Identification of Rare Metals in Maiganga Coal Nigeria Using Inductively Coupled Plasma Optical Emission Spectrometry Technique

R. A. Saleh, A. Gimba, A. Adeleke, A. Usman

Abstract**—**One fossil fuel used to generate electricity is coal, a nonrenewable energy source. Despite its utility, many individuals steer avoid coal, often overlooking its significance. Notably, coal is considered to contain notable amounts of rare metals, which serve as basic materials in the production of renewable energy. The occurrence of rare metals in Garin Maiganga Coal Deposit was analyzed using ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry), 16 rare metals were determined in the coal: cesium (Cs), gold, platinum, osmium, iridium, palladium, ruthenium, rhodium, tellurium, rhenium, indium, tantalum, tungsten, gallium, lithium, and cobalt. The results indicated the occurrence of Cs in all three decarbonized coal ash samples. The objective of this study is to expand the data necessary for initiating metal recovery experiments. The focus is on using ICP-OES to measure the concentration of these metals in Garin Maiganga coal resource in Gombe, Nigeria. In order to do this, the contents of rare metals were detected, and the economic values of the elements were explored.

Keywords**—**Coal, Maiganga, rare metals, ICP-OES.

I. Introduction

IN the metallurgical industry, coal is a crucial raw resource functioning both as a reductant and a source of fuel. Although high-grade coking coals are desired for use in blast furnace operations, in particular, their supply is restricted globally [1]. This scarcity has prompted the development of alternative methods to utilize coal as a reductant and fuel, including extracting rare metals (such as cesium (Cs), lithium, rhenium, and platinum) from coal ash. Coal's notable concentration of rare metals makes it a significant source of these essential raw materials for renewable energy production [2]. The primary components of coal are hydrocarbons and carbon, both characterized by high energy density, which is released upon combustion. Historically, coal combustion powered the initial phase of the Industrial Revolution, marking a significant economic breakthrough [3]. In the modern era, coal, alongside oil, gas, and emerging energy sources, is projected to account for 25% of the world's energy consumption, with specific contributions of 32.6%, 23.7%, 30.0%, and 13.7%, respectively. Despite the rise of new energy sources, coal remains a dominant choice for energy generation in many nations [4]. Coal, a fossil fuel formed from compressed plant matter, is a combustible sedimentary rock with black or brownish-black coloring.

Primarily used for generating electricity and heat, global coal consumption reached approximately 7.25 billion tons in 2010. By 2030, estimates suggest this figure will rise to 9.05 billion tons [5]. Moreover, with its massive coal resources, developing nations like Nigeria stand to gain a great deal from the generation of electricity from clean coal technologies (CCTs) in terms of socioeconomic progress, sustainable development, and environmental protection. The estimated amount of coal reserves in Nigeria is two billion metric tons [6], with more than 650 million metric tons of resources that can be recovered economically. In addition, Nigeria's chances for producing coal power have been revived by the discovery of fresh reserves in Shankodi-Jangwa, Afuze, and Garin Maiganga [7].

The Maiganga Coal Deposit, located within the Maastrichtian Gombe Formation in northeastern Nigeria's Northern Benue Trough, is a unique geological story. The Pindiga Formation, which has a marine origin, indicates a period of seaway dominance, while the Gombe sandstone, where the coal resides, hints at a shift towards a non-marine environment. The Maiganga coal exhibits characteristics that bridge the gap between lignite and sub-bituminous coal, with high ash content, moisture, and volatile matter leaning towards lignite properties. However, analysis also reveals low fixed carbon content and calorific value, typical of lignite [8]. The coal's geological context extends beyond its formation environment and coalification stage, with a significant presence of silica within the coal matrix. The ongoing exploration efforts aim to assess the concentration of rare metals present in Garin Maiganga Coal Deposit. Nigeria is endowed with abundant mineral resources, including but not limited to coal, bentonite, petroleum, gypsum, talc, kaolin, gold, dolomite, limestone, and iron ore [9]. However, after Nigeria gained independence, coal exploration fortunes took a hit due to the country's economy being primarily dependent on crude oil and domestic refining. Technological advancements led to a drop in coal output from almost one million metric tons in 1959 to fewer than 10 thousand tons in 2005 [10]. The presence of these elements raises concerns about environmental contamination and radiation exposure. Strict regulations govern the handling and

Saleh, R. A. is with the Department of Industrial Chemistry, Nile University of Nigeria Abuja, Nigeria (corresponding author, e-mail: rabiatuadamusaleh@yahoo.com).

Gimba A. is with the Department of Petroleum and Gas, Nile University of Nigeria Abuja, Nigeria (e-mail: Abdullahi.gimba@nileuniversity.edu.ng).

Adeleke A. is with the Department of Mechanical Engineering, Nile University of Nigeria Abuja, Nigeria (e mail: Adekunle.adeleke@nileuniversity.edu.ng).

Usman A. is with the Nigerian Mining and Geoscientist Society, Nigeria (e-mail: ahmed0411@gmail.com).

disposal of coal ash containing actinides [11]. The development of renewable energy and contemporary technologies depends on rare metals. The shift to clean energy is complicated by the fact that their supply is confined to a small number of nations. It is essential to diversify the sources of rare metals through recycling and sustainable practices [12]. Coal byproducts are a plentiful source of non-traditional rare metals that may expand the rare metals marketplace [13]. Coal reserves are plentiful in Nigeria and can produce up to 30% of the country's energy requirements.

This coal is currently one of the main investment targets for the Nigerian government and foreign investors for power generation, the industrial and manufacturing sector. So, the goal of this study is to determine the metal concentration and level in Garin Maiganga coal in Northeastern Nigeria. Estimating extraction efficiency will be made easier thanks to this. This research will yield baseline concentration data that are comprehensive enough to help the government design efficient coal power plant projects and hydrometallurgical separation methods. To extract or isolate the identified metals from Garin Maiganga Coal Nigeria, coal investors would find the investigation's conclusions to be pertinent.

II. Methodology

A. Study Area

Garin Maiganga is a community located in the Akko local government area of Gombe, Northeast Nigeria. It lies between latitudes 10°02’ to 10°05’ and longitudes 11°06’ to 11°08’ (Fig. 1). Maiganga coal is located in the northeastern part of Nigeria, Gombe State. Exploration work is underway to determine the size and grade of this deposit. Currently, it is the primary energy source for one of Nigeria's largest cement manufacturers [14].

B. Sample Collection

Before collecting the sample, the surface was cleared, at least 25 cm of coal from the top was scraped away, and the area was leveled. A total of 20 kg each of fresh samples of coal-out crops were collected from the Garin Maiganga coal deposit in Gombe State, North-east Nigeria. These coal samples were stored in appropriately labeled, airtight containers to retain their as-received conditions.

C. Sample Preparation

The coal sample collected was reduced to a laboratory sample size. The coal was pulverized and ashed at 900 °C, 1000 °C, and 1100 °C to achieve a carbon-free state. The decarbonization process took place in the chemical laboratory at Umaru Musa Yaradua University Katsina, Katsina State, Nigeria. A sample of 5 g of each decarbonized coal ash was then transferred to All School Laboratory in Ogun State for ICP-OES.

III. Inductively Couple Plasma Atomic Emission Spectroscopy

The solvent extraction method was conducted with a Soxhlet extractor using commercial ethanol at different temperatures of 50 ºC, 60 ºC, and 70 ºC for 2 h, 3 h, and 4 h, respectively. The combination of temperature and time was determined in a preliminary set of experiments. Three replicates were carried out for all nine treatments to reduce error. Garlic powder was used (10 g) at a sample to solvent ratio of 1:20. The oil was obtained after the solvent was evaporated by placing it over a water bath (LABARD, LI –WBPR-14A) for about 2-3 hours under reduced temperature (50 ºC) and refluxing at 70 ºC to remove any excess solvent. The extracted garlic oil was stored in a refrigerator at 4 ºC for subsequent physicochemical analyses.

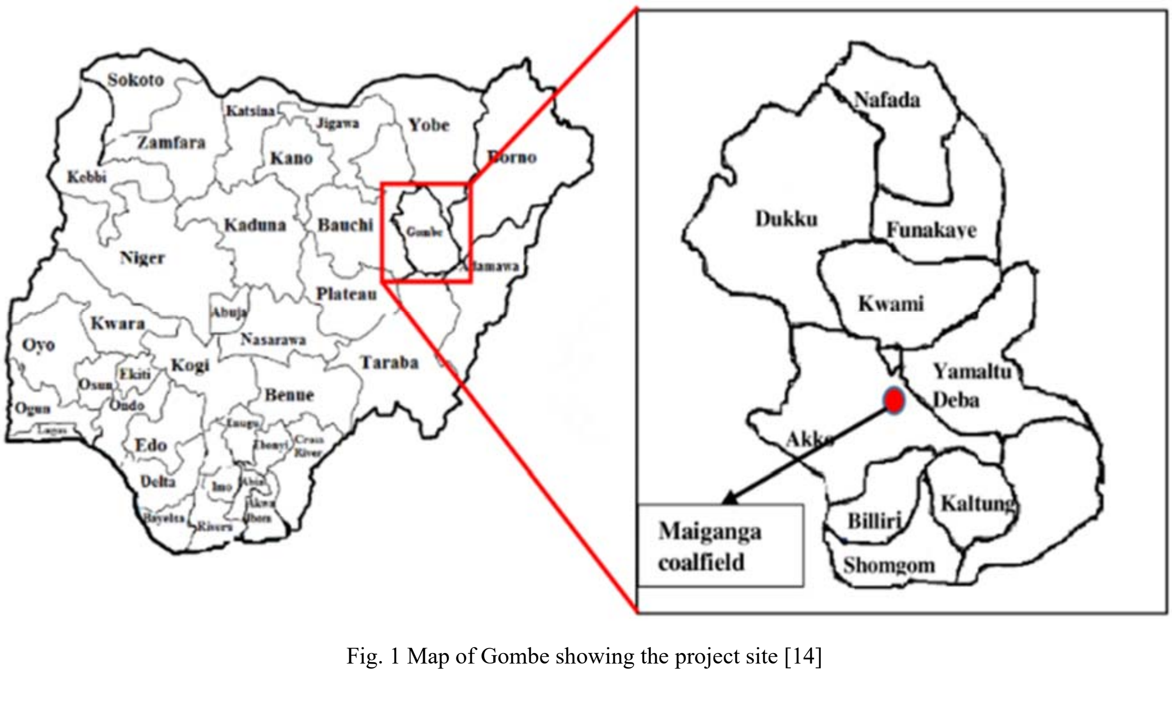

Fig. 1 Map of Gombe showing the project site [14]

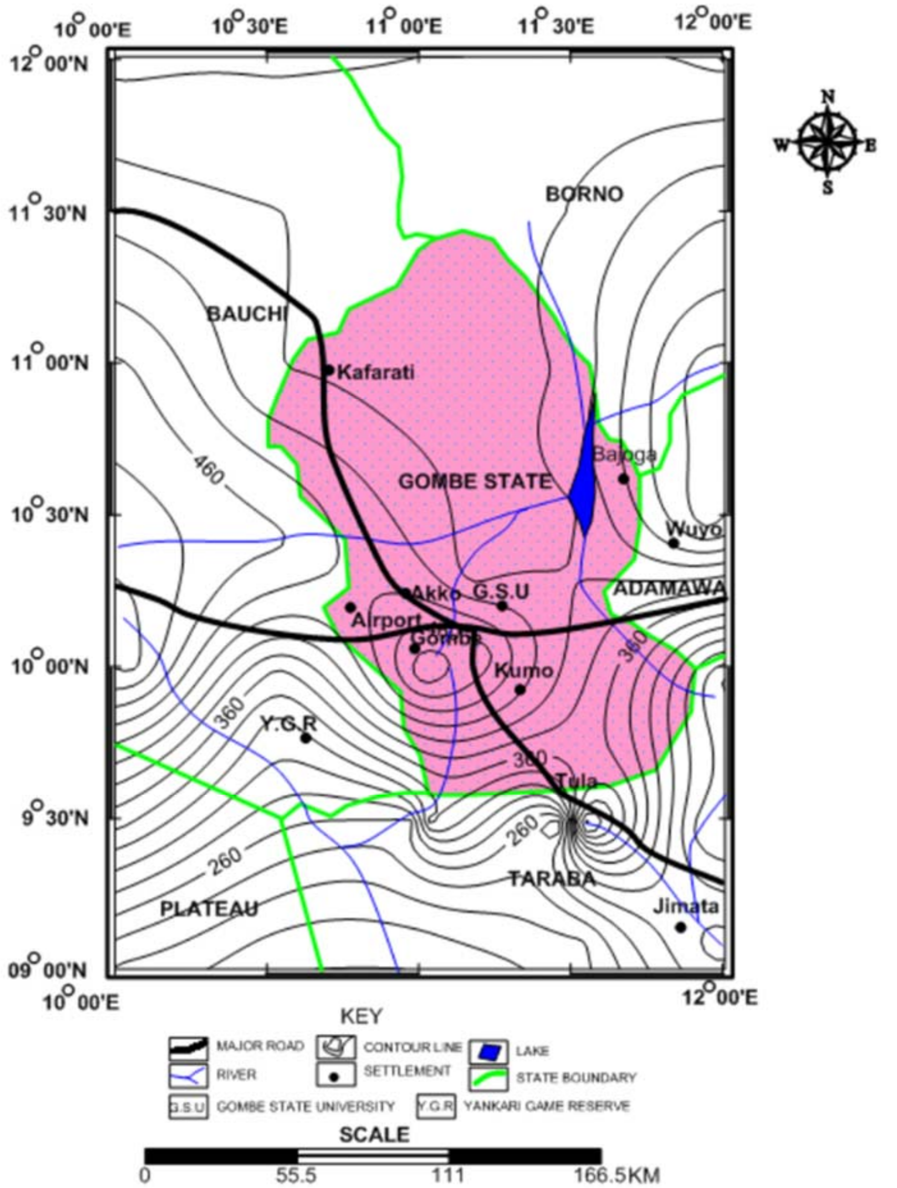

Fig. 2 Geological image of Maiganga coal deposit, Gombe State, Nigeria [15]

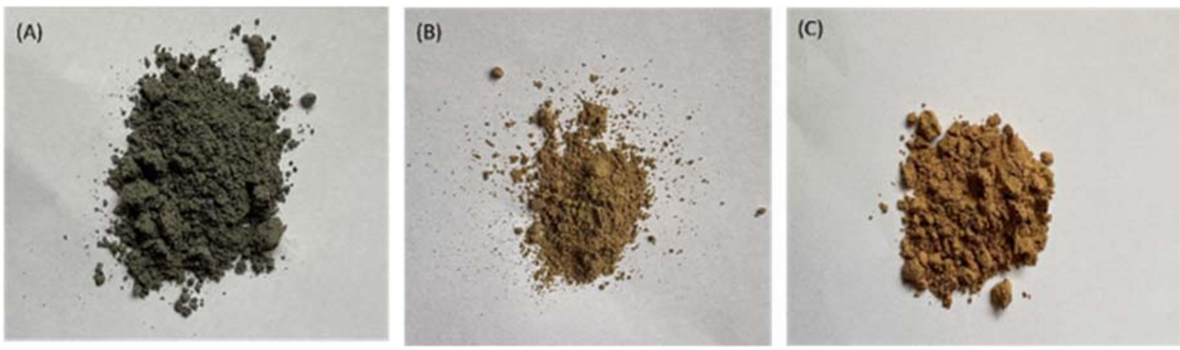

Fig. 3 Decarbonize ash at (A) 900 °C, (B) 1000 °C, (C) 1100 °C

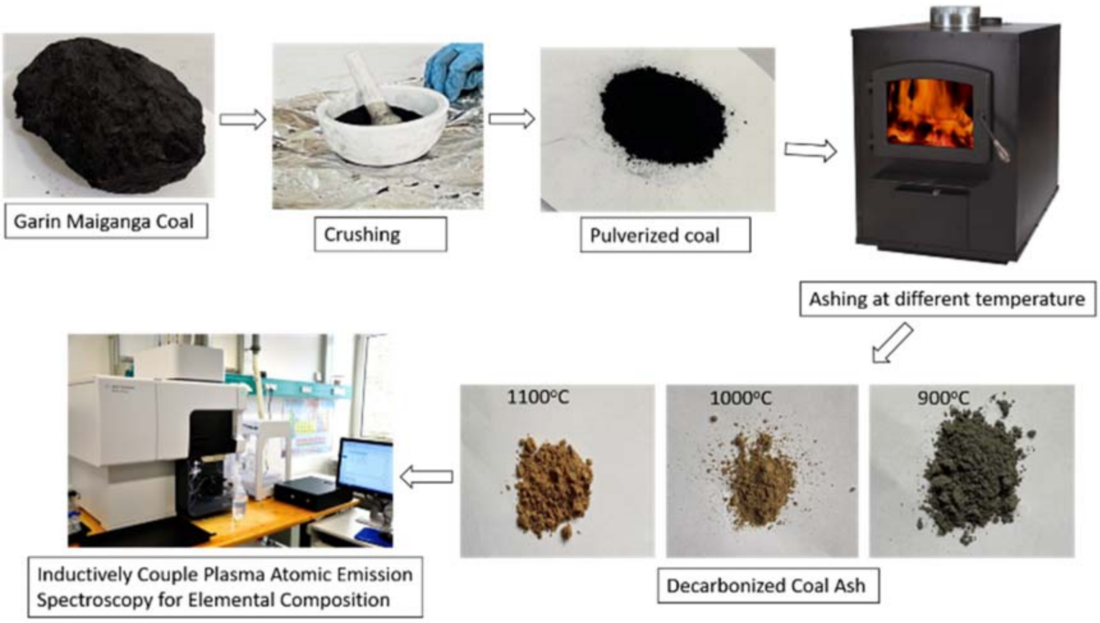

Fig. 4 Flowsheet showing Maiganga coal burnt into coal fly ash

IV. Discussion

After the sample was reduced to tiny droplets, it was heated and broken down into individual atoms in a plasma. The excited atoms in the plasma produced light, and the elements in the sample were determined by the ICP-OES. The elements with concentration values are displayed in Table I according to the analytical result. The concentration of cesium in the result was 54.40 ppm, 222.49 ppm, and 413.60 ppm, respectively. This indicates that the coal has a greater concentration of a rare metals (cesium) than all other rare metals present. Cesium can potentially replace lithium-ion battery production, particularly in the context of replacing developing new type batteries. Another interesting application of cesium is it can be used in the oil industry; cesium formate can be used in drilling fluids for oil and gas extraction. Its high density helps in stabilizing the wellbore and also control pressure during drilling operations. The flowsheet for identifying these compounds from Maiganga coal is shown in Fig. 4. Fly ash, which is produced when coal is burned, might, nonetheless, potentially be economically significant, particularly for rare metals [16]. According to the fly ash study, Cs are substantially concentrated in Maiganga coal fly ash. This elemental concentration suggests that there have been fewer introductions of radioactive elements into the coal deposit's natural environment; however, the notable presence of certain elemental quantities may also point to a different source of strategic minerals and rare metals, whose prices have skyrocketed due to a lack of supply worldwide and growing demand. It is well known that trace elements in coals have both biological and inorganic associations, accounting for the majority of them [17]. According to reports, the components of coal fly ash are influenced by the type of coal burned, the circumstances during combustion, and the effectiveness of the air pollution control device's removal process. Changes in coal supplies contribute to the ongoing fluctuations in metal concentrations. The elevated concentration of these metals in correlation with the ash yield indicates a strong bond with the inorganic materials [18]. According to the current data, Cs is present in larger concentrations at ashing rate of 1100 ºC than 1000 ºC, and 900 ºC, it should be mentioned that Cs usually makes up a sizable portion of Garin Maiganga coal ash; hence, if the analysis of cesium extraction or isolation is needed Garin Maiganga coal deposit can be explored.

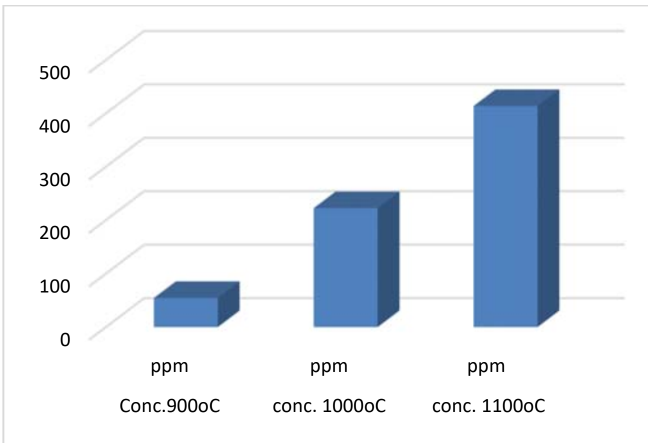

Fig. 5 Cesium concentration in Garin Maiganga coal deposit

TABLE I
ICP-OES SHOWING THE CONCENTRATION OF RARE METALS PRESENT IN GARIN MAIGANGA COAL ASH

Elements	Conc. 900 °C (ppm)	Conc. 1000 °C (ppm)	Conc. 1100 °C (ppm)	Intensity 900 °C (au)	Intensity 1000 °C (au)	Intensity 1100 °C (au)
Au 242.794	0.015334	0.016924	0.01638	16.389144	18.08797	17.507289
Au 267.594	0.012887	0.015989	0.033064	22.982129	28.512916	58.962744
Co 228.615	0.022936	0.023659	0.028713	47.646527	49.148479	59.648093
Co 238.892	0.010807	0.004486	0.010613	27.810333	11.544989	27.312956
Cs 459.311	54.401121	222.496021	413.607849	169.919602	694.956911	1291.886618
Cs 697.327	4.982109	3.09633	1.559801	59.835291	37.187029	18.733265
Ga 294.363	0.013364	0.012813	0.037435	23.063095	22.112457	64.604356
Ga 417.204	0.278996	0.486722	0.798154	785.969084	1371.162706	2248.508545
In 230.606	0.068307	0.036507	0.078916	13.001758	6.948818	15.021142
In 325.609	0.070134	0.064677	0.115977	59.72576	55.078496	98.764911
Ir 212.681	0.003095	0.002486	0.00432	2.355881	1.892328	3.288168
Ir 224.268	0.038025	0.030595	0.075583	26.305683	21.165776	52.287753
Li 610.365	0.00064	0.001351	0.000829	12.827022	27.049639	16.610795
Li 670.783	0.007557	0.001485	0.004994	1051.483683	206.557965	694.812695
Os 225.585	0.0108	0.009538	0.039216	10.202362	9.010194	37.043957
Os 228.228	0.010958	0.04172	0.007033	3.182655	12.116756	2.042504
Pd 229.651	0.040089	0.00496	0.010851	10.062225	1.244984	2.723647
Pd 340.458	0.000955	0.001007	0.008244	3.935279	4.148402	33.961077
Pt 203.646	0.03042	0.064637	0.115905	6.674192	14.181426	25.429796
Pt 214.424	0.027992	0.026543	0.026772	13.92805	13.207005	13.321288
Re 221.427	0.039478	0.022228	0.031424	18.680375	10.517954	14.869385
Re 227.525	0.009641	0.008707	0.024285	9.131039	8.246397	22.999931
Rh 343.488	0.014348	0.003133	0.013486	35.85813	7.829049	33.702033
Rh 369.236	0.002027	0.006742	0.013859	3.530858	11.743244	24.141748
Ru 245.657	0.018063	0.008942	0.018706	15.276439	7.562806	15.820075
Ru 267.876	0.013844	0.0179	0.052736	19.583636	25.321564	74.598893
Ta 263.558	0.003224	0.006298	0.007494	3.585591	7.003513	8.333789
Ta 263.558	0.002689	0.006227	0.007636	2.996719	6.938675	8.509423
Te 182.153	0.037455	0.027742	0.109607	1.885364	1.396463	5.517305
Te 214.282	0.00906	0.006036	0.016497	3.051259	2.032831	5.555954
W 207.912	0.016772	0.014523	0.011956	8.131716	7.041251	5.796701
W 209.475	0.046027	0.0081	0.008692	11.371711	2.001108	2.147543

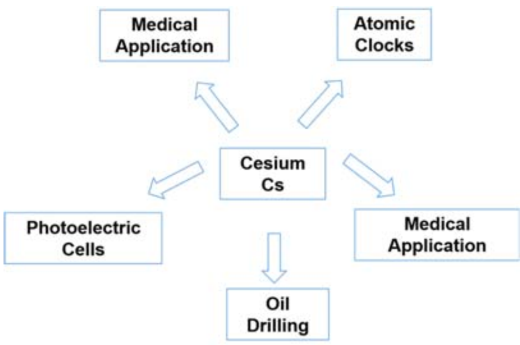

Fig. 6 Economic application of cesium

V. CONCLUSION

ICP-OES was employed to analyze coal ash samples from Garin Maiganga coal deposit. The analysis revealed substantial concentrations of gold, platinum, osmium, iridium, palladium, ruthenium, rhodium, tellurium, rhenium, indium, tantalum, tungsten, gallium, lithium, and cobalt. However, Cs was found to be present in higher concentration in the studied sample. The study highlights the Garin Maiganga coal deposit as a potential reservoir for not only energy resources but also a range of industrial minerals. To fully realize the economic and technological potential of the Garin Maiganga coal deposit, further research is imperative to optimize extraction processes, assess environmental impacts, and explore the possibility of recovering rare metals, especially cesium.

REFERENCES

[1] A. Adeleke, J. K. Odusote, O. A. Lasode, P. P. Ikubanni, M. Malathi and D. Paswan, "Densification of coal fines and mildly torrefied biomass into composite fuel using different organic binders," Heliyon, p. 5(7), 2019.
[2] R. A. Saleh, A. Gimba, A. Adekunle, A. Olosho, T. Sammonu, P. Nzerem and C. R. Odimba, "A Review on Extraction of Rare Earth Elements (REEs) From Coal Using Acid Leaching," In 2023 2nd International Conference on Multidisciplinary, November 2023
[3] J. Gasparotto and K. Martinello, "Coal as an energy source and its impacts on human health.," Energy Geoscience, pp. 2(2), 113-120, 2021.
[4] C. Zou, Q. Zhao, G. Zhang and B. Xiong, "Energy revolution: From a fossil energy era to a new energy era.," Natural Gas Industry B, pp. 3(1), 1-11., 2016.
[5] Y. Chen, Y. Shen, S. Xiao, Z. Liu, M. Li, Z. Peng and X. Wang, "A detailed magnetic characterization of combustion products from various metamorphic grade coals," Journal of Applied Geophysics, pp. 217, 105168, 2023.
[6] B. M. S. Yandoka, W. H. Abdullah, M. B. Abubakar, M. H. Hakimi and A. K. Adegoke, "Geochemistry of the Cretaceous coals from Lamja Formation, Yola Sub-basin, Northern Benue Trough, NE Nigeria: Implications for paleoenvironment, paleoclimate and tectonic setting," Journal of African Earth Sciences, pp. 104, 56-70, 2015.
[7] B. B. Nyakuma and A. Jauro, "Physicochemical characterization and

thermal decomposition of Garin Maiganga coal. GeoScience Engineering," GeoScience Engineering, pp. 62(3), 6., 2016.

[8] M. Varol, A. Atimtay, B. Bay and H. Olgun, "Investigation of co-combustion characteristics of low quality lignite coals and biomass with thermogravimetric analysis," Thermochimica acta, Vols. 510(1-2), pp. 195-201, 2010.

[9] O. J. Kolawole, A. A. Akanni, B. S. Ameenullahi and A. A. Adediran, "Preliminary characterisation of iron ores for steel making processes," Procedia Manufacturing, pp. 35, 1123-1128, 2019.

[10] A. R. Odunayo, P. Omoniyi, P. Leslie and O. Olorunfemi, "Comparative chemical and trace element composition of coal samples from Nigeria and South Africa," American Journal of Innovative Research and Applied Sciences, pp. 2(9), 391-404, 2016.

[11] P. K. Sahoo, K. Kim, M. A. Powell and S. M. Equeenuddin, "Recovery of metals and other beneficial products from coal fly ash: A sustainable approach for fly ash management," International Journal of Coal Science & Technology, pp. 3(3), 267-283, 2016.

[12] Z. Hussain, D. Dwivedi and I. Kwon, "Recovery of rare earth elements from low-grade coal fly ash using a recyclable protein biosorbent," Frontiers in Bioengineering and Biotechnology, pp. 12, 1385845, 2024.

[13] D. M. Park, A. Brewer, D. W. Reed, L. N. Lammers and Y. Jiao, "Recovery of rare earth elements from low-grade feedstock leachates using engineered bacteria," Environmental science & technology, pp. 51(22), 13471-13480., 2017.

[14] M. T. Kolo, M. U. Khandaker, Y. M. Amin and W. H. B. Abdullah, "Quantification and radiological risk estimation due to the presence of natural radionuclides in Maiganga coal, Nigeria," PLoS One, pp. 11(6), e0158100, 2016.

[15] C. O. Amosu, C. S. A. Enitan and C. Eniola, "Implication of mining to health in Maiganga coal mine, Gombe State, Nigeria," Indian J Manag Lang, pp. 1(2), 4-15, 2021.

[16] S. Dai, V. V. Seredin, C. R. Ward, J. C. Hower, Y. Xing, W. Zhang and P. Wang, "Enrichment of U–Se–Mo–Re–V in coals preserved within marine carbonate successions: geochemical and mineralogical data from the Late Permian Guiding Coalfield, Guizhou, China," Mineralium Deposita, pp. 50, 159-186, 2015.

[17] J. Liu, Z. Yang, X. Yan, D. Ji, Y. Yang and L. Hu, "Modes of occurrence of highly-elevated trace elements in superhigh-organic-sulfur coals," Fuel, pp. 156, 190-197, 2015.

[18] J. Marrero, G. Polla, R. J. Rebagliati, R. Plá, D. Gómez and P. Smichowski, "Characterization and determination of 28 elements in fly ashes collected in a thermal power plant in Argentina using different instrumental techniques," Spectrochimica Acta Part B: Atomic Spectroscopy, pp. 62(2), 101-108, 2007.