Nucl. Sci. and Tech., Vol.8, No. 3 (2018), pp. 20-28

Nuclear Science and Technology

Journal homepage: https://jnst.vn/index.php/nst

Estimation of radiological parameters associated with mining and processing of coastal sand in Binh Dinh province, Vietnam

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Abstract: In Vietnam mining industry is significantly contributing to the socio-economic development. For the industrialization, many kinds of minerals are being exploited and processed that caused the Earth surface to be disconcerted leading to the increase of erosion of soil that possibly carries radioactive nuclides of the natural radioactive chains. Mining could cause increasing radioactive background to the miners as well as to the public members around the mines. This paper presents radiological parameters associated with mining and processing ilmenite minerals in coastal sand for titanium for export in Binh Dinh province, Central Part of Vietnam.

Keywords: *Radiological parameters, ilmenite mineral, titanium, Binh Dinh, Vietnam.*

I. INTRODUCTION

Mining and processing of minerals are necessary for the development of national economy. However, mining and minerals processing are environmentally unfriendly industries. Mining can affect all the environmental compartments: land, air, water and biosphere, and the impact of mining on the environment is manifold and complex.

The first impact of mining on the environment can be named as the occupation of the land, sometimes with a large area to open the mine and then the release of tail rock that causes the change of the landscape. The second negative impact of mining is the increase of soil erosion during the mineral extraction leading to the high sedimentation rate in surrounding water bodies. Minerals exploitation affects the water environment, e.g. it changes the hydrological regime, hydrogeology, etc. During the minerals exploitation heavy metals as well as radioactive substances could be released into the aquatic environment and ultimately affected the human health. However, the specific impacts caused by minerals exploitation and processing to the environment depend on the type of minerals, mainly ores and waste rock, and on the exploitation size, method of processing, and the management approach for that activities.

In the Central Part of Vietnam several minerals resources such as coastal ilmenite minerals containing titanium; sand; coal and uranium etc. are being exploited and processed. These mining and processing activities in the area are reportedly to cause negative impacts on the environment over the last years.

In this paper, results of a radioactive environment survey in an area of coastal ilmenite (titanium-iron oxide) minerals mining and processing in Binh Dinh province were presented. Based on the survey results, radiological parameters such as outdoor absorbed dose rate (OADR), outdoor annual effective dose (OAED), radium equivalent activity (Ra_{eq}) and external hazard index (H_{ex})

https://doi.org/10.53747/jnst.v8i3.70
Received 03 October 2018, accepted 23 December 2018

were estimated in order to elucidate whether the environment in that area be safe for miners and the public living around the mine. The study area was My An - My Thanh, Phu My district of Binh Dinh province as shown in Fig. 1.

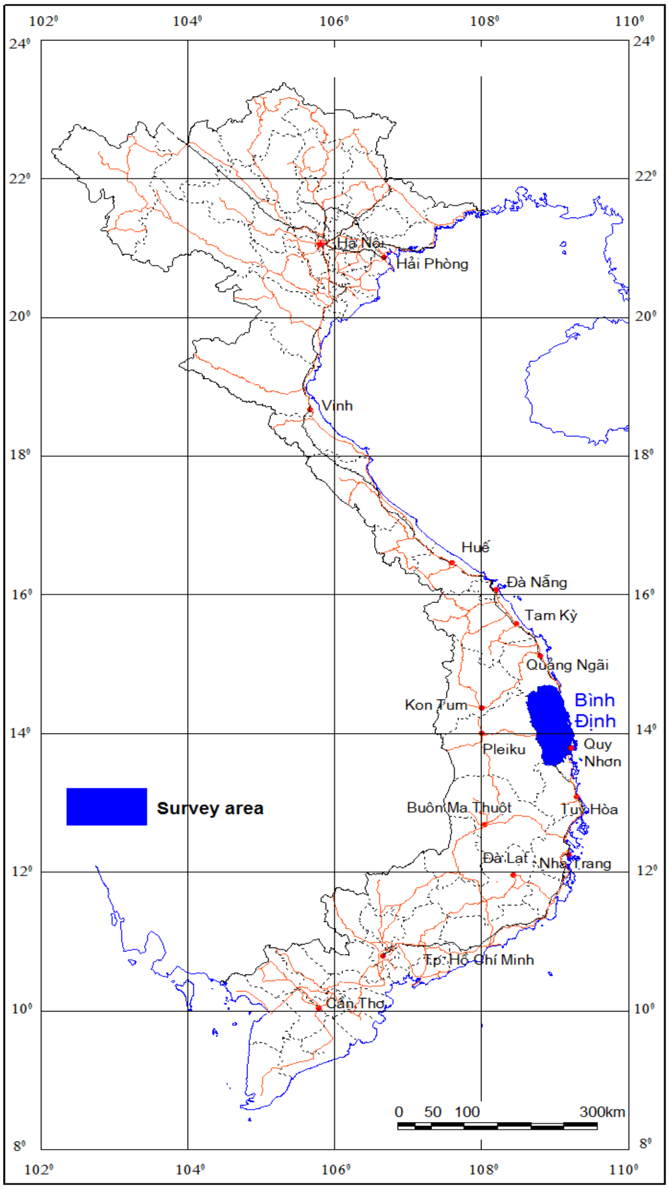

Fig. 1. Location of the survey

II. OVERVIEW OF COASTAL SAND MINING IN BINH DINH PROVINCE

Binh Dinh is a coastal province in the South-Central Part of Vietnam. The administrative center of the province is Quy Nhon city. The province is bordering with Quang Ngai province in the North, with Phu Yen province in the South, with Gia Lai province in the West. The sea coast line in the East is 134 km long [1, 2].

According to the results of a geological and minerals investigation, the coastal sand in Binh Dinh province was found in Hoai Nhon, Phu My, Phu Cat, Quy

Nhon districts but it mainly concentrated in Phu My and Phu Cat [1]. The minerals found there were ilmenite, monazite, zircon, rutile, anatase, leucoxene, manhetite, limonite. The content of titanium-iron oxide ($FeTiO_3$) in the ilmenite varies from 0.301% to 11.86%. Rutil has a TiO_2 content, ranging from 0.0017% to 0.145% [1]. It was also found that the contents of radioactive substances like thorium (ThO_2) and uranium (U_3O_8) were, respectively, up to 0.13% and 0.005% which producing a dose as high as from 0.34 to 10.53 μSv/h [2].

Results of geological exploration surveys proved that the reserve of the coastal sand containing titanium in Binh Dinh province has potential value for industrial exploitation [3]. Currently, the mines of the sand in Binh Dinh province are De Gi, My Thanh, My An. These mines have been approved by the Government for exploration, exploitation, processing and utilization of the titanium minerals in the period 2002-2015, with an orientation to 2025[4].

From the 2003 up to now, the Binh Dinh Minerals Joint Stock Company and Sai Gon - Quy Nhon Joint Stock Company were investing in wire transfer, reclaiming and processing titanium minerals products. The tide mines in the De Gi, My An, My Thanh etc. are being intensively exploited as shown in Fig. 2 [3].

Fig. 2. The ilmenite minerals exploitation in My An-My Thanh, Phu My district, Binh Dinh province

Coastal sand mining activities but mainly for titanium minerals in the region actualy could cause negative impact to the environment. The main methods of sand mining currently applied in the region are primitive digging, excavation and enriching the minerals by gravitational followed electro-magnetic method. The primitive technology of mining and processing the coastal sand would make the soil, water, and air around the mines to be polluted with heavy metals as well as radioactive substances. Therefore, assessment of the impact of radioactive substances resulted from the mining and processing the coastal sand for titanium minerals to the environment is necessary in term of the development of solutions for prevention, mitigation and control the harmful effect of ionization radiation to the miners as well as to the public living around the mines.

III. RESEARCH METHODOLOGY

Sampling procedure

Sand samples were taken from surface layers of 20 cm depth within the ilmenite mining areas according to the guideline [5].
Fig. 3 depicted the sampling locations.

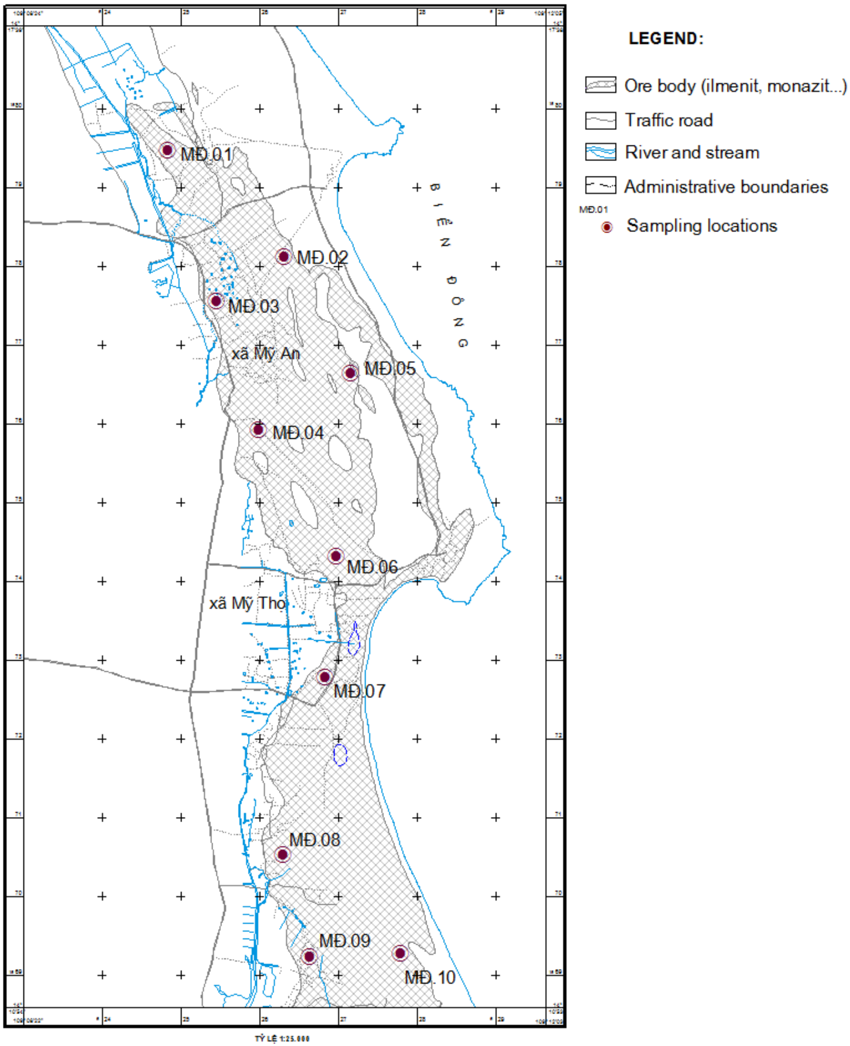

Fig. 3. Sampling locations of coastal sand for radioactivity analysis

Totally 10 coastal sand samples were collected.

Samples preparation and radioactivity determination

In this study the radioactivity concentration of the following radionuclides ^{40}K, ^{226}Ra and ^{232}Th were identified and quantified. For this, upon arrival the laboratory the samples were tightly sealed off in 3 pi-Marinelli boxes for at least 3 weeks to attain radiochemical equilibrium that allowed to derive the activity concentration of ^{232}Th in the samples from the mean activity concentrations of ^{228}Ac and ^{208}Tl; the activity of ^{226}Ra was derived from the mean activities of ^{214}Bi and ^{214}Pb [6]. To identify the radionulides in samples, a gamma-spectrometer equipped with HPGe detector of wide energy range, from 40 keV to 3.0 MeV (Canberra, US), was used. The energy resolution of the detector was around 1.8- 2.0 keV at 1.33 MeV peak. As the radioactivity in the samples was expected to be low, the counting time for each sample was set at least for 24 hours to achieve a counting uncertainty of less than ±30%. The ^{40}K, ^{228}Ac, ^{208}Tl, ^{214}Bi, and ^{214}Pb nuclides were identified and quantified by the peaks of 1.46 MeV, 911 keV, 583 keV, 609 keV, and 352 keV, respectively [6]. The analyses were conducted at the Radio-chemical Analytical Laboratory of the Geological Division of Radioactive and Rare Elements, Department of Geology and Minerals (Vietnam).

A quality control program was applied to ensure the accuracy of the measurement by the analysis of an IAEA standard sample SOIL-6, and the deviation between measured and certified values for the radionuclides was less than 10%.

Estimation of radiological parameters at the ilmenite minerals mine

The outdoor absorbed dose rate (OADR, nGy h^{-1}) of the external exposure was estimated by applying the formula [7]:

$$OADR(nGy\ h^{-1}) = 0{,}4368*SR_{Ra} + 0{,}5993*A_{Th} + 0{,}0417*SA_{K} \quad (1)$$

Where 0.4368, 0.5993 and 0.0417 are conversion fators to convert from activity unit (Bq kg^{-1}) into dose unit ($nGy.h^{-1}/Bq.kg^{-1}$) of ^{226}Ra, ^{232}Th, and ^{40}K, respectively; SR_{Ra}, SA_{Th}, and SA_K are the activity concentrations of radionuclides ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}), repsectively.

The outdoor annual effective dose (OAED) *to the miners* was estimated by a formula:

$$OAED_m\ (mSv\ y^{-1}) = OADR\ (nGy\ h^{-1})\times 2000(h\ y^{-1})\times 0.7\ (Sv\ Gy^{-1}) \quad (2)$$

The working time of miners was estimated based on the regulation that in a year there is 50 working weeks, and each week has 5 working days and each day workers should be available at their workplaces for 8 hours, so that totally there are 2000 working hours in a year. The conversion factor of Gy to Sv was accepted to be 0.7 [7].

The outdoor annual effective dose (OAED) *to the public* members surrounding the mine was estimated by using a formula [7]:

$$OAED_p\ (mSv\ y^{-1}) = OADR(nGy\ h^{-1})x8760\ (h\ y^{-1})x0.7\ (Sv\ Gy^{-1})x0.2 \quad (3)$$

where 0.2 is the outdoor occupancy of the public[7].

The radium equivalent activity (Ra_{eq}) was estimated following OECD guideline[8, 9] as:

$$Ra_{eq} = SA_{Ra} + 1.43*SA_{Th} + 0.077*SA_{K} \quad (4)$$

The meaning of the R_{aeq} is that if the Ra_{eq} = 370 (Bq/kg) then the external exposure dose be equal to 1.5 mGy y^{-1}[10, 11].

A modified quantity of radium equivalent activity is external hazard index H_{ex}, which is denied as [8]:

$$H_{ex} = \frac{SA_{Ra}}{370} + \frac{SA_{Th}}{259} + \frac{SA_{K}}{4810} \quad (5)$$

The value of H_{ex} must be lower than unity in order to keep the radiation hazard insignificant. The maximum value of unit for H_{ex} correspond to the limit of 370 Bq kg^{-1} for Ra_{eq}.

IV. RESULTS AND DISCUSSION

Table I presents radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K in 10 coastal sand samples taken from the ilmenite minerals processing location in My An - My Thanh, Phu My district, Binh Dinh province.

Table I. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40} K in coastal sand samples taken from My An - My Thanh, Phu My district, Binh Dinh province

Sample ID	Activity concentration (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
MĐ - 01	75.56±8.69	82.11±9.10	70.89±8.42
MĐ - 02	57.18±7.56	72.90±8.54	48.94±7.00

Sample ID	Activity concentration (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
MĐ - 03	67.84±8.24	60.50±7.78	68.26±8.26
MĐ - 04	44.35±6.66	22.06±4.70	120.27±11.00
MĐ - 05	47.57±6.90	41.32±6.43	73.49±8.57
MĐ - 06	52.06±7.22	42.99±6.56	101.42±10.10
MĐ - 07	38.30±6.19	38.25±6.18	91.26±9.55
MĐ - 08	42.45±6.52	48.54±6.97	92.21±9.60
MĐ - 09	34.54±5.88	34.89±5.91	45.78±6.77
MĐ - 10	43.56±6.60	37.65±6.14	67.43±8.21
Mean	50.34	48.12	78.23
Standard deviation	10.07	18.43	23.27

Applying formula (1) and (2) one can estimate the OADR within the mine as high as (54.08±16.41) nGy h^{-1}, and OAED to the miners and public would be as high as (0.076±0.023) mSv y^{-1} and (0.066±0.020) mSv y^{-1}, respectively. This means that the OAED for miners was about 15% higher than that to the public members surrounding the mine as the miners are directly contacting the minerals in the mine. The value of the OADR estimated based on the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in sand samples (Eq.1) was in good agreement with those measured directly in the field using an Inspector survey-meter that displayed a range of 20 to 550 nGy h^{-1}.

A comprehensive survey for external radiation exposure from soil in Binh Dinh province[12] had been revealed that the OADR in that province was 110.87 nGy h^{-1} that would produce an OAED to the public in average of 0.14 mSv y^{-1}. The higher OAED to the public in the whole Binh Dinh province compared to the OAED to the public surrounding the ilmenite minerals processing location could be explained by a fact that in many places of Binh Dinh province there are granite stones mines containing high content of urranium and thorium. The granite stones are currently being mined for the construction purposes, therefore from this activity it could release more radioactive substances into the environment and caused higher OAED in the province. For the population in whole 63 provinces and cities in Vietnam territory the OAED was found to be 0.082 mSv y^{-1} [12] that was comparable to the OAED to the miners and public in the coatsal sand mining and processing in My An-My Thanh, Phu My (Binh Dinh province).

A comparison of the OAED to the public in the coastal sand mining and processing in Binh Dinh with those in other location woldwide is presented in Table II.

Table II. A comparison of OAED values to the public living around locations of coastal sands mining and processing worldwide

Location	Mining activity	OAED, mSv y^{-1}	Ref
Karela, India	Monazite mining	4	[13]
Guarapari, Brazil	Monazite	5.5	[14]
Yangjiang, China	Monazite mining	3.5	[15]
Bình Dinh, Vietnam	Ilmenite mining	To public: 0.066 To miners: 0.076	This work

As seen from Table II the OAED to miners and public surrounding the ilmenite minerals mining and processing site in Binh Dinh province is in 46 to 72 times lower than that values to the public around monazite minerals minings.

The radium equivalent activity (Ra_{eq}) and external hazard index (H_{ex}) in the ilmenite mining location in Phu My, Binh Dinh province were estimated (Eqs 4 and 5) to be as high as (125.16±38.22) Bq kg^{-1} and (0.34±0.10), respectively. The Ra_{eq} and H_{ex} in this case were far from the limit of 370 Bq kg^{-1} and 1, respectively, implying that the radiation to both miners and public in that area was insignificant. For Vietnamese people in the whole country the H_{ex} caused by radiocative substances from soils was found to be of (0.43±0.15) [12].

The distribution of gamma radiation dose rate within the ilmenite mining area was simulated based on results of a field survey using an Inspector surveymeter (GM detector) and it is depicted in Fig. 3.

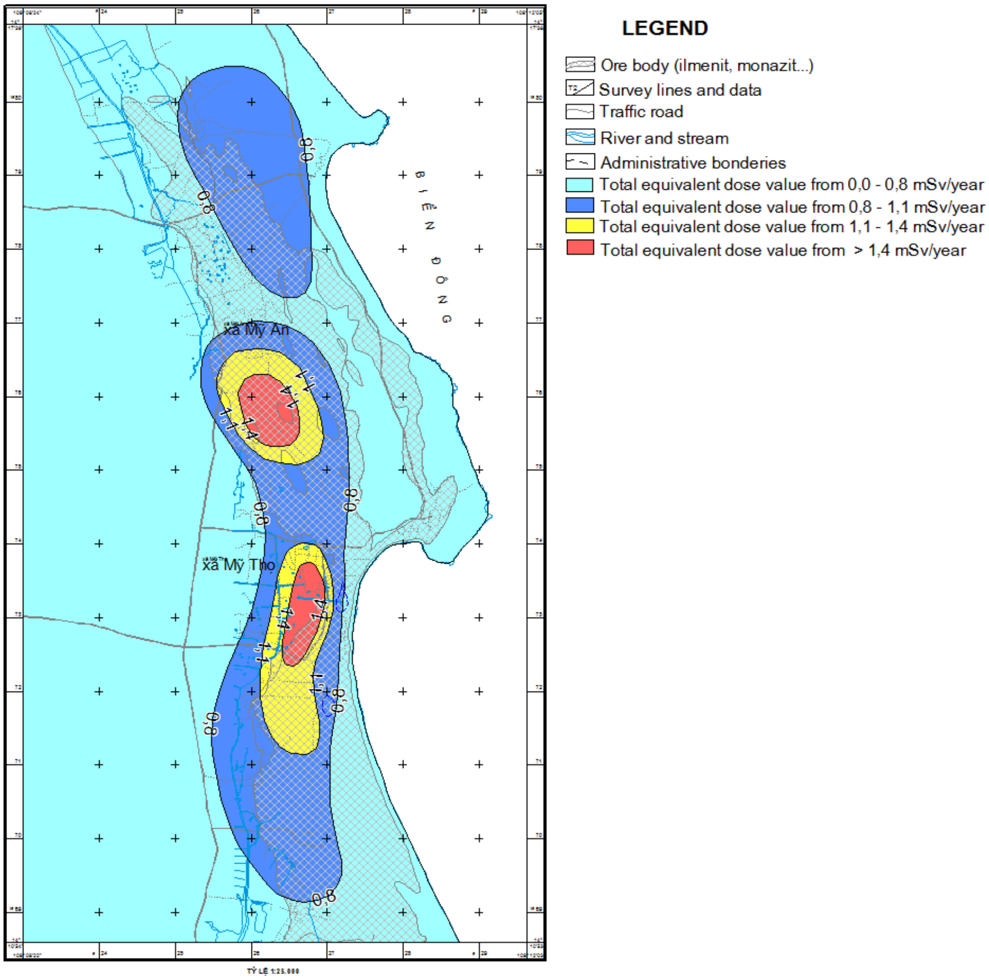

Fig. 3. Distribution of gamma radiation dose rate within the ilmenite mining and processing in My An-My Thanh, Phu My district, Binh Dinh province

As seen from Fig. 3, the highest gamma dose rate was prevailed in locations where the tails from the enrichment of the minerals were stored. The dose rate there was found at a value of up to 150 nSv h^{-1}(red colour areas in Fig.3). In the yellow coulor area where the coastal sands were processed the dose rate is from 100 to 150 nSv/h, whereas in the green colour area where the sands were gathered for processing the dose rate is less than 100 nSv/h.

V. CONCLUSIONS

From the results of the study following conclusions could be drawn:

1. The outdoor annual effective dose (OAED) caused by mining and processing ilmenite minerals to the miners as well as the public around the mines in My An-My Thanh, Phy My district, Binh Dinh province was lower than the OAED caused by the radioactive substances in soils in the province being of 0.14 mSv a year as well as that to public in the whole Vietnam territory being 0.082 mSv a year.

2. The OAED caused by radioactive substances in ilmenite minerals was in 46 to 72 times lower compared to that in monazite minerals.

3. The radium equivalent activity (Ra_{eq}) and external hazard index (H_{ex}) in the sand mining and pocessing in Binh Dinh province were lower than the limit for radiological safe conditions for the miners as well as for the public surrounding the mining area. This implies that at present the mining and processing ilmenite minerals in My An-My Thanh, Phu My district (Binh Dinh province) are safe for the population in respect of ionization radiation.

4. Though the radiological condition is safe by now, however the composition of the coastal sand could change by the depth, so that the OAED could be changed time by time. Therefore it is recommended that the radioactive environment in the mine should be continuously monitored in order to have immediate measures to protect the miners and public from the increase of radiation dose if it occurs.

ACKNOWLEDGMENT

The author would like to thank the leaders of the Geological Division for the Central Part (Vietnam), the Saigon – Quy Nhon Minerals Joint Stock Company for providing related to the study documents and creating conditions for conducting the survey of radioactive environment in the area.

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