A Survey of Natural Occurring Radionuclides and Particle Concentrations from Erupting Mount Bromo in East Java, Indonesia

Johan A.E. Noor and Eko Pujadi

***Abstract*— Mount Bromo in East Java, Indonesia is erupting from 23 November 2010 and ejects ash with a maximum height of 1,500 meter and throws lava as high as 50-300 meters from the crater. In any eruptions the presence of natural radioelements is evident with high concern to affect the human health living near the volcano. This survey was aimed to determine the levels of radiation from the volcanic ash. We measured radiation dose rate, soil gamma-ray concentration, soil heavy metals contents and dust/ash concentration at four spots along the volcano's caldera located at the village of Cemorolawang, District of Probolinggo just 2 km east of the crater. It was revealed that the radiation exposure rate was 14-16 μR/hr and the concentrations of K-40, Ra-226 and Th-232 were 760.8±84.6 Bq/kg, 31.9±4.2 Bq/kg and 57.0±6.8 Bq/kg, respectively. We also found that the concentration of the particulate (PM10) was 52.9±5.1 μg/m^3.**

***Index Terms*— Mount Bromo, natural occurring radioactive materials, volcanic eruption, human health.**

I. Introduction

NATURALLY occurring radioactive materials (NORMs) have gained a great interest among scientists. Many applications could be performed ranging from geological exploration to environmental radiation monitoring and health physics problems, most of them involving the determination of the U, Th, K and other alkali metals' (e.g. Li, Na, K, Rb, and Cs) concentrations in air, soils and water [1, 2]. For instance, being one of the so-called large ion lithophile (LIL) elements, potassium remains on or close to the surface in the form of oxides [3]. Potassium has 25 known isotopes from ^{32}K to ^{56}K. There are three isotopes of potassium available naturally (^{39}K, ^{40}K, and ^{41}K) and only ^{40}K is radioactive. Potassium in general is a primary constituent of several common rock-forming minerals.

Volcanic events always certainly involve eruptions of smoke and magmatic materials. During eruptions, volcanic ashes are deposited almost instantly in a geological sense [4]. In such way NORMs are introduced to the area. Many researchers [5-8] have shown that volcanic debris contains natural radioactive elements. The presence of low γ-ray activity produced by natural radioactive isotopes is of growing interest in human health. The interest is provoked by the long term effect of such isotopes to humans (e.g. stochastic effects of radiation), which is mainly controlled by their amount in the ecosystem, their average life, and chemical-physical properties.

From the interactions between volcanic ash and human, the danger from volcanic ash containing radioactive nuclides can be categorized into two: breathing and environmental risks. Breathing volcanic ash may lead to the risk of cancer due to radioelement deposit in the respiratory system. Radionuclides in the environment will expose to the humans in the vicinity.

Mount Bromo is a quieter volcano compared to its neighboring sister Mount Semeru. While Mount Semeru shows daily activities of smoke puffing and small tremors and volcanic shocks, Mount Bromo shows long quiescence behavior. This makes Mount Bromo attracted less interest for scientific study. Only few studies have been conducted using Mount Bromo as the object of interest [9-12]. Studies were directed more to Mount Semeru [13-19].

Mount Bromo has erupted many times. There are more than 50 eruptions recorded since 1804 [10] with the last was in 2010. The latest eruption started on Tuesday, 23 November 2010, 15.30 WIB (Western Indonesian Time) when the highest alert-notification system was raised from 'watch' to 'warning' [20] and lasted for more than one year. The status of 'normal' (level 1) was resumed by the authority on 30 March 2012 [21]. The typical eruption of Mount Bromo is vulcanian-strombolian eruption. During eruptions the volcanic ash plume could reach as high as 1,500 meters above the crater and fall in a radius of 6-10 km. However, the frequency and severity of the eruptions have reduced from 20 times/day to 3 times/day. In normal condition, Mount Bromo puffed up volcanic smoke (white sulphuric fumarol) 60-80 m high.

This paper presents the results of the radiologic survey carried out in a village close to Mount Bromo crater during the recent eruption. We focus on the abundance of the natural elements K, Ra and Th. Evaluation and interpretation of the distribution of these radionuclides were searched and compared with other studies. Geochemical and radiometric determinations performed in the laboratory are also reported.

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II. Study Area and Methods

A. Study Area

The study area is located at the vicinity of Mount Bromo (in Indonesian: Gunung Bromo) in the Tengger-Kendeng mountain zone in East Java Province.

Mount Bromo is a small pyroclastic cone active volcano and a member of the chain of active volcanoes of Java Island in Indonesia. The volcano itself is part of the Tengger massif with a 600 × 800-m^2 crater sitting in Tengger caldera (9×10 km^2) within the Bromo Tengger Semeru National Park in East Java, Indonesia (coordinates 7° 55′ 30″ S; 112° 37′ 00″ E), that also includes Mount Semeru, the highest mountain of the island, some 20 km southward. Mount Bromo crater is situated inside the Tengger Caldera with summit at 2,329 meters above sea level. The caldera base is covered by sand deposited from primary processes. The caldera wall stands 50 – 500 m high. There are four other less active volcanoes in the Tengger caldera: Mount Widodaren, Mount Kursi, Mount Giri and Mount Batok [9].

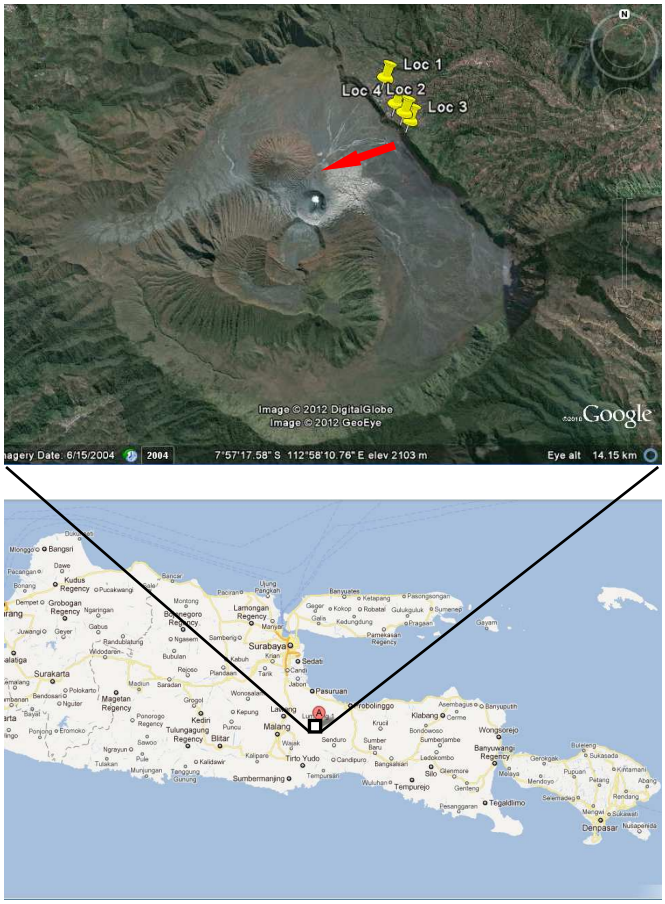


Fig. 1 Map showing the location of Mount Bromo in East Java Province of Indonesia with red arrow pointing to the Mt. Bromo crater and the yellow pins indicating the sampling sites (not to scale). The picture shows the island of Bali in the eastern side. The lower image was generated from Google maps and the upper image from Google Earth.

Geologically, Mount Bromo belongs to Quarter time volcanic zone which arises from subduction of Eurasia and India-Australia plates. The subduction zone is located in the south of Java Island heading east-west [9].

The environmental measurements were conducted *in situ* at four locations along the mouth of the Mt. Bromo caldera in the village of Cemorolawang, District of Probolinggo, East Java Province. They are situated about 2 km north-eastern of the volcano's crater (the yellow nails on Fig. 1). The exact geographical position of the sampling locations is given in Table I. The measurements were carried out on 22-23 April 2011. At the time of data acquisition the status of the erupting volcano was level 3 'watch' (e.g. the highest status for disaster mitigation is level 4 'warning').

TABLE I
Geographical Position of the Sampling Locations

Location Code	GPS Coordinates	
	S	E
1	7.92188	112.96560
2	7.92831	112.96908
3	7.92966	112.97011
4	7.92665	112.96756

B. Measurement Technique

The data collected were radiation dose rate, soil gamma-ray concentration from K-40, Ra-226, and Th-232, soil heavy metal contents and particulate matters ≤10 μm (PM_{10}) concentration from the air at the sampling spots, all with five repeats. The radiation exposure rates were measured using Ludlum-19 survey-meter (Ludlum Measurements Inc., USA). The ATOMTEX AT6101D (ATOMTEX, Belarus) gamma spectrometer was used to measure the soil gamma-ray concentration. The soil heavy metal contents were scanned by using a portable X-ray Fluorescence XMET-5100 (Oxford Instruments Llc., UK). We used Lighthouse Particle Counter REMOTE 5102V (Lighthouse Worldwide Solutions, USA) to measure the PM_{10} concentrations.

III. Results and Discussion

Sampling and measurements were carried out at the locations listed in Table I. We found a stable reading of the exposure rates of 14-16 μR/hr at all sampling locations. The concentrations of K-40, Ra-226 and Th-232 were 761 ± 85 Bq/kg, 32 ± 4 Bq/kg and 57 ± 7 Bq/kg, respectively. Ra-226 showed a rather consistent reading (see Table II).

Measurement of the particulate matters with diameter ≤10 μm (PM_{10}) indicates consistency at locations 2, 3, and 4 (55.3±1.5 μg/m^3), while location 1 shows lower reading (Table III).

TABLE II
MEASUREMENT RESULTS FOR RADIATION DOSE RATE AND GAMMA–RAY CONCENTRATION OF K-40, RA-226, AND TH-232 FROM SOILS AT OUR FOUR SAMPLING LOCATIONS

Location Code	Exposure rate (μR/hr)	Concentration (Bq/kg)		
		K-40	Ra-226	Th-232
1	14 – 16	840.5	36.4	62.7
2	14 – 16	672.0	29.3	51.0
3	14 – 16	705.3	27.5	51.2
4	14 – 16	826.3	34.3	63.1
Average	15 ± 1	761 ± 85	32 ± 4	57 ± 7

TABLE III
PM_{10} CONCENTRATION FROM THE AIR AT THE SAMPLING LOCATIONS

Location Code	PM_{10} Concentration ($\mu g/m^3$)
1	45.5
2	54.0
3	57.0
4	55.5
Average	53 ± 5

TABLE IV
HEAVY METAL CONCENTRATION OF THE SOIL AT THE SAMPLING SPOTS. WE MEASURED 12 ELEMENTS OF INTEREST

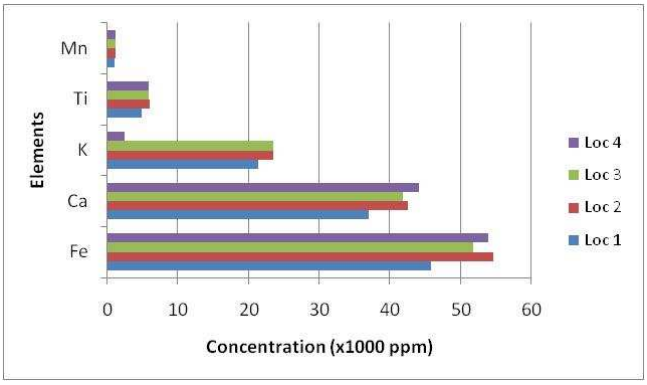
Element	Concentration (ppm)			
	Loc 1	Loc 2	Loc 3	Loc 4
Fe	45,835	54,631	51,709	53,842
Ca	36,903	42,562	41,759	44,074
K	21,374	23,413	23,514	2,480
Ti	4,880	6,031	5,789	5,850
Mn	1,028	1,106	1,118	1,116
Ba	389	459	547	565
Sr	286	354	346	358
Zr	171	219	202	215
Sn	84	121	110	126
Rb	81	108	97	104
Cu	78	104	96	105
Zn	49	63	55	65

We detected 12 elements from the heavy metal measurements (Table IV). Iron was the most abundant elements in the region, followed by calcium and potassium. Titanium and manganese were available in a moderate concentration. Whereas, Ba, Sr, Zr, Sn, Rb, Cu, and Zn were found as traces with concentrations below 400 ppm.

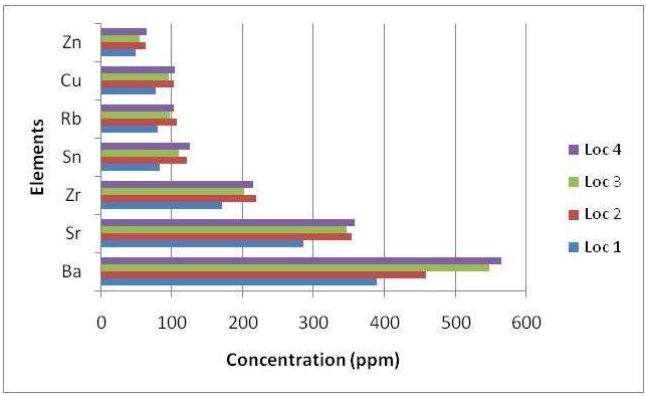
IV. CONCLUSION

A survey on radioelements and heavy metal elements has been conducted in a region along the caldera of an erupting Mount Bromo. The measurements took place when the volcano was in the 'standby' status. Eruption occurrence was almost every hour.

We found that the concentration of the radioelements, K-40, Ra-226 and Th-232, from all sampling locations were 761 ± 85 Bq/kg, 32 ± 4 Bq/kg and 57 ± 7 Bq/kg, respectively; and the exposure rates were the same at 15 ± 1 μR/hr. The particulate matters PM_{10} concentration from the airborne was tagged at 53 ±5 $\mu g/m^3$. For the metal we detected some 12 elements (Fe, Ca, K, Ti, Mn, Ba, Sr, Zr, Sn, Rb, Cu, and Zn) with concentrations ranging from 49 ppm (Zn at location 1) up to 54,631 ppm (Fe at location 2).



(a)



(b)

Fig. 2 Bar charts representation of Table IV, (a) elements with concentrations >1000 ppm and (b) for elements with concentrations <1000 ppm.

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REFERENCES

[1] P. Chiozzi, P. De Felice, A. Fazio, V. Pasquale, and M. Verdoya, "Laboratory application of NaI(Tl) γ-ray spectrometry to studies of natural radioactivity in geophysics," *Appl. Radiat. Isot.*, vol. 53, p. 127, 2000.

[2] P. Chiozzi, V. Pasquale, and M. Verdoya, "Ground radiometric survey of U, Th and K on the Lipari Island, Italy," *J. Appl. Geophys.*, vol. 38, p. 209, 1998.

[3] S. M. McLennan, "Large-ion lithophile element fractionation during the early differentiation of Mars and the composition of the martian primitive mantle," *Meteorit. Planet. Sci.*, vol. 38, pp. 895-904, 2003.

[4] T. Kiipli, K. Orlova, E. Kiipli, and T. Kallaste, "Use of immobile trace elements for the correlation of Telychian bentonites on Saaremaa Island, Estonia, and mapping of volcanic ash clouds," *Est. J. Earth Sci.*, vol. 57, pp. 39-52, 2008.

[5] S. Bellia, M. Brai, S. Hauser, P. Puccio, and S. Rizzo, "Natural radioactivity in a volcanic island: Ustica, Southern Italy," *Applied Radiation and Isotopes*, vol. 48, pp. 287-293, 1997.

[6] M. Brai, S. Hauser, S. Bellia, P. Puccio, and S. Rizzo, "Natural γ radiation of rocks and soils from Vulcano (Aeolian Islands, Mediterranean Sea)," *Nuclear Geophysics*, vol. 9, pp. 121-127, 1995.

[7] P. Chiozzi, P. De Felice, V. Pasquale, D. Russo, and M. Verdoya, "Field γ-ray spectrometry on the Vulcano island (Aeolian Arc, Italy)," *Appl. Radiat. Isot.*, vol. 51, p. 247, 1999.

[8] P. Chiozzi, V. Pasquale, and M. Verdoya, "Naturally occurring radioactivity at the Alps Apennines transition," *Radiat. Meas.*, vol. 35, p. 147, 2002.

[9] A. Susilo, A. Wijayakusuma, and S. Maryanto, "3D Polarization Analyses of Tremors and Vulcanic Shocks of Mount Bromo to Understand the Source Mechanism," *Natural* vol. 11, pp. 44-54, 2007 (in Indonesian).

[10] E. Gottschämmer and I. Surono, "Locating tremor and shock sources recorded at Bromo Volcano," *J. Volcanol. Geotherm. Res.*, vol. 101, pp. 199-209, 2000.

[11] E. Gottschämmer, "Volcanic tremor associated with eruptive activity at Bromo volcano," *Ann. Geophys.*, vol. 42, pp. 465-481, 1999

[12] H. Triastuty, *Physical analysis on the volcanic activity stages of Mt. Bromo based on tremor spectral analysis and hypocenters of volcanic earthquakes*. S1 thesis Thesis. Dept. of Geophysics and Meteorology, ITB Bandung. 1997 (in Indonesian).

[13] S. Maryanto, D. R. Santosa, I. Mulyana, and M. Hendrasto, "Fractal and Chaos Properties of Explosion Earthquakes Followed by Harmonic Tremor at Semeru Volcano, East Java, Indonesia," *Int. J. Sci. Eng. Res.*, vol. 2, pp. 1-7, 2011.

[14] S. Siswowidjoyo, U. Sudarsono, and A. D. Wirakusumah, "The threat of hazards in the Semeru volcano region in East Java, Indonesia," *J. Asian Earth Sci.*, vol. 15, pp. 185-194, 1997.

[15] I. Mulyana, "Characteristics of harmonic tremor at Semeru volcano, East Java, Indonesia," JICA, Final Report of Volcanology and Comprehensive Sediment-related Disaster Prevention Measures. J05-00876, Sept. 2006.

[16] S. Maryanto and I. Mulyana, "Temporal Change of Fractal Dimension of Explosion Earthquakes and Harmonic Tremors at Semeru volcano, East Java, Indonesia, using Critical Exponent Method," *Int. J. Eng. Appl. Sci.*, vol. 5, pp. 394-398, 2009.

[17] S. Maryanto, D. R. Santosa, I. Mulyana, and M. Hendrasto, "Preliminary Chaos Analyses of Explosion Earthquakes Followed by Harmonic Tremors at Semeru volcano, East Java, Indonesia " *Int. J. Environ. Earth Sci.*, vol. 1, pp. 103-108, 2010.

[18] F. Lavigne and H. Suwa, "Contrasts between debris flows, hyperconcentrated flows and stream flows at a channel of Mount Semeru, East Java, Indonesia," *Geomorphol.*, vol. 61, pp. 41-58, 2004.

[19] J.-C. Thouret, F. Lavigne, H. Suwa, B. Sukatja, and Surono, "Volcanic hazards at Mount Semeru, East Java (Indonesia), with emphasis on lahars," *Bull. Volcanol.*, vol. 70, pp. 221-244, 2007.

[20] CVGDM, "Decrease Status Mt. Bromo from Standby to Alert ". vol. 2011: Center for Vulcanology and Geological Disaster Mitigation, 2011.

[21] CVGDM, "Decrease Status Mt. Bromo from Alert to Normal, 30 March 2012." vol. 2012: Center for Vulcanology and Geological Disaster Mitigation, 2012.