |
| Avg. 2010 | 3.34   | 0.30    | 23.98   | 11.1    | 7.2     | 79.9    |
| 5/2011 (n = 26) | 2.96   | 0.26    | 14.43   | 11.4    | 4.9     | 55.5    |
| 11/2011 (n = 26) | 2.57   | 0.38    | 19.29   | 6.8     | 7.5     | 50.8    |
| Avg. 2011 | 2.77   | 0.32    | 16.86   | 8.7     | 6.1     | 52.7    |
| 6/2012 (n = 22) | 2.92   | 0.36    | 12.68   | 8.1     | 4.3     | 35.2    |
| 11/2012 (n = 22) | 2.51   | 0.31    | 17.46   | 8.1     | 7.0     | 56.3    |
| Avg. 2012 | 2.71   | 0.34    | 15.07   | 8.0     | 5.6     | 44.3    |
| 6/2013 (n = 22) | 2.55   | 0.27    | 9.71    | 9.4     | 3.8     | 36.0    |
| 11/2013 (n = 22) | 2.68   | 0.25    | 21.18   | 10.7    | 7.9     | 84.7    |
| Avg. 2013 | 2.61   | 0.26    | 15.45   | 10.0    | 5.9     | 59.4    |
| 6/2014 (n = 22) | 2.74   | 0.25    | 8.18    | 11.0    | 3.0     | 32.7    |
| 11/2014 (n = 22) | 2.86   | 0.23    | 10.61   | 12.4    | 3.7     | 46.1    |
| Avg. 2014 | 2.80   | 0.24    | 9.39    | 11.7    | 3.4     | 39.1    |

P limitation: > 22
N limitation: < 10
Si limitation: < 1
4. Conclusions

Because seawater quality in entire Nha Trang Bay was strongly affected by freshwater from the rivers, although there were evidences showing that freshwater still in good condition, the riverine water quality should be also monitored thoroughly.

The water quality in rainy seasons were a bit worse than in dry seasons, but still in controlled level; although there were some partial contamination of some parameters at few moments, the seawater quality of Nha Trang Bay was still quite good in both dry and rainy seasons (according to Vietnam and Asian standard for coastal seawater quality).

There were some changes between seasons and over years, decreasing, increasing, or unobvious trends. However, these differences were not so much; there was not the sign of environmental degradation in the bay from 2007 to 2014.

It seems to support the hypothesis that Si can play an important role in coastal eutrophication [14]. Since Si ratios here were always higher compare to N and P, there was not increased potential for non-diatom algal blooms. Together with the recorded nutrients concentration data, it can be said that there was no evidence of eutrophication in Nha Trang bay.

Besides, in my opinion, there are some values in the standard such as Iron, Hydrocarbon... parameters should be reconsidered, sometimes, they are quite unrealistic when we apply to assess the environment of the coastal seawater in Vietnam.

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