19. DuBois, M., Gilles, K., Hamilton, J. K., Rebers, P. A. and Smith, F., A colorimetric method for the determination of sugars. *Nature*, 1951, **168**(4265), 167–16.
20. Piper, C. S., *Soil and Plant Analysis*, Hans Publishers, Bombay, 1950.
21. AOAC, *Official Method of Analysis*, Association of Official Agricultural Chemists. Washington DC, USA, 1984, 14th edn.
22. Chaube, H. S. and Pundhir, V. S., *Crop Diseases and their Management*, PHI Learning Pvt Ltd, New Delhi, 2005.
23. SPSS for Windows, Version 16.0, SPSS Inc., Chicago, USA, 2007.
24. Perrier, X. and Jacquemoud-Collet, J. P., DARwin Software, 2006; http://darwin.cirad.fr/darwin
25. Naskar, S. K. and Sreekumar, J., Evaluation of taro (*Colocasia esculenta* (L.) Schott.) germplasm using multivariate analysis. *J. Root Crops*, 2011, **37**(2), 150–154.
26. Tewodros, M. B., Morpho-agronomical characterization of taro (*Colocasia esculenta*) accessions in Ethiopia. *Plant*, 2013, **1**(1), 1–9.
27. Boampong, R., Aboagye, L. M., Nyadanu, D. and Esilfie, M., Agromorphological characterization of some taro (*Colocasia esculenta* (L.) Schott.) germplasms in Ghana. *J. Plant Breed. Crop Sci.*, 2018, **10**(8), 191–202.
28. Kathayat, K., Kushwaha, M. L. and Rawat, M., Genetic diversity among taro (*Colocasia esculenta* (L.) Schott var. antiquorum) germplasm – a review. *Agric. Rev.*, 2018, **39**, 255–258.
29. Xia, H. O. N. G., Yongbin, Z. H. A. O., Weidong, Q. U., Yinlong, C. H. E. N., Liping, Q. I. U. and Jiaoyang, W. A. N. G., Comparative analysis on genetic diversity of *Colocasia esculenta* germplasm in Zhejiang Province based on phenotype and simple sequence repeats markers. *Acta Agric. Zhejiangensis*, 2020, **32**(9), 1544.
30. Guei, R. G., Sanni, K. A. and Fawole, A. F. J., Genetic diversity of rice (*O. sativa* L.). *Agron. Afr.*, 2005, **5**, 17–28.
31. Singh, D. *et al.*, Assessment and rationalization of genetic diversity of Papua New Guinea taro (*Colocasia esculenta*) using SSR DNA fingerprinting. *Genet. Resour. Crop Evol.*, 2008, **55**, 811–822.

ACKNOWLEDGEMENTS. We thank the Protection of Plant Varieties and Farmers' Right Authority, New Delhi for financial assistance. We also thank the Director, ICAR Research Complex for NEH Region, Umiam for providing the necessary facilities to conduct this study.

Received 2 September 2022; accepted 11 December 2022

doi: 10.18520/cs/v124/i6/748-753

REE-mineral phases in Indian red mud from the east coast bauxite deposit

Sasmita Prusty*

CSIR-Institute of Minerals and Materials Technology, Bhubaneswar 751 013, India

Red mud is often considered a prospective secondary resource of rare earth elements (REE). The Indian red mud samples were characterized using XRD, WD-XRF, ICP-OES and SEM-EDS to study their REE mineralogy and REE content. A major fraction (77%) of the sample was below 45 μm, with total REE content of 433 ppm. There was an enrichment of LREE over HREE, and La, Ce, Nd and Sc were the main contributors to the total REE value. REE-bearing minerals like monazite and zircon occurred as discrete mineral phases in the bauxite residue.

Keywords: Bauxite deposit, monazite, rare earth elements, red mud, zircon.

RED mud or bauxite residue is a solid waste that is produced by aluminium industries during the extraction of alumina from bauxite. It mainly comprises iron oxide, aluminium oxide, silicon oxide and titanium oxide. Generally, it is reddish-brown in colour, and the characteristic red colour is due to the presence of large amounts of iron oxide. The average composition of red mud is Fe_2O_3 (48–54%), Al_2O_3 (17–20%), TiO_2 (3–4%), SiO_2 (4–6%), CaO (1–2%), Na_2O (3–5%)[1]. It also contains many trace elements such as Ga, V, Mn, Cr, Ni, Cu, Pb, Zn, Cd, P, Mg, Hf, Zr, Th, U, Nb, Ba, Sr, K and rare earth elements (REEs) in varied proportion[2,3]. However, the mineralogical and chemical composition of red mud varies widely depending on the source of bauxite and the technological processing conditions applied to recover alumina[4,5]. It is reported that 0.8–1.5 tonnes of red mud is generated per tonne of alumina produced from bauxite[6]. World inventory of red mud shows that about 60–120 million tonnes are produced annually from the bauxite industry. India is one of the largest producers of red mud, producing about 2 million tonnes[7]. The production of red mud has been rising rapidly[8–10] and its disposal is one of the major concerns as red mud is highly alkaline and is a potential threat to air, water and land. Hence, red mud is a source of environmental pollution on the one hand[11,12] and a promising source for obtaining valuable elements on the other[13]. It can be utilized to recover Fe, Al, Ti, Na and REE[3,14]. It is reported that bauxite residue contains a high amount of scandium (70–260 ppm) that is close to its primary resources[15,16]. The approximate range of total REE content in red mud is about 500–1700 ppm (ref. 17). Several studies have reported that red mud is a secondary source

*e-mail: prustysasmita52@gmail.com

Table 1. Bulk chemical composition of red mud

Oxide	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	CaO	MgO	TiO_2	Cr_2O_3	MnO	P_2O_5	LOI
Weight %	10.11	17.98	47.93	6.12	0.18	1.26	0.22	3.55	0.09	0.18	0.37	12.01

Table 2. Weight % distribution of different sized fraction of the red mud samples and their REE concentration (ppm)

Size (μm)	+75	–75 + 45	–45
Distribution (wt %)	14.90	8.30	76.80
REE (ppm)			
La	26.5	26	89
Ce	2.2	34.5	151.5
Pr	20.3	14	36.5
Nd	41	37	57
Sm	23.5	24.5	26
Eu	–	–	1
Gd	–	–	–
Tb	7	8	8.5
Dy	–	–	–
Ho	–	–	–
Er	–	–	–
Tm	–	–	–
Yb	5.5	6	6
Lu	8	8.5	7.5
Sc	41.5	42.5	41.5
Y	4.5	5	9
TREE	180	206	433.5
TLREE	113.5	136	361
THREE	66.5	70	72.5
TLREE/THREE	1.7	1.9	5.0

– indicates not detected by ICP-OES.

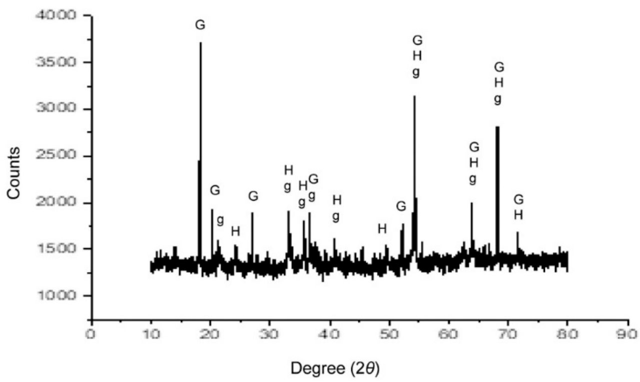

Figure 1. XRD pattern of red mud (G, gibbsite; g, goethite; H, Hematite).

for the recovery of REE[13,17–19]. As the mineralogy and composition of red mud depend on the source of bauxite ore and the technological process, red mud from India may have some peculiar characteristics, including its REE content[20]. Though some work has been done on the extraction of REE, mostly La and Sc, from Indian red mud, only a few studies are available on its REE mineralogy. In this present study, we characterize red mud samples from NALCO, Damanjodi, Odisha, India, intending to learn its REE mineralogical characteristics. NALCO is one of the major alumina-producing industries in the country, and its source of bauxite ore is from the East Coast bauxite deposit in southern Odisha. For this study, dry and powdered red mud samples were obtained from NALCO. They were thoroughly mixed and coning, quartering was done to prepare 1 kg of representative sample for characterization. Size classification was done using standard sieves. To ascertain the metal concentration, chemical analysis was performed by WD-XRF (PAN analytical–Zetium) for major oxides and ICP-OES (Perkin, Optical Emission Spectrometer Optima 2100 DV) for REE. The mineralogical study was carried out using XRD (PAN-analytical Model-Xpert PRO) and SEM-EDS (Zeiss EVO18, UK). For the SEM study, polish sections were prepared from the red mud samples by mounting them in epoxy resin. All these studies were carried out at the CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, Odisha.

From size classification, it is found that ~77% of the samples were below 45 μm in size, ~15% above 75 μm, and ~8% of the samples were within 45–75 μm in size. Tables 1 and 2 provide results of the analysis. Table 1 shows that red mud contains 47.93% Fe_2O_3, 17.98% Al_2O_3, 3.55% TiO_2, 10.11% SiO_2, 6.12% Na_2O and other minor elements. Table 2 shows that total REE (TREE) content is more in the finer fractions of the red mud samples. TREE is maximum (433 ppm) in the size fraction of –45 μm followed by 206 ppm in –75 + 45 μm and 180 ppm in +75 μm samples (Table 2). It was also observed that the concentration of LREE was more than the HREE, with the LREE/HREE ratio varying from 1.7 to 5. The LREE value increased from the coarser to the finer fractions, whereas the concentration of HREE did not vary much in different-sized fractions. Major LREE contents of the –45 μm sample were La (89 ppm), Ce (151 ppm) and Nd (57 ppm).

The XRD pattern showed that gibbsite, goethite and hematite were the major mineral phases present in the sample (Figure 1). Using SEM, the other mineral phases such as magnetite, ilmenite, rutile, zircon and monazite were identified along with the major minerals (Figure 2 *a*, *c* and *e*). Monazite and zircon were the major REE-bearing minerals that occurred as discrete grains. Figure 2 *b* and *d* shows the electron dispersive spectra along with semi-quantitative analysis of monazite and zircon. Monazite occurred in an irregular shape, whereas zircon was subrounded to rounded. The grain size of the REE phase varied from 10 to 60 μm. Elemental mapping of monazite and zircon, as well as the associated grains, clearly revealed the distribution of REE (La, Ce, Nd, Y) (Figures 3 and 4). The monazite grains contained La – 13%, Ce – 28.2%, Nd – 9.6%, Th – 6.4% and P – 17.2%. The semi-quantitative analysis of all mineral phases measured by SEM-EDX is given in Table 3.

Table 3. Semi-quantitative analysis of different mineral phases present in the red mud samples

Elements/points	1	2	3	4	5	6	7	8
O	28.0	37.6	27.2	35.7	58.7	30.3	31.8	41.9
Si	0.8	15.0		0.6				
Al				3.4	41.3			
Fe			72.8	60.4		29.6	68.2	
Ti						40.1		58.1
Zr		47.3						
P	13.9							
La	12.3							
Ce	28.2							
Nd	10.0							
Th	6.7							
U	0.9							
Mineral	Monazite	Zircon	Magnetite	Goethite	Gibbsite	Ilmenite	Hematite	Rutile

Blank spaces are not detected in the EDAX analysis for a particular mineral at a certain point.

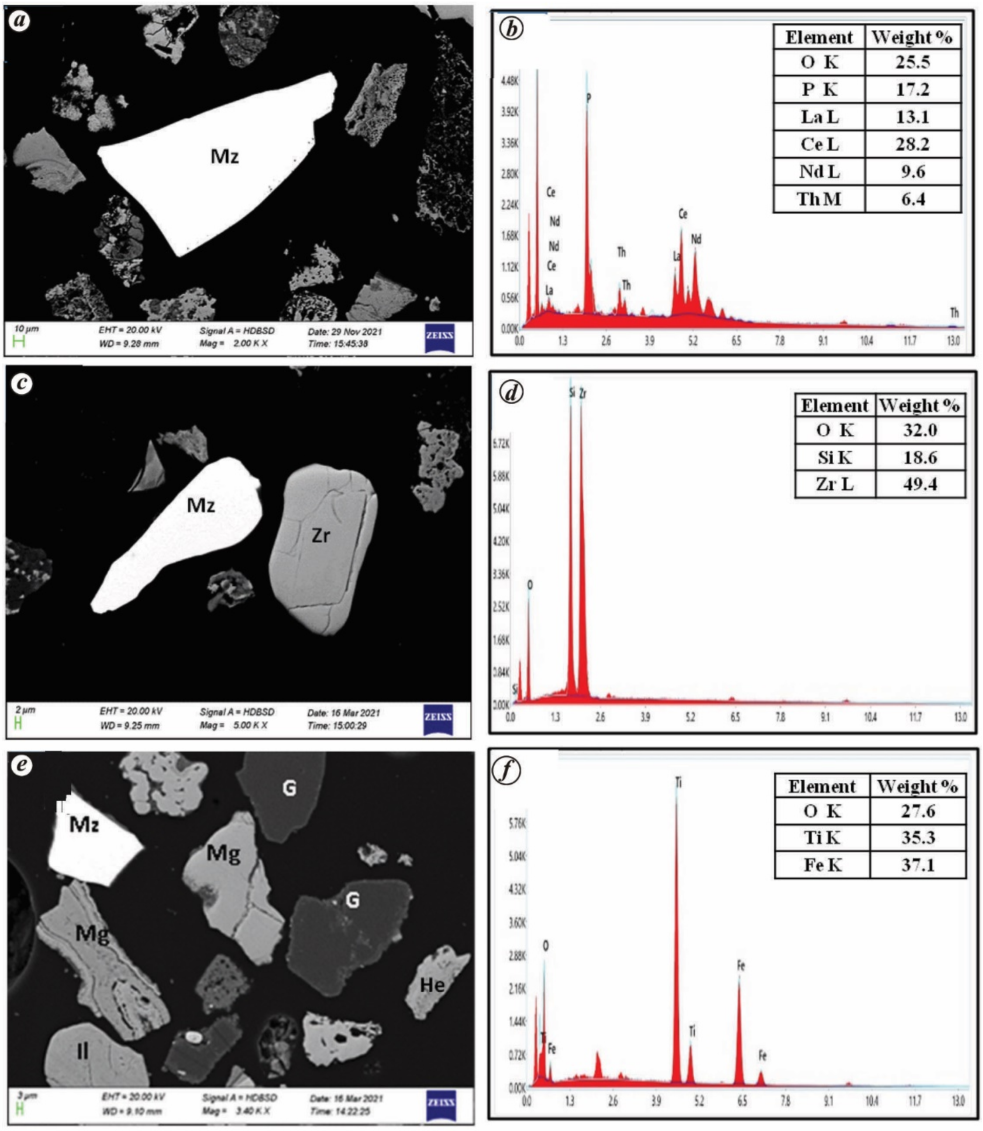

Figure 2. Backscattered electron image of red mud showing mineral phases and their electron dispersive spectra and semi-quantitative analysis. Mz, Monazite; Zr, Zircon; G, Gibbsite; Mg, Magnetite; Il, Ilmenite; H, Hematite. ***a***, Monazite grain. ***b***, Electron dispersive spectra and semi-quantitative analysis of monazite. ***c***, Sub-rounded monazite and zircon grain. ***d***, Electron dispersive spectra and semi-quantitative analysis of zircon. ***e***, Association of monazite, gibbsite, magnetite, hematite and ilmenite. ***f***, Electron dispersive spectra and semi-quantitative analysis of ilmenite.

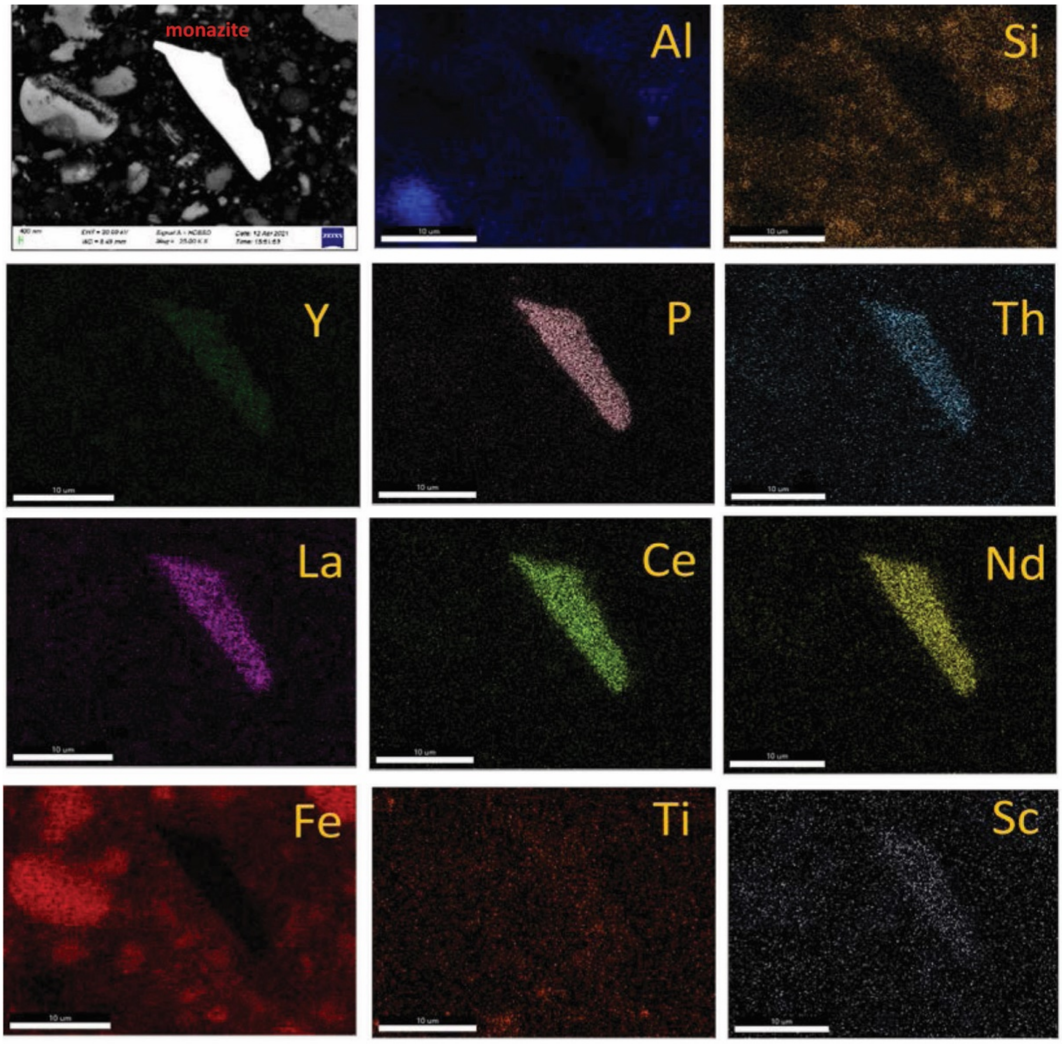

Figure 3. X-ray elemental map of monazite and other associated phases in the red mud samples.

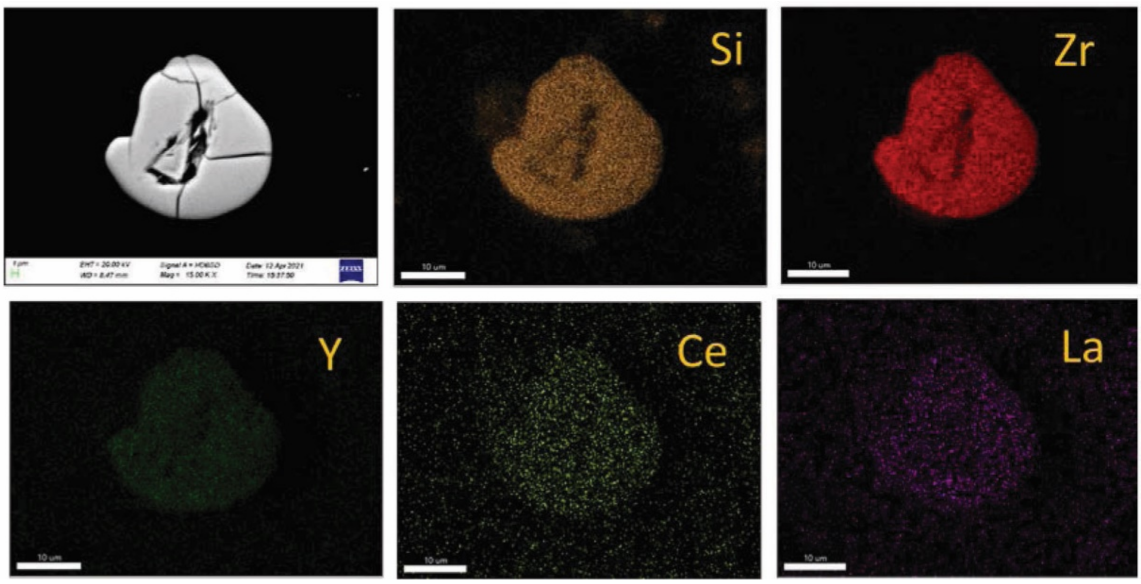

Figure 4. X-ray elemental map of zircon grain showing the presence of REE (La, Ce and Y).

In summary, the red mud samples of NALCO contain about 77% of very fine particles, i.e. below 45 μm, having TREE of 433 ppm. Monazite and zircon are the main REE-mineral phases present as discrete grains along with other minerals such as gibbsite, hematite, goethite, ilmenite, rutile and magnetite. These REE-mineral phases may be concentrated using suitable mineral processing techniques such as floatation and magnetic separation. In view of the current demand and geo-political scenario, there is a need to secure critical resources like REE. Red mud could be a viable feedstock for extracting REE, provided there is a complete understanding of its REE characteristics. This makes the huge accumulation of red mud a resource rather than a waste product. As mineralogy plays a vital role in mineral beneficiation or any route of metal extraction, this study may help in the recovery of REE from Indian red mud in the future.

1. Fois, A., Lallai, G. and Mura, Sulfur dioxide absorption in a bubbling reactor with suspensions of Bayer red mud. *Ind. Eng. Chem. Res.*, 2007, **46**, 6770–6776.
2. Mohapatra, B. K., Rao, M. B. S., Rao, R. B. and Paul, A. K., Characteristics of red mud generated at NALCO Refinery, Damanjodi, India. In Proceedings of 129th the Minerals, Metals and Materials Society, Annual Meeting (eds Eckert, C. E. and Peterson, R. D.), Nashville, Tennessee, USA, 2000, pp. 161–165.
3. Abhilash, Sinha, S., Sinha, M. K. and Pandey, B. D., Extraction of lanthanum and cerium from Indian red mud. *Int. J. Min. Proc*., 2014, **127**, 70–73.
4. Glenister, D. J. and Thornber, M. R., Alkalinity of red mud and its applications for management of acid wastes. *Chemica*, 1985, **85**, 100–113.
5. Hind, A. R., Bhargava, S. K. and Grocott, S. C., The surface chemistry of Bayer process solids: a review. *Colloid. Surf. A*, 1999, **146**(1–3), 359–374.
6. Liu, X. and Zhang, N., Utilization of red mud in cement production: a review. *Waste Manage. Res*., 2011, **29**, 1053–1063.
7. Agrawal, A., Sahu, K. K. and Pandey, B. D., Solid waste management in nonferrous industries in India. *Resour. Conserv. Recycl*., 2004, 99–120.
8. Abhilash, Sinha, S., Meshram, P. and Pandey, B. D., Red mud: a secondary resource for rare earth elements. In Proceedings of International Bauxite, Alumina and Aluminium Symposium, Visakhapatnam, India, 2014, vol. 3, pp. 148–162.
9. Power, G., Grafe, M. and Klauber, C., Bauxite residue issues: I. Current management, disposal and storage practices. *Hydrometallurgy*, 2011, **108**, 33–45.
10. Akcil, A., Akhmadiyeva, N., Abdulvaliyev, R., Abhilash and Meshram, P., Overview on extraction and separation of rare earth elements from red mud: focus on scandium. *Miner. Process Extract. Metall. Rev.*, 2018, **39**(3), 145–151.
11. Kovács, T., Horváth, M., Csordás, A., Bátor, G. and Tóth-Bodrogi, E., Tobacco plant as possible biomonitoring tool of red mud dust fallout and increased natural radioactivity. *Heliyon*, 2020, **6**, e03455.
12. Alam, S., Das, B. K. and Das, S. K., Dispersion and sedimentation characteristics of red mud. *J. Hazard. Toxic Radioact. Waste*, 2018, **22**, 04018025.
13. Liu, Z. and Li, H., Metallurgical process for valuable elements recovery from red mud – a review. *Hydrometallurgy*, 2015, **155**, 29–43.
14. Sun, Y. F., Dong, F. Z. and Liu, J. T., Technology for recovering iron from red mud by Bayer process (in Chinese). *Met. Mine*, 2009, **9**, 176–178.
15. Rivera, R. M., Xakalashe, B., Ounoughene, G., Binnemans, K., Friedrich, B. and Van Gerven, T., Selective rare earth element extraction using high-pressure acid leaching of slags arising from the smelting of bauxite residue. *Hydrometallurgy*, 2009, **184**, 162–174.
16. Chaikin, L., Shoppert, A., Valeev, D., Loginova, I. and Napol Skikh, J., Concentration of rare earth elements (Sc, Y, La, Ce, Nd, Sm) in bauxite residue (red mud) obtained by water and alkali leaching of bauxite sintering dust. *Minerals*, 2020, **10**(500), 1–13.
17. Binnemans, K., Jones, P. T., Blanpain, B., Gerven, T. V., Yang Y., Walton, A. and Buchert, M., Recycling of rare earths: critical review. *J. Clean. Prod.*, 2013, **51**, 1–22.
18. Deady, E., Mouchos, E., Goodenough, K., Williamson, B. and Wall, F., Rare earth elements in Karst-bauxites: a novel untapped European resource. In Proceedings of the 1st Europe Rare Earth Resources Conference, Milos Island, Greece, 2014, pp. 397–409.
19. Sinha, S., Sinha, M. K. and Pandey, B. D., Extraction of lanthanum and cerium from Indian red mud. *Int. J. Miner. Process*., 2014, **127**, 70–73.
20. Nath, H. and Sahoo, A., A study on the characterization of red mud. *Int. J. Appl. Bioeng*., 2014, **8**(1), 1–4.

ACKNOWLEDGEMENT. I thank Prof. Suddhasatwa Basu (Director, Institute of Minerals and Materials Technology, Bhubaneswar) for permission to publish this paper.

Received 23 August 2022; revised accepted 12 December 2022

doi: 10.18520/cs/v124/i6/753-757

Chemical constituents of essential oil from leaves of an invasive weed *Ageratina adenophora* in Central Nepal

Khadka Bahadur Pal[1], Seeta Pathak[2], Tayer Mohamad Miya[3], Tej Bahadur Darji[2,4], Gunanand Pant[5], Ramesh Raj Pant[6], Lok Ranjan Bhatt[7] and Lal B. Thapa[2,*]

[1]Department of Chemistry, Trichandra Campus, Tribhuvan University, Kathmandu, Nepal
[2]Central Department of Botany, Institute of Science and Technology, Tribhuvan University, Nepal
[3]Department of Food Technology and Quality Control, Government of Nepal, Kathmandu, Nepal
[4]Department of Forest Resources, Ministry of Forest and Environment, Plant Research Center, Jumla, Nepal
[5]Department of Biology, Kailali Multiple Campus, Far Western University, Kailali, Nepal
[6]Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University, Nepal
[7]Biological Resource Unit, Nepal Academy of Science and Technology, Lalitpur, Nepal

This study aims to identify volatile chemical components in the essential oil of an invasive plant, *Ageratina adenophora*, from Central Nepal. Leaf samples of *A. adenophora* were collected, and the chemical composition

*For correspondence. (e-mail: lal.thapa@cdb.tu.edu.np)