Risk zonation and assessment of environmental pollution in coastal area of Quang Tri province

LÊ VĂN PHƯỚC[1]
NGÔ XUÂN HUY[2], NGUYỄN PHÚ BẢO[3]
[1] Southern Center for Planning and Invertigation of Marine resources - Environment
[2]Industrial University of Ho Chi Minh
[3]Vietnam Institute for Tropical Technology and Environmental Protection

Abstract

The coastal area of Quang Tri province is less affected by socio-economic development but it was affected by oil spill environmental incidents and the Formosa in the period 2015 - 2019. For risk zonation and environmental risk assessment on coastal area of Quang Tri province, quantitative research method and approaches of Circular 26/2016/TT-BTNMT have been applied. Within the coastal area of Quang Tri province, 1,631 cell of near the shore and 83 cell of coastal areas have been identified, classified and zoned risk and assessed environmental risk. The results show that the environmental risk in the coastal area of Quang Tri province is medium – small level, 84% for near the shore and 99% for coastal areas. Besides, the number of locations with small levels of pollution or low environmental risk is significantly high compared to locations with high environmental risk.

Keywords: *Environmental risk zonation, environmental risk assessment, Quang Tri province.*
JEL Classifications: *Q51, Q56, P48.*
Received: *1st July 2024;* ***Revised:*** *10th August 2024;* ***Accepted:*** *23rd August 2024.*

1. INTRODUCTION

Quang Tri is a coastal province in the North Central region, with a coastline of about 75 km and zone of over 8,400 km^2. According to the synthesis of research results (Phuoc 2023) on marine biodiversity in coral reef ecosystems and the coastal area of Con Co island is very diverse and rich. 954 species of marine life were recorded, including: 133 species of phytoplankton; 97 species of plankton; 137 species of corals (144 species of hard corals, 23 species of soft corals); 182 species of reef fish; 302 species of benthic animals (186 species of mollusks, 49 species of echinoderms, 48 species of arthropods, 19 species of arthropods); 96 species of seaweed; 1 species of seagrass and 6 species of mangrove plants. Of which, 12 precious species were identified and endangered species that need to be prioritized for protection, restoration and development.

In the coastal waters of Quang Tri province, there are three main types of environmental pollution in coastal and estuarine areas (Anderson 2013): (i) Nitrogen-phosphorus pollution from agriculture, wastewater, urban wastewater and industrial wastewater and with average of about 20% of nitrogen fertilizers lost from agricultural production and up to 60% can evaporate into the atmosphere, some of which will fall into the ocean; (ii) Chemical pollution. This type of pollution is mainly from oil spills and statistics show that the volume still accounts for more than 10% of the oil entering the ocean (Anderson 2013); (iii) Plastic waste pollution. Therefore assessment and zoning of coastal environmental pollution risks in Quang Tri province with the guidance on coastal environmental risk zoning (Monre 2016), assessment and communication of environmental risks in coastal (GESAMP 2008) is important and necessary. In this study, the quantitative research methodology (Rana, Gutierrez and Oldroyd 2021) was used. The values of the risk quotient (RQ) are calculated and shown on the risk zoning map. The results of this study are a practical basis to help local management agencies implement measures to control, mitigate and coastal environmental risks in water of coastal of Quang Tri province.

2. MATERIALS AND METHODS

2.1. Study area

For risk zonation and assessment of environmental pollution in coastal of Quang Tri province, the study area is the coastal which include coastal and near the shore waters shown in *Figure 1.* The coastal area is 1,337.91 km^2 and the outer limit of coastal is 6 nautical milesaway (Decision N0.853/QĐ-BTNMT). The coastal include 11 commune belongs to 4 districts and Con Co island, natural area is about 142.94 km^2.

2.2. Methodology

2.2.1. Methods of computational grid for risk zonation of environmental pollution

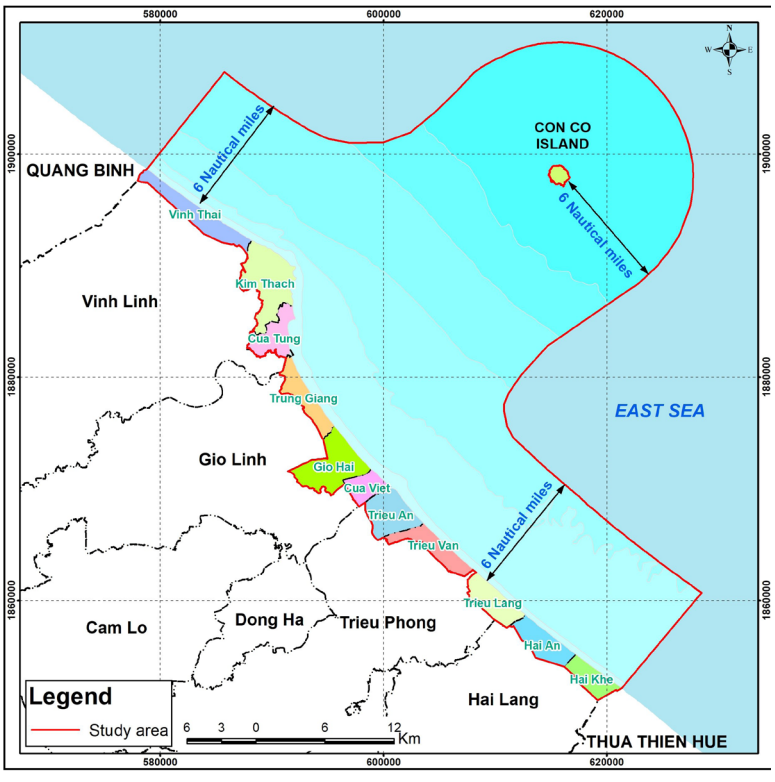
Arcgis softwave were used for computational grid of near the shore and coastal areas. The grids have dimensions of 40 x 60 and are consistent with the characteristics of the research area and regulations (Monre 2016).

Computational grid of near the shore area: Implemented with the following criteria: (i) The distance between the high tide and low tide lines is ranging from 70 to 120 m, especially in areas near the estuary such as in Cua Tung and Cua Viet, this distance is from 150 to 200 m; (ii) Combining cells with a very small area (less than 0.001 km^2).

The total number of coastal cells in Quang Tri province was calculated 1,631 cells, including 2 cells with area of ≤ 0.001 km^2, 11 cells with area between 0.001 - 0.0014 km^2, 342 cells with area of 0.0014 - 0.0024 km^2, 966 cells with area of 0.0024 - 0.0036 km^2 and 310 cells with area between 0.0036 - 0.0048 km^2.

Computational grid of coastal area: Implemented with the following criteria: (i) The size of coastal cells of 4 x 5 km and the total area of 1,338 km^2; (ii) The inner boundary of the coastal cell area with a small area of 1 - 14 km^2 which is maintained. These coastal cells was changed due to fluctuations in the range of the multi-year average high tide line to the 6 nautical mile line.

The total number of coastal cells in Quang Tri province are calculated as 83 coastal cells. In which, the number of coastal cells has area of about 20 km^2 accounting for the highest number of 66 cells, the number of cells with area of 19 km^2 is 7 cells and the number of coastal cells with area is in the range of 7 - 18 km, there are 8 cells and the number of coastal cells with area of 15 km^2 is 2 cells.



▲ *Figure 1. Study area*

2.2.2. Methodology of calculation of risk quotient and coastal environmental pollution risk assessment

Calculation of Risk Quotient (RQ): The risk quotients and total risk quotients are shown in formula 1 (Z. Vryzas, et al. 2011) and in formula 2 (Monre 2016), respectively.

$$RQ = \frac{PEC}{PNEC} \quad (1) \qquad RQ = \frac{\sum_{j=1}^{n} W_j \left(\frac{PEC}{PNEC}\right)}{\sum_{j=1}^{n} W_j} \quad (2)$$

Notes:

RQ: Risk Quotient for parameter j.

PEC: Concentration of pollutant jin coastal water of Quang Tri province.

PNEC: Maximum allowable value concentration of pollutant j according to QCVN 10-MT:2015/BTNMT.

m: Total number of parameters for zoning and risk assessment (12 parameters).

W_j: The weight for pollutants j as prescribed in Article 11, Circular 26/2016/TT-BTNMT (Monre 2016) such as BOD, COD, DO are 1.5; pH, ammonia (N-NH_4^+), phosphate (PO_4^{3-}) are 1.7; arsenic (As), iron (Fe), manganese (Mn) are 2.0; fluoride (F^-) is 1.0 and coliforms is 1.3.

Environmental pollution risk assessment of coastal area: The criteria for risk rating were used in this study (Hernando, et al. 2006): RQ < 0.01, no risk; 0.01 ≤ RQ < 0.1, low risk; 0.1 ≤ RQ <1, medium risk; and RQ ≥ 1, high risk or as directed (Monre 2016): RQtb > 1.5 very high risk; 1.25 < RQ_{tb} ≤ 1.5 high risk; 1 <RQ_{tb} ≤ 1.25 medium risk and RQ_{tb} ≤ 1 low risk.

2.2.3. Model method to measure predict pollutant concentrations in the coastal water

In this study, the MIKE21/3 Coupled FM model set with HD and SW modules (using a flexible and suitable unstructured mesh).

2.2.4. Model calibration and validation

Model calibration is carried out by comparing the actual measured data and the data calculated by the model at hydrological stations. Nash-Sutcliffe coefficient is used to validate the accuracy of model.

Nash-Sutcliffe coefficient was calculated according to formula (3):

$$NSE = 1 - \frac{\sum_{t=1}^{T}(H_0^t - H_m^t)^2}{\sum_{t=1}^{T}(H_0^t - \overline{H_0})^2}$$

where:

- H_{0t}: Measured data.
- H_{mt}: Simulation data.
- NSE: Error between measured data and simulation data according to Nash-Sutcliffe.

Table 1. Sensitivity level classification of simulation model according to Nash-Sutcliffe

Sensitivity level	Nash-Sutcliffe (NSE)
Very High	0.75 ÷ 1.0
High	0.65 ÷ 0.75
Medium	0.50 ÷ 0.65
Small	≤ 0.50

In this study, the calibration and validation of the simulation model was quite good accuracy, the Nash balance coefficient was quite high and met the regulations for determining the concentration of pollutants at each near the shore and coastal by simulation model.

Calibration and validation for water concentration: The parameters of TSS, NH_4^+, Florua, PO_4, Fe, As, Mn is used for calibration and validation of the pollutants propagation model and were samled at 11 locations in the estuary and coastal areas of Quang Tri province in the period of May 2018, June 2020 and November 2020 (Donre 2020). Sampling sites coastal of Quang Tri province for model calibration of are shown in Figure 2. The results of calibration and validation of the mass propagation model showed a negligible difference between the measurement and the simulation. Thereby, the simulation results ensure reliability and the set of parameters of the model can be used to calculate the pollutants propagation.

Table 2. Results of calibration and validation for depth

Hydrogies station and measurement duration	Nash-Sutcliffe coefficient		R2
	NSE	Notes	
Cua Viet: since May 2018	0.675	High	0.827
Cua Viet: since June 2020	0.683	High	0.831
Con Co: since May 2018	0.601	Medium	0.776
Con Co: since June 2020	0.591	Medium	0.876

Table 3. Results of calibration and validation for flow velocity simulation

Hydrogies station	Nash-Sutcliffe coefficient		R2
	NSE	Notes	
S1 Station: since June 2023	0.543	Medium	0.675
S2 Station: since June 2023	0.557	Medium	0.712
S3 Station: since May 2018	0.638	Medium	0.745
S3 Station: since June 2020	0.686	High	0.826
S3 Station: since November 2020	0.606	Medium	0.740

Table 4. Results of calibration and validation for waves

Name of Station	Nash-Sutcliffe coefficient		R2
	NSE	Notes	
S1 Station: since June 2023	0.678	High	0.778
S2 Station: since June 2023	0.629	Medium	0.748
S3 Station: since June 2020	0.516	Medium	0.672

2.2.5. Method of simulation model

East-sea model: The main boundaries of the aimulation model was used be the Taiwan Strait, Luzon, Mindoro, Babalac, and Malacca. With the HD hydrodynamic module, these boundaries are water level boundaries and tidal water level data calculated from conditioning constants. With the SW spectrum module, these boundaries are assumed to be "lateral boundaries". The coastal area from Quang Binh to Da Nang is updated with a fine coastal net.

Detailed model: The grid resolution is set to be very detailed with a grid pitch of about 1m to 5m. The simulation range is also set to be large enough to minimize the effects of boundaries on the study area. (Figure 3).

▲ *Figure 2. Sampling sites for model calibration*

▲ *Figure 3. Computational grid and calculation scope of detailed model*

3. RESULTS AND DISCUSSIONS

3.1. Simulation of pollutants concentration in coastal water

The parameters used for study of environmental pollution zoning and assessment in coastal of Quang Tri province include: Dissolved oxygen (DO), biochemical oxygen demand $(BOD)_5$), chemical oxygen demand (COD), pH, ammonium ($N\text{-}NH_4^+$), phosphate (PO_4^{3-}), suspended solids (TSS), Fluoride (F), coliform, arsenic (As), dissolved iron (Fe), manganese (Mn)... The summary results of the concentration of pollutants are shown in Table 5.

The simulative results of pollution concentrations in near the shore waters of Quang Tri provinve showed:

The concentration of dissolved oxygen (DO) is high and relatively stable, with a monthly average of approximately 5.1 - 8.0 mg/l and average of the typical climatic year per of 7.14 mg/L. Concentrations of DO is no significant difference between the rainy season and dry season, the trend of the Northeast monsoon period is more scattered. In the compared to the DO concentration in coastal waters of Quang Tri province in recent years, 5.6 - 6.2 mg/L (Donre Quang Tri 2023), the dissolved oxygen concentration is forecasted to be significantly higher.

Concentration BOD_5 in water of coastal of Quang Tri provine is unstable over time and spatially (standard deviation > mean), concentration of BOD_5 has a large variation, about 0.5 - 13.8 m/L (the average is low, 1.5 mg/L). The reason is due to effect of the Northeast monsoon and the Southwest monsoon. Concentration of BOD_5 was the

Table 5. Summary of calculation results of predicted concentration of pollutants in the coastal of Quang Tri province

Parameters	Descriptive Statistics						
	Mean	Standard Error	Median	Standard Deviation	Min	Max	Confidence Level (95.0%)
DO (mg/L)	7.14	0.01	7.12	0.54	5.12	8.02	0.03
BOD_5 (mg/L)	1.48	0.05	1.08	2.00	0.50	13.76	0.10
COD (mg/L)	5.18	0.06	4.51	2.49	2.88	14.88	0.12
pH	7.95	0.00	7.98	0.09	7.41	8.00	0.00
NH_4^+ (mg/L)	0.24	0.00	0.20	0.17	0.05	0.89	0.01
PO_4^{3-} (mg/L)	0.09	0.00	0.08	0.06	0.02	0.31	0.00
TSS (mg/L)	6.48	0.07	5.88	3.00	5.00	24.92	0.15
Floridemg/L)	1.09	0.00	1.06	0.10	1.00	1.50	0.00
Coliform (MPN100mL)	159	10	30	397	0	2.716	19
As (mg/L)	0.02	0.00	0.02	0.01	0.01	0.05	0.00
Fe (mg/L)	0.68	0.01	0.63	0.20	0.50	1.50	0.01
Mn (mg/L)	0.17	0.00	0.15	0.08	0.10	0.50	0.00

largest value in December and the lowest in January. Concentration of BOD_5 at locations from Cua Tung to Cua Viet are higher than the average and the point locations along the coast of Quang Tri province.

Concentration of COD in coastal water tends to change according to the monsoon mode, with a small fluctuation amplitude and only approximately 2.5 - 4.0 mg/L. During the Northeast monsoon, concentration of COD is highest value of the year (ranging from 2.9 - 14.9 mg/L) at all locations and concentration of COD is the lowest of the year (ranging from 2.0 - 3.0 mg/L) during the Southwest monsoon period.

The pH value in the waters of Quang Tri province is relatively stable, in the range of 7.4 - 8.0 and has seasonal fluctuations but not significantly. These results are lower than the pH coastal water quality monitoring results of Quang Tri province (Donre Quang Tri 2023), the pH value ranges from 7.6 - 8.3 (at the foot of the tide) and 7.7 - 8.1 (at the peak of the tide).

Concentration of ammonium (NH_4^+) in water of coastal is about 0.24 mg/L and little change in the whole region. These values are significantly different when compared to the results of coastal water quality monitoring of Quang Tri province, ranging from undetected to 0.15 mg/L (tidal peak) and ranging from undetected to 0.19 mg/L (tidal peak) (Donre Quang Tri 2023).

Concentration of phosphate (PO_4^{3-}) in water of coastal tends to vary markedly seasonally and is relatively stable and concentrations of phosphate approximately 0.04 - 0.09 mg/L.

Average concentration of total suspended solids in the study area ranged from 5.0 to 24.9 mg/L, with an average of about 6.5 mg/L and little major variation between regions and seasons under typical 1-year climatic conditions. At the estuary locations (Cua Tung, Cua Viet), total suspended solids tends to disperse stronger, the largest concentration can range from 20 to 30 mg/L or greater. Concentration of TSS is forecasted to be significantly smaller when compared to the monitoring results of coastal water quality in Quang Tri province, the average TSS concentration is about 5.2 - 47.9 mg/L (at the foot of the tide) and 4.4 - 46.0 mg/L (at the peak of the tide) (Donre Quang Tri 2023). This contributes to reducing the coastal environmental risk vulnerability index.

Concentration of fluoride in water of coastal is relatively stable, varies from 1.0 mg/L (minimum) to 1.5 mg/L (maximum), with an average of about 1.1 mg/L.

Concentrations of Coliform in water of coastal are quite stable and the only change is the difference in the near the shore and the river area. The forecast concentration of coliform in water of coastal area of Quang Tri province is in the range of 0 - 2,700 MPN/100mL, the average is about 160 MPN/100mL and this value is very low compared to QCVN 10-MT:2015/BTNMT.

The concentration of As in water of coastal tends to vary seasonally and spatially. The highest value appears in the flood season months (November and December), approximately 0.02 mg/L in the coastal area from Cua Tung to Cua Viet and varies from 0.015 - 0.050 mg/L in other areas. The concentration of As is relatively stable, about 0.01 - 0.015 mg/L and the lowest in the dry months (June, July) with a concentration of less than 0.012 mg/L.

Concentrations of Fe in water of coastal tend to vary seasonally and spatially. The highest concentration of Fe appears in the flood season months (November and December), approximately about 0.80 mg/L in the coastal area from Cua Tung to Cua Viet and varies from 0.60 to 0.75 mg/L in other areas, the average is 0.68 mg/L.

Concentration of Mn in water of coatal is low and insignificantly chanes in seasonally and spatially. The highest value appears in the flood season months (November and December) with a concentration of approximately 0.17 mg/L in the coastal area from Cua Tung to Cua Viet and the concentration of Mn fluctuates between 0.1 - 0.50 mg/L in other areas. Most of the concentrations of metals (As, Fe, Mn) with is lower than the limit value of QCVN 10-MT:2015/BTNMT.

In general, the concentration of pollutants in coastal of Quang Tri province is quite stable except for the BOD5, COD due to the influence of changes in wind direction in the area. Overall, concentration of pollutants in water of near the shore is small and the dispersion of pollutants concentration is small and relative standard deviation (RSD) in near the shore cells (n = 1631) < 20%, which is acceptable in environmental analysis.

3.2. Risk zonation and environmental risk assessment in coastal area of Quang Tri province

3.2.1. Calculation results of risk quotient $I_ô$ for cells of near the shore

In this study, Environmental risks zonation of coastal area was only considered in the Northeast monsoon scenario and shown in Figure 4. Environmental risk zonation results are classified and risk assessed according to 3 levels: medium, high and very high risk.

Area of very high environmental risk ($I_ô \geq 3.5$) accounting for 78/1,631 cells (corresponding to 5%) of the number of cells of near the shore, these cells of very high environmental risk were main distributed in area of Trung Giang commune, Cua Viet commune (Gio Linh district), Trieu An commune (Trieu Phong district). Because of very high environmental risk in these areas and therefore, it is necessary to have appropriate risk mitigation solutions for these areas. The reason is due to the impact of high density living activities and socio-economic development in the areas. For example, in 02

communes Gio Hai and Trung Giang, the population rate accounts for 61.59%, the aquaculture area (32.7 hectares) accounts for 93.69% and the number of boats accounts for 63.5% of the Gio Linh district (Phuoc 2023).

Area of high environmental risk (2.5 ≤ $I_ô$ < 3.5) accounting for 190/1,631 cells (corresponding to 12%) of the number of cells of near the shore and concentrated mainly in Gio Hai commune and a part of Trung Giang commune, a part of Trung Giang commune and Cua Viet commune (Gio Linh), a part of Trieu An (Trieu Lang district).

Area of medium environmental risk (1.5 ≤ $I_ô$ < 2.5), accounting for 1,363/1,631 cells (corresponding to 84%) of the number of cells of near the shore.

3.2.2. Calculation results of risk quotient $I_ô$ for cells of coastal

The results of environmental risk zonation show that environmental risk level in the coastal area of Quang Tri province is medium - low, as follows:

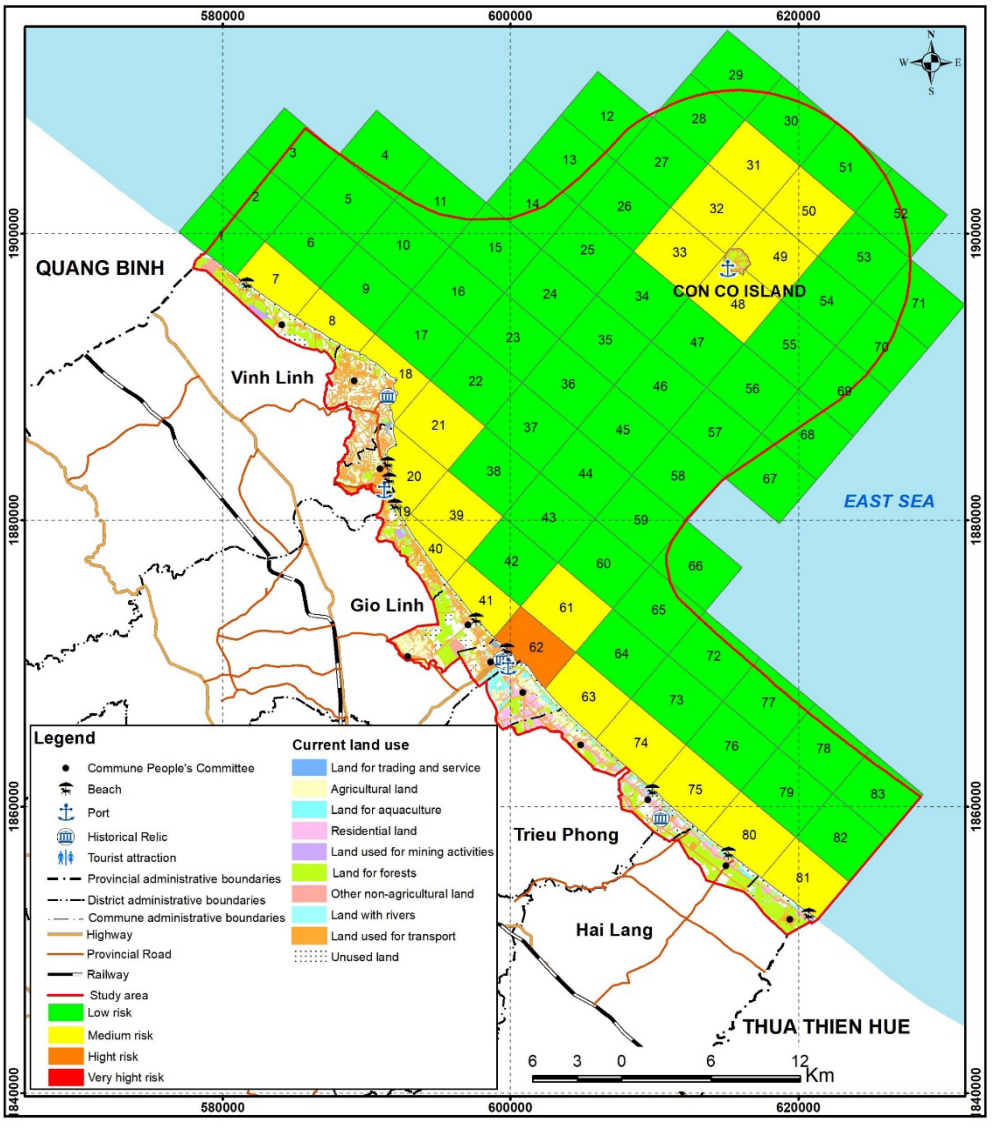
Area of high environmental risk (2.5 ≤ $I_ô$ < 3.5) is only concentrated in 62 cell (Cua Viet port), accounts for 1% of the number of coastal cells. The cause of high environmental risk in this area is due to the activities of Cua Viet port such as ships gathering, activition of fishing boats and importing seafood, provision of seafood logistics... A lot of waste was generated from these activities but have not been treated and managed strictly.

Area of medium environmental risk (1.5 ≤ $I_ô$ < 2.5) is concentrated in the area adjacent to the near the shore and and in the area around Con Co island where there is a marine conservation area that needs to be strictly protected, accounts for 25% of the number of coastal cells.

The cells of coastal have low environmental risk ($I_ô$ ≤ 1.5), accounts for about 74%.

General, environmental risk in coastal area of Quang Tri province was medium – low ($I_ô$ ≤ 1.5) of about 84% for near the shore and 99% coastal. This shows that natural factors, human activities, and socio -economic development activities have negligible impacts on the coastal waters of Quang Tri province.

The summary results of the calculation of risk quotients for coastal waters areas of Quang Tri province are shown in Table 6. For the coastal area, because the area of the cells is quite large (7 - 20 km2/cell), so the cells are divided into 4,281 points for 83 coastal cells. For near the shore cells, because the area of the cells is small, the risk quotient of each cell only calculates of 1 location, so RQj = RQtb.



▲ *Figure 4. The risk zonation map of environmental pollution in coastal of Quang Tri province*

Table 6. Summary of calculation results of risk quotient (RQ) in the coastal of Quang Tri province

Descriptive Statistics	Risk Quotient of near the shore area (n = 1631 cell)	Risk Quotient of coastal area (n = 4281 point/83 cell)	
	$RQ_j = RQ_{tb}$	RQ_j	RQ_{tb}
Mean	0.867	0.585	0.590
Standard Error	0.009	0.002	0.010
Median	0.776	0.549	0.549
Standard Deviation	0.350	0.108	0.090
Minimum	0.541	0.543	0.546
Maximum	2.291	2.489	1.012
Confidence Level (95.0%)	0.017	0.003	0.020

It can be seen that the level of pollution and environmental risk in the near the shore area is greater than that in the coastal area when both the average risk quotient of each cell or the whole the near the shore area is higher than that of the coastal area. The reason can be easily seen is the activities of people's livelihood, production and aquaculture in the near the shore area of Quang Tri province.

The statistics (Table 6) also show that the number of locations with low environmental pollution risk levels is higher because the median value is smaller than the average value. Comparing with the current state of the coastal waters environment quality in recent years in the Central region (MONRE 2021), it shows that the level of coastal waters environmental risks in Quang Tri province is significantly higher, 6-8 times higher than in Dong Hoi, Quang Binh waters (RQ = 0.10 in the 2018 rainy season) and Thuan An, Hue waters (RQ = 0.12 in the 2018 rainy season) and only equivalent to the waters of Sam Son, Thanh Hoa province (RQ = 0.43) and lower than that of Phan Thiet waters (RQ = 2.66).

For minimization of the hight risk of environmental pollution areas in coastal waters of Quang Tri province, some solutions for integrated management of coastal are proposed:

i) Building a management tools for sustainable development in coastal of Quang Tri province, including regulations of technical, environmental, economic and social…

ii) There is a need for an economic tool, in which the costs/benefits and minimum costs are analyzed and calculated in detail for management of high environmental pollution risks.

iii) Community consultation should be implemented to manage effectively coastal pollution and ensure the common interests of management and community.

iv) The main cause of the environmental pollution risk were high and very high level in coastal areas of Quang Tri province, that conflicts of interest between stakeholders have not been resolved. Therefore, it is necessary to solve or have appropriate technical solutions to solve these causes.

4. CONCLUSION

The results of risk regional zonation and assessment of coastal environmental pollution in Quang Tri province have been carried out according to the guidance of Circular No. 26/2016/TT-BTNMT and are referenced in studies of environmental risk assessment. The results of the study have shown, coastal environmental risks in Quang Tri province is medium and low with theRQ_{tb}rate <1.25 accounted for coastal areas 84% and coastal areas 99%; The level of environmental risk in the coastal waters of Quang Tri province has the tendency of leaning towards a medium and low level and was significantly higher than in the waters of the Central region.

In this study, the risk of environmental pollution assessment coastal water of in Quang Tri province are have only been based on the limited concentration of some physicochemical parameters in coastal water according to QCVN 10-MT:2015/BTNMT and the corresponding weights proposed in Article 11 in Circular No. 26/2016/TT-BTNMT. Therefore, there is a need for further research on the effect limit concentrations and risk weights for sensitive ecological objects because each coastal area has different sensitivities. In addition, coastal environmental pollution risk assessment for persistent organic pollutants (POPs), microplastics and sediments is needed ▪

REFERENCES

1. Anderson, Tracy L. 2013. "One World, One Ocean, One Mission." Earth Common Journal 3 (1): 1-2.

2. Donre Quang Tri. 2023. Report on Results monitoring of Resources and Evironment in Quang Tri province 2019 - 2023. Dong Ha: Department of Natural Resources and Environment of Quang Tri province.

3. Donre. 2020. Report on Environmental Current of Quang Tri province, 2016-2020. Dong Ha: Department of Natural Resources and Environment of Quang Tri province.

4. GESAMP. 2008. Assessment and communication of environmental risks in coastal aquaculture. Rome: UN, UNEP, FAO, UNESCO-IOC, WMO, UNIDO, IMO, IAEA.

5. Hernando, M D, M Mezcua, A R Fernandez-Albá, and B Barcelo'. 2006. "Environmental risk assessment of pharmaceutical residues in wastewater effluents, surface waters and sediments." Talanta 69: 334-342.

6. Monre. 2016. Circulars 26/2016/ TT-BNTMT Regulation on Criteria of Risk Classification and Zoning. Ha Noi: Ministry of Natural Resources and Environment.

7. MONRE. 2021. Report on the National Sea and Island Environment in the 2016-2020 period. Ha Noi: Ministry of Natural Resources and Environment.

8. Phuoc, Le Van. 2023. Risk regional zonation of environmetal pollution on the sea and islands of Quang Tri. Dong Ha: The Department of Natural Resources and Environment of Quang Tri province.

9. Rana, Juwel, Patricia Luna Gutierrez, and John C Oldroyd. 2021. "Quantitative Methods." Global Encyclopedia of Public Administration, Public Policy, and Governance 1-6.

10. Z. Vryzas, C. Alexoudis, G. Vassiliou, K. Galanis, and E. Papadopoulou-Mourkidou. 2011. "Determination and aquatic risk assessment of pesticide residues in riparian drainage canals in northeastern Greece." Ecotoxicology and Environmental Safety 74: 174–181.

1. INTRODUCTION

Open burning of rice straw in the fields is a method of cleaning the fields after harvest, preparing for the next crop in Vietnam. Emissions from the burning of rice straw contribute greatly to air pollution in Vietnam, negatively affecting human health, contributing to increasing the greenhouse effect and acid rain. The results of calculating the air pollution load [01] due to open burning show that in 2020, open burning of rice straw in Vietnam emitted 905,544.6 tons of $PM_{2.5}$, 1,017,802.2 tons of PM_{10}, 104,773.8 tons of SO_2, 97,289.9 tons of NO_2, 170,631.6 tons of NO_x, 2,596,892.0 tons of CO. By 2030, open burning of rice straw in Vietnam will emit 258,062.1 tons of $PM_{2.5}$, 290,053.3 tons of PM_{10}, 29,858.4 tons of SO_2, 27,725.7 tons of NO_2, 48,626.6 tons of NO_x, and 740,062.4 tons of CO.

During the period 2022-2025, the Vietnam Association for Conservation of Nature and Environment (VACNE) has coordinated with the Global Alliance for Pollution and Health (GAHP) to implement the project "Reducion of risks of open burning practices and unsafe use of pesticides to the environment and human health in Vietnam" funded by the UK Department of Environment, Food and Rural Affaire (DEFRA).

Within the framework of this project, some demonstration models on straw open burning alternatives were implemented, including rice-straw composting, rice-straw fermented for cattle feed, and straw mushroom production in Chau Thanh district, An Giang province [02],[03], models of in-field microbiological decomposing straw in Khanh Thanh commune, Yen Khanh district, Ninh Binh province [04] and in Song Ray commune, Cam My district, Dong Nai province [05].

The implementation of the above mentioned open burning alternative models brings many economic benefits (i.e. enhancing the value chain of the rice production sector), social benefits (i.e. creating new jobs, improving farmers' lives) and environmental benefits (i.e. reducing environmental pollution, reducing greenhouse gas (GHG) emissions).

The purpose of this study is to assess the potentials of GHG emission reduction due to open burning alternatives. The applied methods are rapid assessment based on investigation, survey, data collection and application of GHG emission factors [06].

2. METHODOLOGY

2.1. Study Subjects

This study focused on some straw open burning alternative models, including:

- Three technical models utilizing rice straw in some selected communes of Chau Thanh district, An Giang province such as rice straw mushroom production, rice straw composting and rice straw fermented for cattle feed.
- One model of in-field decomposing straw in Khanh Thanh commune, Yen Khanh district, Ninh Binh province.
- One model of in-field decomposing straw in Song Ray commune, Cam My district, Dong Nai province.

2.2. Study methods

2.2.1. Data collection

Data were collected in the selected communes, Chau Thanh district, An Giang province including area of rice cultivation, mass of rice straw generated, mass of straw transported and used for the open burning alternative models.