ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

Solid Minerals as Alternate means of Nigeria's Economy Recovery Using Artificial Intelligence

[1]Adeyemo, Jacob Titilope; [2]Salvatore, Fava; [3]Lawal, Abiodun Ismail; [4]Oyeleke, Tolulope Ayobi
[1,4]Geocardinal Engineering Services, Abuja, Nigeria.
[2]Selinus University, Italy.
[3]Federal University of Technology, Akure, Nigeria

Abstract:- Nigeria is one of the nations blessed with vast number of mineral resources which can make its economy one of best in the world. However, very little attention is directed to this sector as the sector contributes less than 10% to the country's Gross Domestic Product (GDP). Therefore, this study evaluates the economic potentials of Nigeria mineral resources as means of liberating the country from its current economic woes. Data obtained from the existing company, internet sources, U.S. Geological Survey, Nigeria Geological Survey Agency among others were used to form the bases for the analyses. The economic indicators were first computed to determine the dependency of Nigeria mineral demands on the import and forecasting was also done using the moving average method and forecast command. The obtained import reliance and self-sufficiency indicated that Nigeria still depend largely on the importation to meet its mineral requirements and hence not self-sufficient. The Net Profit Value (NBP), Internal Rate of Return (IRR) and Payback Period (PBP) revealed that the minerals investigated are economically viable. To enhance the easy assessment of the NPV, artificial intelligence approach, Artificial Neural Network (ANN) was used to develop models for barite and iron ore. The model was validated, and the validation results are compared with the actual values. They were found to be very close to the actual NPV and can be used for the NPV predictions. Therefore, ANN model was transformed through the weights and biases to mathematical form. Hence, the study has revealed the dependency of Nigeria on import and the economic viability of the minerals in Nigeria.

***Keywords:-** Mineral Resources, Economic Indicators, Economic Parameters, Viable, Artificial Intelligence.*

I. INTRODUCTION

Nigeria, located in the West African region, is endowed with vast mineral resources. These resources have the potential to significantly boost the country's economy, which is less prone to natural disasters compared to other regions. The six geopolitical zones of Nigeria are each blessed with a variety of mineral resources (Federal Republic of Nigeria 2010). The Southern part of the country is rich in both liquid (oil and gas) and solid minerals, while the Northern zones possess different economic minerals (Hoseini et al. 2023).

African nations often rely heavily on their mineral resources as a primary income source, with mineral exports contributing significantly to their gross domestic product (GDP). For instance, countries like DR Congo, Guinea, Mauritania, South Africa, Namibia, Zambia, and Ghana have mining sectors contributing between 10% and 26% to their GDPs. However, Nigeria's mining sector contributed only 0.3% to the country's GDP in Q3 of 2022, slightly higher than the 0.2% in Q3 of 2021 (Nigeria Bureau of Statistics 2022). This indicates a slow but progressive growth in the sector.

Despite Nigeria's vast mineral wealth, the sector's contribution to the economy GDP remains minimal. According to CBN (2018), the contribution of solid minerals decreased from N67.14 billion in 1981 to N29.09 billion in 1990. In 2000, it dropped even further to N21.31 billion. It has increased since 2003, though, going from N23.20 billion to N51.88 billion in 2010 and N96.60 billion in 2018, respectively. On the other hand, CBN (2018) notes that the solid mineral component of GDP has been decreasing over time when expressed as a percentage. From 0.44% in 1981 to 0.15%, 0.089%, and 0.093% in 1990, 2000, and 2010, respectively, it experienced a drop. The percentage contribution is still significantly less than what was recorded in the 1980s.

This is primarily due to the lack of detailed information about the economic feasibility of exploiting these resources. Consequently, the country continues to rely heavily on oil and gas, missing out on the potential benefits of a diversified mineral-based economy. This study aims to address this gap by evaluating the economic potentials of Nigerian mineral resources as an alternative means to economic recovery. This study seeks to answer the following research question: What are the economic potentials of Nigerian mineral resources, and how can they contribute to the country's economic recovery? The significance of this study lies in its potential to provide a comprehensive analysis of Nigeria's mineral resources and their economic viability. By highlighting the benefits of diversifying the economy through the mining sector, this research can inform policy decisions and investment strategies aimed at boosting the sector's contribution to the national GDP.

Furthermore, this study builds on existing literature by providing an in-depth analysis of selected minerals across Nigeria's geopolitical zones, using both qualitative and quantitative methods to assess their economic potentials.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

Through this comprehensive evaluation, the study aims to demonstrate how Nigeria can leverage its mineral resources to achieve economic recovery and sustainable growth.

Previous studies have shown that mineral resources can be a significant driver of economic growth. For example, African countries with robust mining sectors have seen substantial contributions to their GDPs. Adu and Dramani (2018) emphasize that countries like DR Congo, Guinea, and South Africa have leveraged their mineral resources to achieve notable economic growth.

However, the Nigerian mining sector has lagged due to various challenges, including inadequate information on resource potentials and economic feasibility. Sharaky (2014) notes that Nigeria's mineral wealth is underutilized, and Hoseini et al. (2023) highlight the regional distribution of these resources, emphasizing the need for a more structured approach to their exploitation. Roderick (2001) underscored the potential for sustained economic benefits from mining activities through proper economic development responses. This perspective aligns with the findings of Akongwale et al. (2013), who emphasized the solid mineral sector's significant contribution to Nigeria's economy and its potential to alleviate poverty through job creation. Several studies have shown that Nigeria oil sector has undoubtedly the major contributors to the country’s export earnings. The overdependence in the oil sector however has been without significant improvement in job creation and poverty minimization (Onodugo 2013; Damulak 2017).

Comparative studies by Ayodele et al. (2013) and Olalekan et al. (2016) focused on the economic potential of specific minerals but were limited in scope. This thesis offers a more comprehensive analysis, applying the latest analytical tools, and covering a broader range of minerals in 6 different geopolitical zones of the country. The geological framework of Nigeria, comprising the basement complex, younger granites, and sedimentary basins, underpins the diversity and abundance of its mineral resources within these terrains. The country is endowed with over 44 different minerals dispersed across more than 500 locations, reflecting a significant untapped economic potential.

The review delves into various industrial and metallic minerals, highlighting their occurrences, uses, and economic significance. For instance, minerals like barite, lead-zinc, tin, iron ore, tantalite, and gold are essential to various industrial applications and hold substantial economic value. Gold is not only critical for its use in electronics and dental applications but also as a long-term store of wealth, reflecting global production trends and industrial importance.

This study seeks to bridge this knowledge gap by providing robust information on the economic potential of solid minerals across Nigeria's six geopolitical zones. The goal is to guide the government in making informed decisions that could diversify the economy and reduce poverty. By highlighting the opportunities within the solid mineral sector, this study aims to shift the focus from the over-reliance on crude oil to a more diversified economic strategy that includes mining and mineral exploitation. The study's comprehensive approach aims to provide valuable insights and data to support policymaking and attract investment, ultimately contributing to Nigeria's economic recovery and sustainable development.

II. REVIEW OF THE RELATED LITERATURE

A. Lithium

Innovative ideas and new technology lead to new methods of generating and using resources, including energy and materials. The abrupt switch from fuel-powered to electric vehicles is a testament to human evolution and the need to protect the environment by lowering carbon emissions into the atmosphere, which is the main factor behind the need for eco-friendly systems and applications (Talens Peiro et al. (2013). The scope and desire of the world to switching to eco-friendly source of energy was well documented and the contribution of lithium in achieving this aim can never be over-emphasized (Huang et al. 2022). A recent review has identified about 395 articles on lithium related topics which entails occurrence, exploration, exploitation and contribution to the world economy (Agusdinata et al. 2018).

B. Tantalite

Tantalite is a valuable mineral resource found in various regions of Nigeria, including Cross River State, Ekiti State, Kogi State, Kwara State, and Nasarawa State (Figure 1). Historical records indicate that the recovery of tantalite in Nigeria began in the 1940s as a by-product of cassiterite mining (Miller, 1959; Saint Simon de, 1999). Over the years, substantial quantities of tantalite have been identified, notably within granitic rocks containing about 0.26% Nb_2O_5 in Urania pyrochlore and pegmatite belts of Nigeria (Chukwu and Obiora, 2021). This mineral composition includes significant percentages of uranium (3.1% U_3O_8), thorium (3.3% ThO_2), niobium (37.5% Nb_2O_5), and tantalum (3.5% Ta_2O_5). Tantalite is essential for manufacturing capacitors, which are crucial components in electronic devices like cell phones and laptops. Nigeria is recognized as the 7th largest producer and exporter of tantalum globally, producing over 25 metric tons of tantalum in 2004 (Cunningham 2005).

C. Kaolin

Kaolin is a type of clay derived from the weathering of naturally occurring hydrated aluminum silicates. The term encompasses both raw clay and its refined commercial products (Bloodworth et al. 1993). Kaolin is chemically inert and can be processed into a fine white powder, valued for its brightness and whiteness. This makes it ideal for applications in ceramics, paper, paint, cosmetics, medicine, and agrochemicals. Kaolin deposits are widespread in Nigeria, particularly in the southwestern part of the country (Jones and Hockey 1964), with additional deposits reported in states like Akwa Ibom, Anambra, Bauchi, and Bayelsa (Elueze 1983; Enu and Adegoke 1986). The demand for kaolin in various industries, especially papermaking, is significant, with Nigerian reserves estimated to be in the billions of tonnes (RMRDC 2003).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

D. Mica

Mica is another important silicate mineral found in states such as Ekiti, Kogi, Kwara, Nasarawa, and Oyo (Figure 1). It has various industrial applications, including electrical insulation, paints, cosmetics, and fillers in plastics and rubber.

E. Other Minerals

Nigeria is also rich in other minerals such as gold, diamonds, uranium, talc etc. which are distributed across different states. The mineral map of Nigeria (Figure 1) illustrates the geographical spread of these resources. Additionally, there are numerous other untapped mineral resources in Nigeria, including iron ores, bauxite, industrial minerals and rocks, gemstones, and rare earths (Taylor et al. 2005). However, the primary focus of both government and private sector efforts has historically been on the oil and gas sector, leading to peripheral exploitation of these other mineral resources.

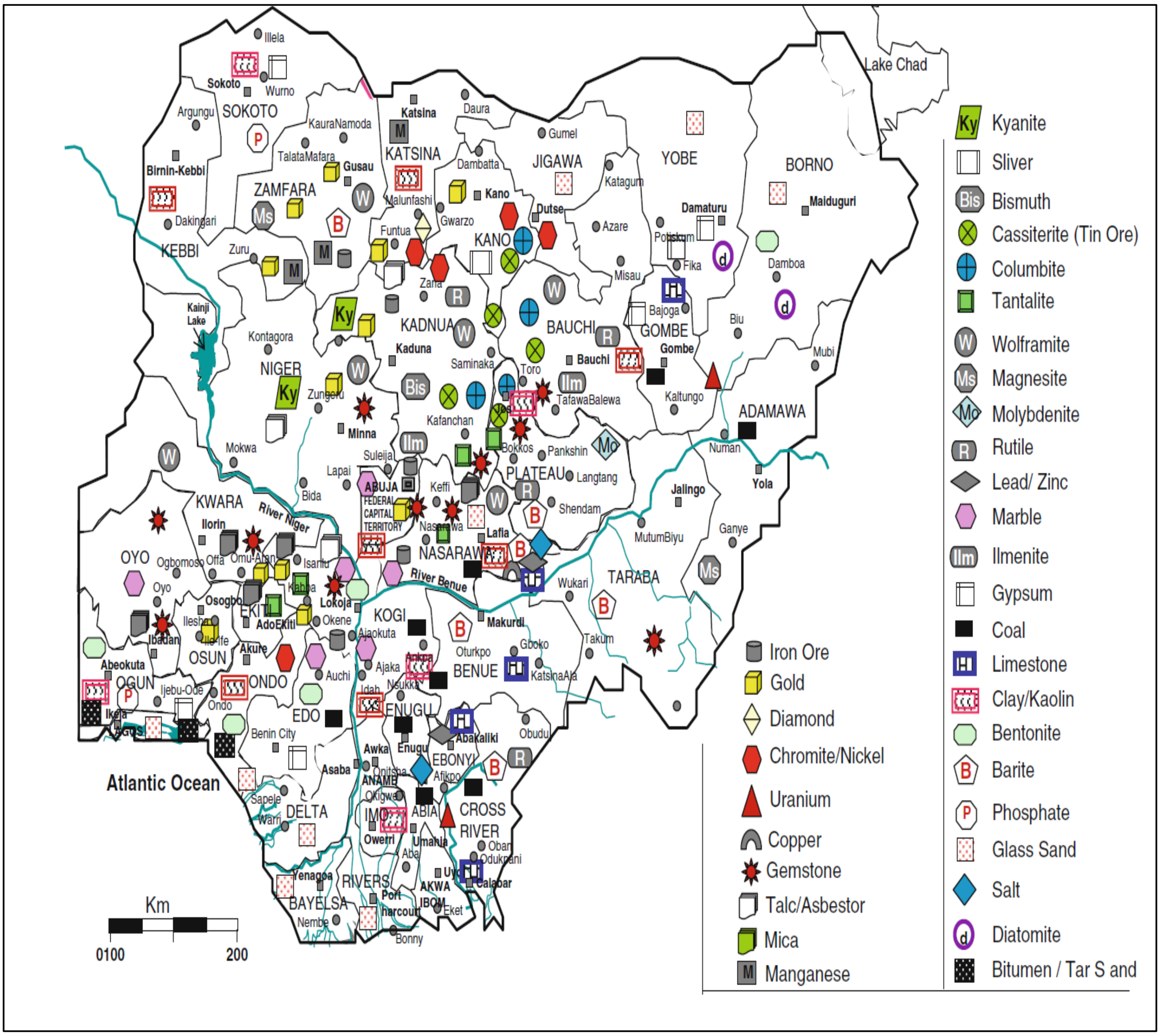

Fig 1: Map of Nigeria Showing Mineral Occurrences (Nigeria Geological Survey Agency 2004)

F. Location and Geology of the Study Area

Nigeria approximately lies between latitudes 4°N and 15°N and Longitudes 3°E and 14°E. Geologically (Figure 2), Nigeria is made of three major litho-petrological components which are basement, Younger granites and sedimentary basin. The basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo cratons (Figure 2) and south of the Taureg shield (Black 1980). It is intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by cretaceous and younger sediments. The 600 Ma Pan-African orogeny had an impact

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

on the Nigerian basement, which is in the reactivated zone created by plate collision between the active Pharusian continental margin and the passive continental margin of the West African craton (Burke and Dewey 1972; Dada 2006). It is thought that at least four major orogenic cycles of deformation, metamorphism, and remobilization correspond to the formation of the basement rocks. These are the Liberian orogeny (2,700 Ma), the Eburnean orogeny (2,000 Ma), the Kibaran orogeny (1,100 Ma) and Pan-African cycles (600 Ma) (Dada 2006). Intense deformation and isoclinal folding were seen during the first three cycles, along with regional metamorphism and widespread migration. Syntectonic granites and homogenous gneisses were created because of the Pan-African deformation, which was also followed by regional metamorphism, migmatization, and significant granitization and gneissification (Abaa 1983). Late tectonic emplacement of granites and granodiorites and related contact metamorphism accompanied the closing phases of this last deformation. Faulting and fracture indicated the end of the orogeny (Gandu et al. 1986; Olayinka 1992).

There are four major petro-lithological units within the basement complex which are the Migmatite–Gneiss Complex (MGC), the Schist Belt (Metasedimentary and Metavolcanic rocks), the Older Granites (Pan African granitoids) and undeformed Acid and Basic Dykes.

Due to the scarcity of naturally corroborating information regarding the physico-chemical conditions of the Earth during that epoch, discussions regarding the Precambrian geodynamic history typically result in dispute (Kohanpour et al. 2017). As noted by Hubbard 1975, many studies on the evolution of the Nigerian Basement Complex have been grossly and generally subjected to individual opinion and biases. With such development, the information about the basement rocks. A major contributing factor to these arbitrary decisions has been the dearth of trustworthy information regarding basement rocks (Hubbard 1975).

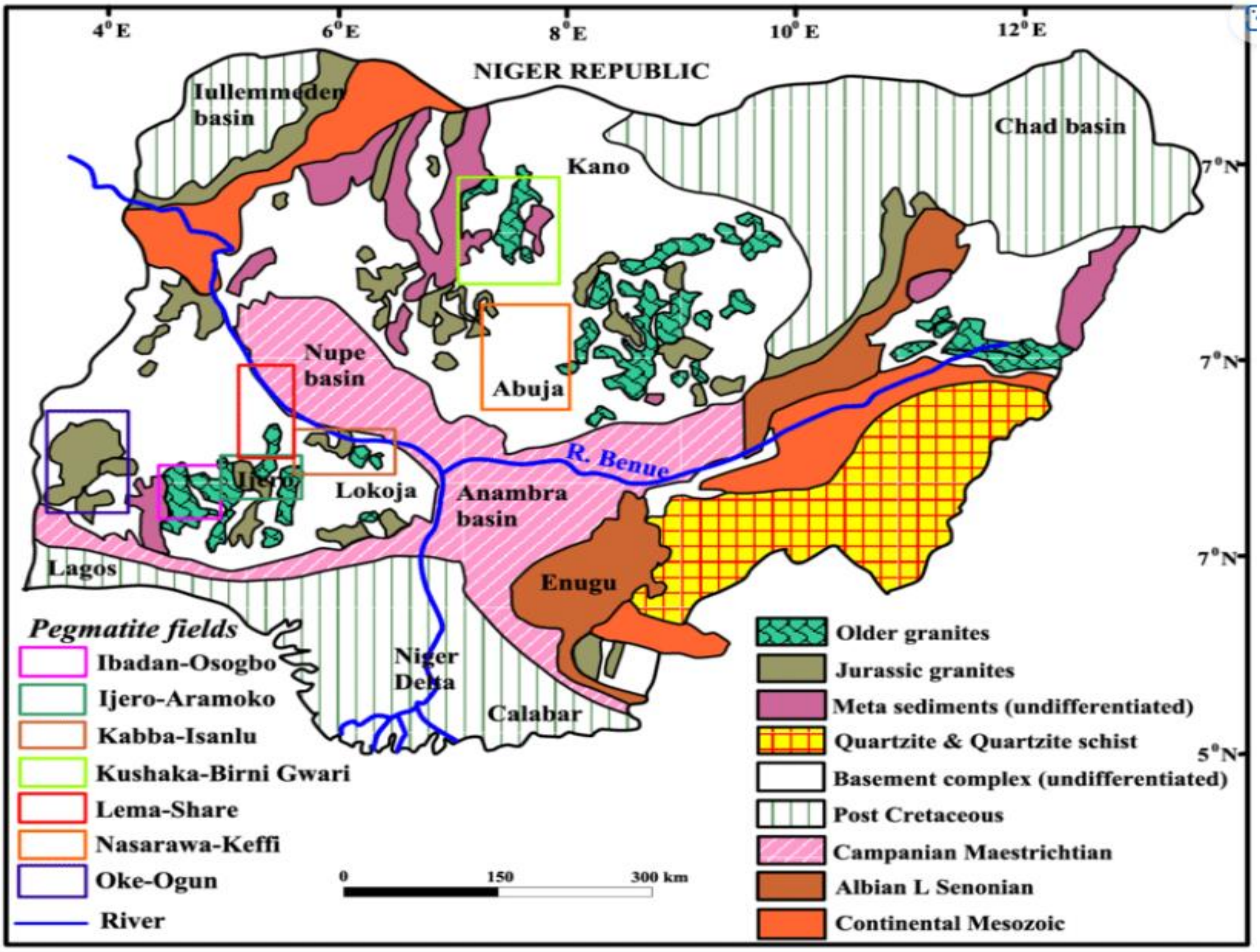

Fig 2: Simplified Map of the Geology of Nigeria, Redrawn after Okunlola, (2005). Colored-Edge Boxes Indicate the Metallogeny of the Rare-Metal Pegmatites of Nigeria

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

G. *Objectives and Research Questions*

The specific objectives of the study are to identify solid minerals available in different geopolitical zones of the federation; estimate the quantity of the selected solid minerals identified in the geopolitical zones; assess the economic potentials of the available minerals; and develop models for management of resources and reserves of mines.

III. METHODOLOGY

A. *Data Collection*

To obtain the imageries, four or more coordinates were obtained from the image location to form a polygon and USGS earth explorer software was set up by aligning the features to world feature, then the coordinates were added on the use map parameters. From the USGS earth explorer, the data set was aligned to Unmanned Aerial Survey (UAS) under which the orthogonal view was picked. The footprint and cloud point were set at 50 %. After the data set was concluded, the results were display showing the image, it size, source, sensor used, date captured among others.

The minerals available in different parts of the country were identified via literature reviews where relevant literature was carefully studied. With over 44 minerals scattered within the country in different locations, the selected minerals were based on the suggestion of Lar et al. 2015 that the suitable minerals are those of active mines within the country. Likewise, the method of data collection adopted in this research involves a combination of data collected from United Geological Surveys (https://www.usgs.gov/centers) and those obtained from International Trade Centre website that span a period of 10 years for the purpose of this study. The obtained historical data on the selected minerals involving minerals production, export and import from Nigeria, a 10-year forecasts were made to the year 2033/4 to predict the apparent selected minerals consumption, import reliance and self-sufficiency indicator. Also, the internal rate of return (IRR) and net present value (NPV), which are key economic indicators, were also computed for the selected minerals. The following relations were also used:

- Apparent consumption = Production + import – export (1)
- $NIR = \frac{Ex-Im}{\text{Pr}+Im-Ex}, Ex > Im$ (2)
- $NIR = \frac{Im-Ex}{\text{Pr}+Im-Ex}, Ex < Im$ (3)
- $SsI = 1 - NIR$ (4)

Where Ex is the export, Im is the import and Pr is the production while NIR is the net import reliance and Ssl is the self-sufficiency indicator.

B. *Data Analysis*

The cash flow was generated for assessing the profitability of the selected minerals in Nigeria using the parameters like yearly production, tax, royalty among others based on the assumptions that the prices of the minerals are in dollar, no allowance is given to sudden increase in cost and price, the price of the minerals are constant, and the ore dilution and loss are unaccounted for. The economic model parameters used are actual actual production in tonnes, activity-based per tonne, operating cost, gross revenue which is a product of tonnage of ore production, grade of ore and the unit price of the selected minerals, royalty. Total operating cost, net income before tax, taxable income, net income and after-tax cash flow which is given as the summation of cash inflow minus the cash outflow. The resulting net present value (NPV), internal rate of returns (IRR), and the payback period (PBP) are the indicators of profit adopted in this study.

C. *Net Present Value (NPV)*

The NPV of a project is defined as the sum of present values of individual cash flows over the project period. According to Remer and Nieto (1995), Torres 1998, Lin and Nagalingam 2000 and Hanafizadeh and Latif (2011), the NPV is an important tool in discounted cash flow (DCF) analysis and is essential for considering time value of money in long-term project evaluation. The NPV can be computed using Equation (5) (Jovanovic, 1999)

$$NPV = \sum_{i=1}^{n} \frac{(R_i - C_i)}{(1+i)^t} \quad (5)$$

Where R_i and C_i are the respective revenues and costs at time t, while I is the discount rate and n is the life time of the project. For the project to be acceptable, NPV must be greater than or equal to zero and if otherwise that is below zero, the project is unacceptable.

D. *Internal Rate of Return (IRR)*

The internal rate of return, otherwise known as the rate of return or discounted cashflow rate of return measures the profitability of an investment. The IRR is the value of *I* in Equation (4) when NPV is zero.

$$NPV = \sum_{i=1}^{n} \frac{(R_i - C_i)}{(1+i)^t} = 0 \quad (6)$$

IRR provides a measure of the expected annual rate of growth to be generated from an investment. The higher the IRR on an investment, the better, and it is uniform across various types of investment opportunities *(*Belhaj 2023). A popular use of IRR is for comparing new investment opportunities with already existing ones within the company. The IRR has some disadvantages which limit its applicability, but it is still adopted in this study to assess the profitability of the selected minerals.

E. *Payback Period (PBP)*

It is the time needed for the net cash flow from the project to payback the invested money considering the time value of money. The shorter the payback period the better the attractiveness of the project. If the PBP is too long, the project may not be worth investing in.

F. *Development of ANN Model for Predicting Profitability Index*

Artificial neural network is a branch of artificial intelligence based on the principle of the functionality of the human being. ANN is employed in this study to predict the net present value and IRR of the project using the prices of the selected minerals and the discount rates as the input parameters for developing the ANN models (Figure 3). The

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

adopted input parameters have been described to be the most effective parameters on the NPV (Smith, 1995; Hustrulid and Kuchta, 1995; Small, 1998; Foster and Tapan, 2003; Saleh and Marais, 2006; Califf et al., 2008; Wiesemann et al., 2010). The revenue forecasting is a crucial part of any economic assessment which can be performed by trend analysis and econometric methods (Hustrulid and Kuchta, 1995; Sayadi et al., 2014). The ANN model is implemented in MATLAB environment. Three layers ANN model is used for each of the minerals with the two hidden layers taken as 1 layer. The number of input neurons is proportional to the model independent variables while the number of neurons in the hidden layer are obtained using trial and error approach (Onifade et al., 2021; Lawal and Kwon, 2023a,b; Lawal et al., 2023a,b) while the number of neurons in the output layer is one for each of the models. The feedforward neural network based on the back propagation training algorithm together with Levenberg-Marquardt training function is used for the training of the ANN models. The transfer functions used are the hyperbolic tangent at the hidden and output layers.

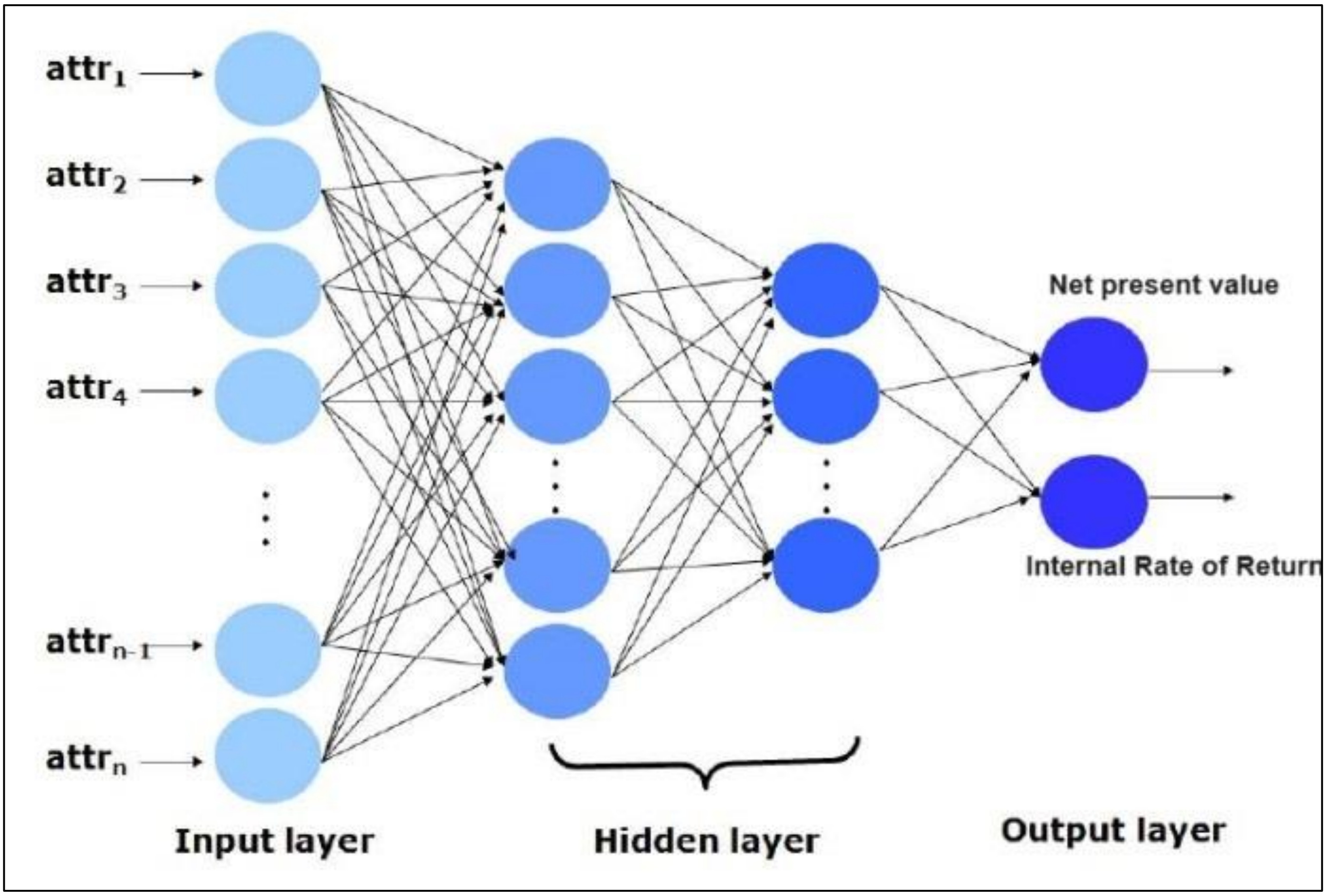

Fig 3: The Structure of Artificial Neural Network. The ANN Model had Two Hidden Layers. The ANN Model for Net Present Value and Internal Rate of Return.

IV. RESULTS AND DISCUSSION

The diverse 44 solid minerals present in the country, a few selected minerals according to their occurrences in the 6 geopolitical zones were considered in this research. In the Southwestern Nigeria, Ibese limestone in Ogun State and lithium from Oke Ogun, Oyo State are chosen. For the North Central, Azara barite in Nasarawa State and Itakpe Iron ore in Kogi State were selected. The Southern region where barite and lead-zinc from Cross River state are selected for the economic evaluations. For the Southeastern region, lead-zinc ore from different locations was selected for the analysis in this study. The lithium from Bauchi and barite from Taraba states in the Northeast are also considered in this research. Finally, for the Northwest, two different minerals which are lithium and iron ore deposits from Kaduna state are considered. The thesis focused mainly on barite, iron ore and limestone due to availability and accessibility of required information. Others can be treated following the same procedures in this thesis. The reserve estimation was conducted for the selected barite, iron ore and limestone using the GIS based approach.

A. Reserve Estimate

Table 1 shows the computed and estimated reserve estimates both from the satellite imagery with GIS-based approach and the literature review approach. The limestone reserve obtained from Ibese, Oyo State is estimated to be 397.59 million tonnes with the company having targeted daily production of 12000 tonnes and working 345 working days/year. The mine life is estimated to be about 60.24 years. The GIS alternative approach through satellite imagery with

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

the field data. It is assumed that 1 pixel of the imagery is equivalent to 0.1m. The thickness used are either gotten from the company, reported previous geophysical surveys or assumed where the two means are not available. The reserve estimate obtained from the GIS-based approach is estimated at 369.96 million tons with life span of about 57.9 years. The years is arrived at using the yearly required limestone of about 6.4 million tons for the cement production.

There is no detailed information about the reserve of lithium deposit in Oyo State and this is valid for most of the lithium deposits in the country. Therefore, a GIS approach is used together with the preliminary borehole data produced by Thor Exploration Ltd. From the published borehole data, the average thickness of 4.1m was used to estimate the reserve for this area as about 6.2 million tonnes with average life span of several hundreds of years.

The two selected deposits in the north central Nigeria are Itakpe iron located in Kogi State and Azari barite deposit in Nasarawa State. These two locations have been subjected to rigorous research from both private individual and government agencies such as Nigeria Geological Survey Agency (NGSA) and Mines Department (Mines Department, 1993; Adebimpe and Akande 2011). The reserve estimate is pegged at about 200 million tonnes with a life span of 27 years (Mines Department 1993, Table 1). The GIS approach gave an estimate of 248.9 million tonnes with estimated life span of 33.89 years (Table 1).

For the Barite deposit in Azara, Nassarawa Satate, the existing estimated ore reserve is about 3.2 million tons as reported by Nigeria Geological Survey Agency (2009). The thickness of the ore used in computing the ore reserve for the GIS is an average of 1.2 m as reported by Abuntori *et al.* (2021). It is a vein deposit. The GIS based approach with the satellite imagery used following the same procedures as presented previously gives an estimated reserve of 4.9 million tons. With the current rate of production as reported by Nigeria Geological Survey Agency (2009) which is an average of 3000 tons per annum, the estimated life span for the deposit is more than 1000 years for both reported reserve and the satellite imagery (Table 1). The production can be increased to more than 10 times the existing artisanal scale level and the resource will still be enough to serve for about 100 years.

For the Barite deposit in Taraba State, the existing estimated ore reserve is about 8.96 million tons as reported by Nigeria Geological Survey Agency (2009). The GIS based approach with satellite imagery gives an estimated reserve of 10.8 million tons. With the assumed current rate of production of an average of 3000 tons per annum as in the case of Nassarawa, the estimated life span for the deposit is more than 1000 years for both reported and the satellite imagery (Table 1). The thickness of the ore used in computing the ore reserve for the GIS is assumed to be 2.7 m since it is also a vein deposit as in the case of Nassarawa (Ebunu et al., 2021). The production can be increased to more than 10 times the existing artisanal scale level and the resource will still be enough to serve for about 100 years. Indicating that the available barite resources can meets the local demand for this mineral.

Barite and lead/zinc ores from the Cross River state are the two ores selected for this zone. For the barite deposit, the reserve of the barite in this area was reported to be about 8.9 million tons according to Nigeria Geological Survey Agency (2009). Using the proposed GIS based approach, with the depth ranging from 1.2 to 4 m as reported by Labe *et al.* (2018), the total ore reserve is about 7.9 million tons (Table 1). With an assumed average yearly production of about 3000 tons/annum reported for the barite deposit in Nassarawa State by Nigeria Geological Survey Agency (2009), the estimated life span is more than 2000 years. Again, the deposit can serve for several years if this yearly assumed production target is increased several thousand tons.

For the lead/zinc deposit from this same Cross River state, the obtained reserve using the GIS approach is about 133 million tons using 19 m thickness obtained from Onunkwo and Nwachukwu (2005) for Ebonyi State but the report of the existing ore reserve for this location has not been reported. This is supported by Mallo (2012) where it was stated that the lead/zinc reserve estimation of this location has not be reported. The lead-zinc ore from Ebonyi State was selected from Enyigba I Ivo LGA. The thickness of 19 m reported by Onunkwo and Nwachukwu (2005) was also used for this location. The obtained reserve is also about 133 million tons with this thickness. The reserve of this location was reported by Obassi *et al.* (2015) to be about 100 million tons for lead and 0.8-million-ton for zinc. The Jawara iron ore from Kaduna State was selected for northwest zone. The inferred quantity of the ore is about 20 million tons according to Ministry of Mines and Steel Development. The GIS based approach adopted assuming 10 m thickness estimated the reserve to be about 32.7 million tons.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

Table 1: Summary of the Reserve Estimates of the Deposits from Both Reviewed Literature and GIS Approach

S/N	Mineral deposit	Geopolitical zone	Location	Reserve estimate (million tonne)		Life span (years)	
				Obtained from the company and others	*Obtained from GIS*	*Obtained from the company*	*Obtained from GIS*
1	Limestone	South-west	Ibese, Oyo State	397.59	369.96	60.24	57.9
2	Iron ore	North-central	Itakpe, Kogi State	200.00*	248.90	27.00	33.89
3	Barite		Azara, Nasarawa State	3.2*	4.9	1081	1665
4	Barite	Northeast	Taraba State	8.96*	10.8	1081	1665
5	Barite	Southeast	Cross River State	8.9*	7.9	Hundreds of years	Hundreds of years
6	Lead Zinc	Southeast	Cross River State	133.0**		Hundreds of years	Hundreds of years
7	Lead Zinc	South-South	Enyigba, Ebonyi State	100.0 for Lead and 0.8 for zinc***		Hundreds of years	Hundreds of years
8	Iron ore	Northwest	Jaruwa, Kaduna State	32.7	32.7	Hundreds of years	Hundreds of years

* Nigeria Geological Survey Agency (2009) and Mines Department (1993)
** Onunkwo and Nwachukwu (2012); Mallo (2012); *** Obassi et al., 2015

B. Mineral Sustainability Assessment

The data obtained from the USGS was used in assessing the apparent consumption based on Equation (1). The equation requires the computation of the quantity of the mineral exports in this case barite was used as example. The data obtained from the USGS was from 2017 to 2021 but the future forecast was done using the moving average technique which made the years to be extended till 2033. The obtained data tagged actual and the forecasted data are plotted for the production, export, import and apparent consumption as shown in Figures 4.1 to 4.6 It can be observed that the yearly barite production of Nigeria is very small and cannot cater for the consumption as the apparent consumption is high and the importation also is very high as compared with the export despite the huge deposit of barite available in Nigeria. This trend is like other natural resources in Nigeria.

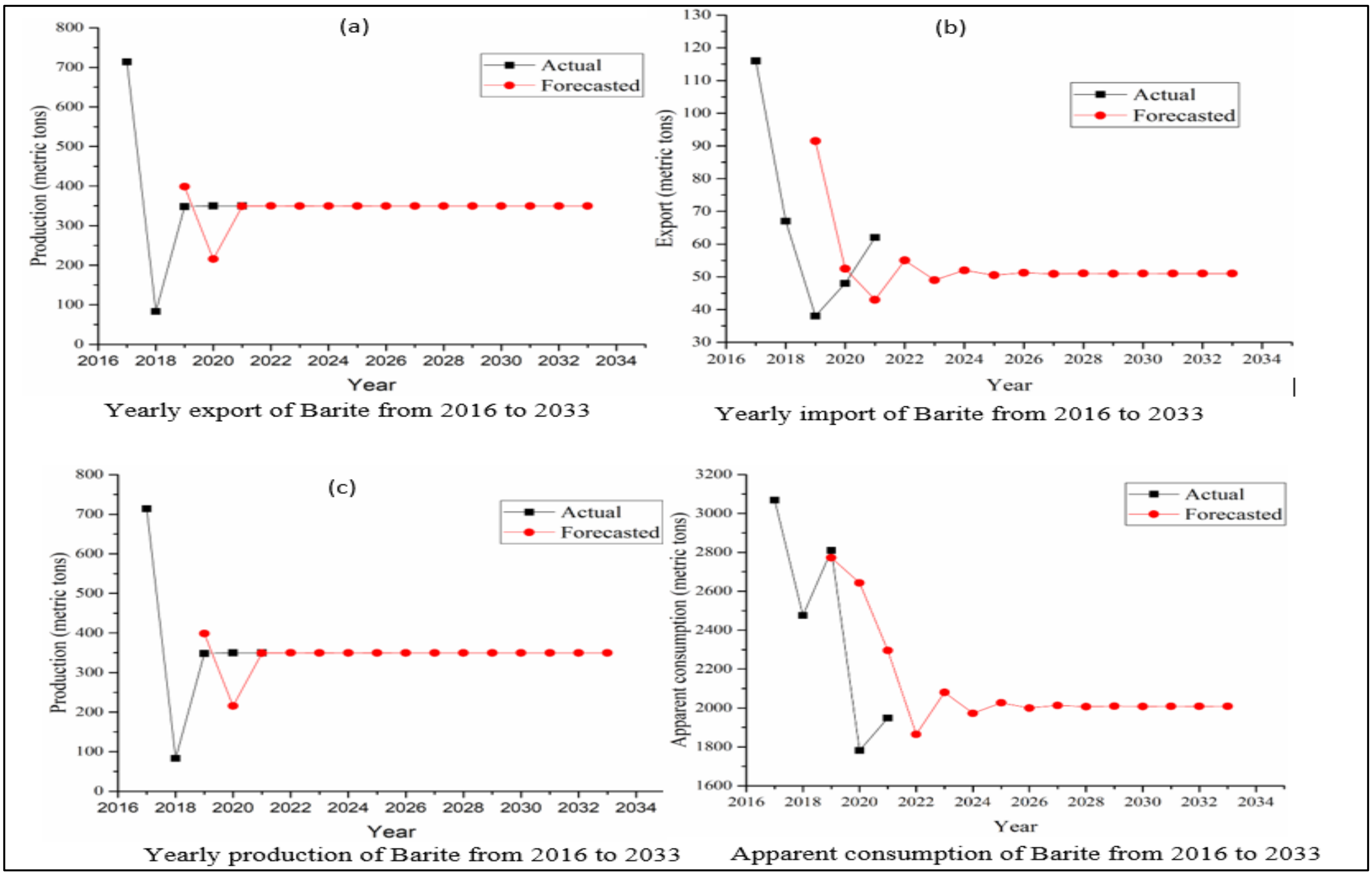

Fig 4: Sustainability Assessment of Barite (a) Export, (b) Import, (c) Production and (d) Apparent Consumption

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

C. Import Reliance and Self-Sufficiency Evaluation

The import reliance and self-sufficiency of the barite production in Nigeria is assessed using the actual and forecasted values. The outcome of the evaluations presented in Figures 4.5 and 4.6 show that the Nigeria is not self-sufficient in their mineral commodity production and still rely on the importation as there is nowhere the self-reliance index is equal to zero. This analysis implies that Nigeria is under exploiting his mineral resources which makes it depend on the importation of the already available minerals in the country.

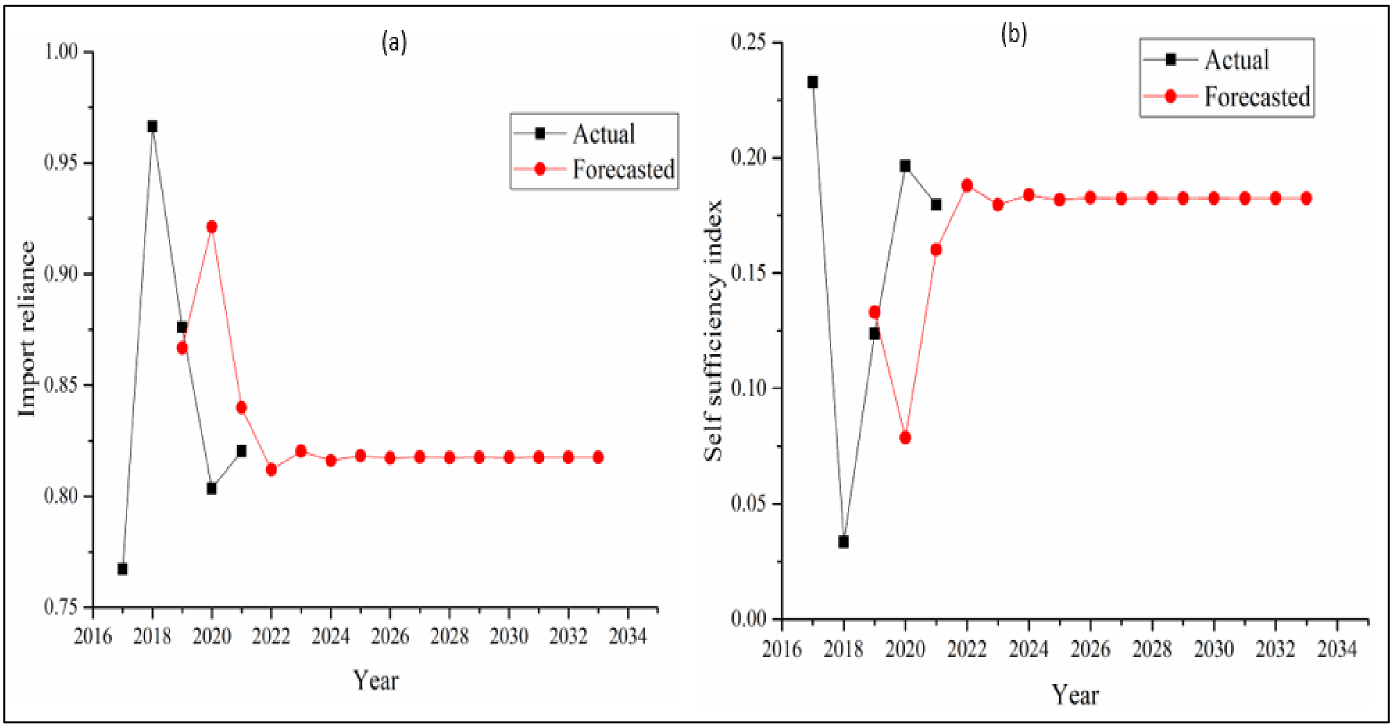

Fig 5: Plot of Actual vs Forecasted for (a) Import Reliance and (b) Self-Sufficiency Index

D. Economic Feasibility

The feasibility of profitable exploitation of the minerals analysed in this thesis is assessed using different economic indicators like NPV, IRR and PBP as presented below.

E. Net Present Value of Ibese Limestone

To compute the economic feasibility of the limestone deposit in Ibese operated by Dangote Cement Company, the data about the deposit was obtained for the purpose of this study. The capital cost and production cost are obtained as 59.66 million USD and 17.2 million USD respectively. Based on this information, the analysis is made for the next 20 years even though the deposit can serve the company for more than 60 years (Table 1). The price of one ton of limestone is assumed to be about 12 USD as obtained from the local selling price information. This price is reasonable as the cost of producing a ton of limestone as estimated by the company is below 4 USD. Using all these parameters, the obtained IRR is 92% while the NPV is about 125.85 million USD. Since the IRR is greater than the discount rate of 10% and the NPV is positive, the project is viable with the payback period of 2 years (Table 2). The analysis is reasonable as the company reported the profit after few years of establishing it.

For the economic analysis of this deposit, the reported annual lithium production of 50 tons by The Conversation (2022) was used. The capital and operational expenditures are assumed to be that of typical small-scale mining/artisanal mining of barite with about 3.06 million USD capital expenditure and 0.018 million USD operation cost. Using these parameters, the NPV is 8.14 million US$ while IRR is 83% this with payback period of 2.2 years. It should be noted that the economic model is not repeated for the Bauchi and other lithium locations selected in this study as their annual production target including the capital and operating cost cannot be confirmed. Therefore, the assumption used for this location with preliminary borehole information is applicable to those lithium locations as well.

Table 2: Table Showing the Economic Indicators

Indicators	Values
IRR @ 10% royalty rate	92%
IRR @ 5% royalty rate	111%
NPV @ 10% royalty rate	125.85 million USD
NPV @ 5% royalty rate	139.81 million USD

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

F. NPV of Selected Locations in North Central

➢ *Itakpe Iron ore Deposit*

To compute the economic feasibility of the iron ore deposit in Itakpe operated by the National Iron Ore Mining Project (NIOMP), the data about the deposit was obtained from existing studies such as Adebimpe and Akande (2011) and Nwosu et al. (2022). The capital cost and production cost are 268 million USD and 28.87 million UDS respectively. Based on these data, the analysis is made for the next 20 years even though the deposit can serve the company for more years, but this is close to the predicted 27 years life span supported by Adebimpe and Akande (2011). The price of one ton of iron ore is taken to be varying from 115 USD per ton to 124 USD as obtained from the prevailing price over the years. Thereafter, forecast was made for the projected years using the moving average method and the forecast command in the Microsoft Excel software. The fiscal terms and values adopted in our analysis are royalty at 40%, income tax at 20%, discount at 10% and tax relief period at 3 years (Nwosu et al., 2022). Using all these parameters, the obtained IRR is 49% while the NPV is about 314.44 million USD. Since the IRR is greater than the discount rate of 10% and the NPV is positive, the project is viable with the payback period of 3 years. The previous studies by Adebimpe and Akande (2011) and that of Nwosu *et al*. (2022) also predicted positive NPV and IRR greater than the discount rate for this location though their projected years are minimal. Since this company is run by the government, to achieve the profit projected by this analysis, the government must be proactive through proper monitoring to prevent excess leakages in the finance of the company.

➢ *Azara Barite Deposit Nasarrawa State*

The information about the capital cost and production cost are 3.063 million USD and 0.018 million USD respectively (Infomine Inc., 2018). Based on these data, the analysis is made for the next 20 years even though the deposit can serve the company for several years based on the previous computation presented earlier. The price of one ton of barite is taken to vary from 174 USD per ton to 182 USD as obtained from the USGS. Thereafter, forecasts were made for the projected years using the moving average method and the forecast command in the Microsoft Excel software. The fiscal terms and values adopted in our analysis are royalty at 40%, income tax at 20%, discount at 10% and tax relief period at 3 years (Nwosu et al., 2022). Using all these parameters, the obtained IRR at 40% royalty rate is 20% while the NPV at 10% royalty is about 1.616 million USD. Since the IRR is greater than the discount rate of 10% and the NPV is positive, the project is also viable with the payback period of about 6 years. The yearly production is still very low which is not even enough to cater for the demand of barite in Nigeria. The payback period could be minimized if the annual production is improved though this will affect the operational expenditure.

G. NPV of Selected Locations in Northwest

The two locations selected from Northwest are the iron ore deposit in Kaduna and lithium ore deposit. While the issue of lithium in term of economic model has been addressed under the Southwest lithium deposit, the detail information about the iron ore deposit is presented. Using similar parameters as in the case of Itakpe iron ore but different production target, the obtained IRR at 40% royalty is about 30% while the NPV at 10% royalty is 186.5 million USD. The payback period is about 4 years. The project is also viable as in the case of Itakpe Iron ore from the economic model point of view.

Hence, the deposit in southeast and southsouth were also subjected to economic analysis and the analysis revealed that the IRR and NPV are positive though the output of the analysis is not reported here to minimize the number of spread sheet tables in the study. This is reasonable as the current barite production cannot meet the local demand not to talk of exporting. The self-sufficient analysis earlier conducted has confirmed that we can are yet to be sufficient in barite mineral production.

H. Effect of Discount Rate on the NPV

The effects of variations in the discount rate on the NPV value were investigated using the used in the computation of economic models. This was done using the Nasarrawa barite, Itakpe iron ore and Ibese limestone as representatives. The representation is necessary since the intention is to study the trend of variations in the NPV as the discount rate grows and the selected locations have detailed information more than any other locations considered in this study. If the pattern of the three graphs is similar, it is an indication that all other locations irrespective of the mineral types will have similar trends. In each of the cases, the capital expenditure used in obtaining the NPV presented in the economic model analysis were used. The obtained results of the variations are shown in Figures 6. It can be observed from the 6 that the NPV values decrease with increase in the discount rate. The discount rate of maximum of 10% is sustainable for all the projects. The discount rate can be increased when the selling price of the commodities increases. Hence, the increase or decrease in the discount rate should be a function of the market price of the commodity. The obtained trends agree with that of Sayadi *et al*. (2014).

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

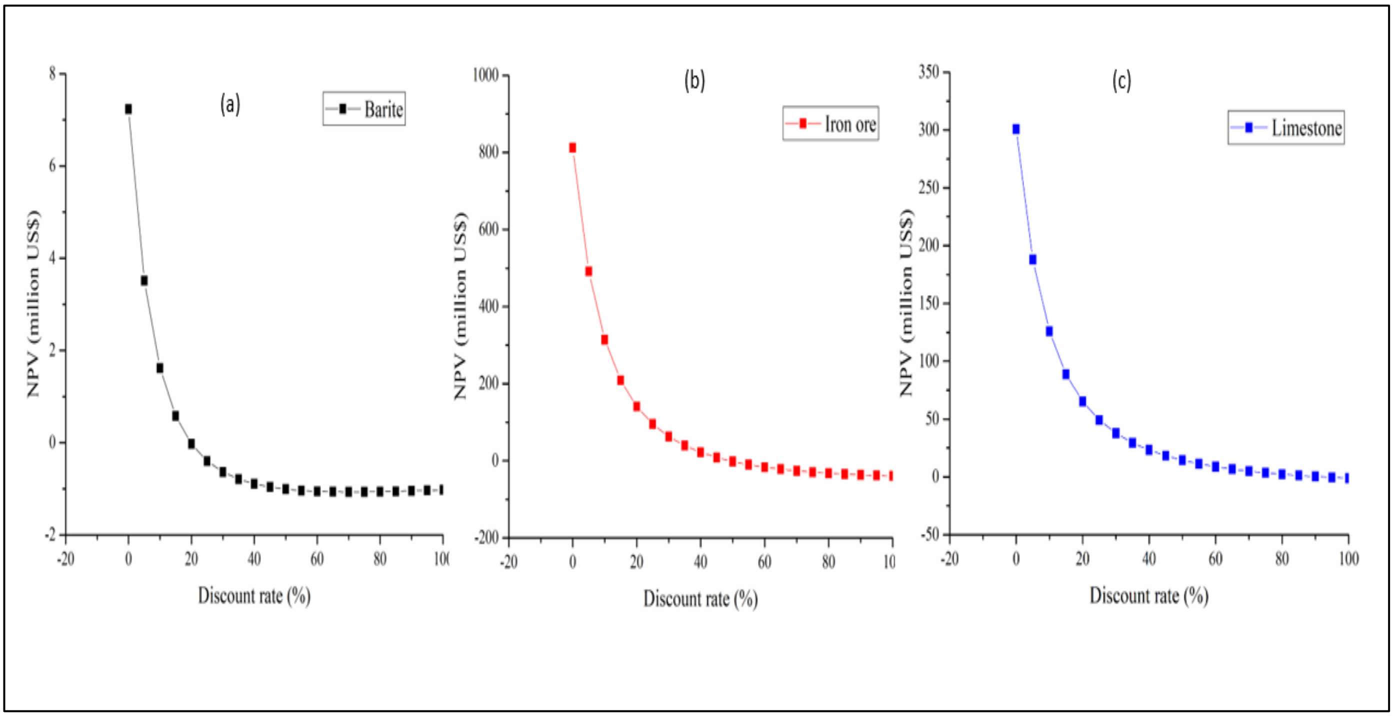

Fig 6: Effect of diacount rate on NPV for (a) barite and (b) iron ore and (c) Limestone

V. MODEL DEVELOPMENT

The descriptive statistics of the datasets was assessed, and the mean value of price is 193.4 US$ while that of discount rate is 50% and that of NPV is 29.74 million US$. The Minimum price is around 55.85 US$ while the maximum price is 406 US$. The minimum discount rate is 0% while maximum discount rate is 100%. For the NPV, the minimum value is -34.0202 million US$ while its maximum value is about 489.633 million US$ implying that the project could either be profitable or not profitable (Table 3). There is also a possibility for the marginal NPV at the transition from positive NPV to negative value. The standard deviation reveals that there is a big deviation in prices than the other two model parameters. There is generally very weak correlation between the prices and the discount rate and the NPV though the correlation between price and NPV is positive and slightly better than that between price and discount rate (Figure 7). The NPV has negative correction with the discount rate though strong. All these information about the data indicates that the parameters are complex and should be modelled using artificial intelligence method that could capture the heterogeneity between the model parameters.

Table 3: Descriptive Statistics

	N	Mean	SD	Sum	Min	Max
Price (US$)	189	50	30.35692	9450	0	100
Discount (%)	189	134.2011	51.47048	25364.01	12	181.53
NPV (million US$)	189	48.14609	157.1731	9099.61	-51.1266	1036.022

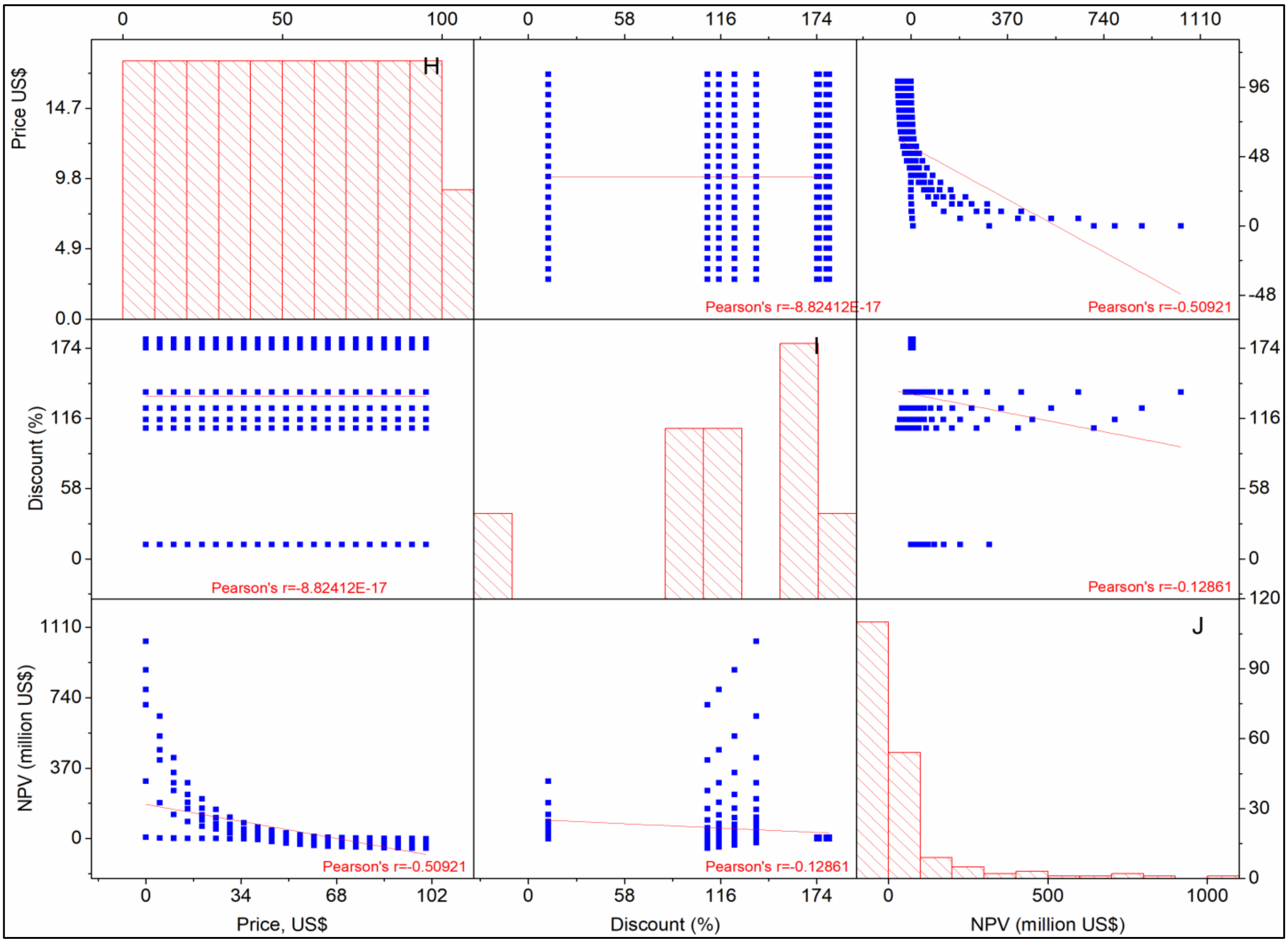

Fig 7: Correlation between the Model Variables

A. Artificial Neural Network Model

The ANN model was developed for the prediction of the net present value based on the discount rate and the price variations. ANN is a class of artificial intelligence which function in relation to the functionality of human brain. It takes in information learn it and relay the output. Because of its performance, it has been used in solving various engineering related problems including mining engineering. In fact, it has been used for the prediction of NPV of Gold and Silver in Iran by Sayadi et al. (2014) and it is also adopted in this study because it has not been used for the prediction of NPV of barite and iron ore. To develop the model, MATLAB software was used. The feed forward back propagation ANN is adopted. The back propagation training algorithm with Levemberg-Marquardt training function was used in this study. The number of neurons at the input layer is two while at the intermediate layer varies between 2 to 7 and that of the output layer is 1. The performance of the model after each iteration was evaluated using coefficient of correlation and mean square error. About 336 datasets were generated and fed into the model. The data was randomly divided into training (70%), testing (15%) and validation (15%) datasets. The simulated ANN model is with respect to the number of hidden neurons and the training process of the optimum ANN network with their performances are presented in Table 4. The R value of the 2-7-15-1 network is close to 1 and the performance curve also revealed similar trend for the training, testing and validation indicating that the model is successful (Figure 9) (Lawal et al. 2021a). The weights and biases of the selected optimum network is also presented in Table 6 which was transformed into the mathematical form that can be used in future NPV prediction. This is novel as such ANN based NPV equation is not available in the literature.

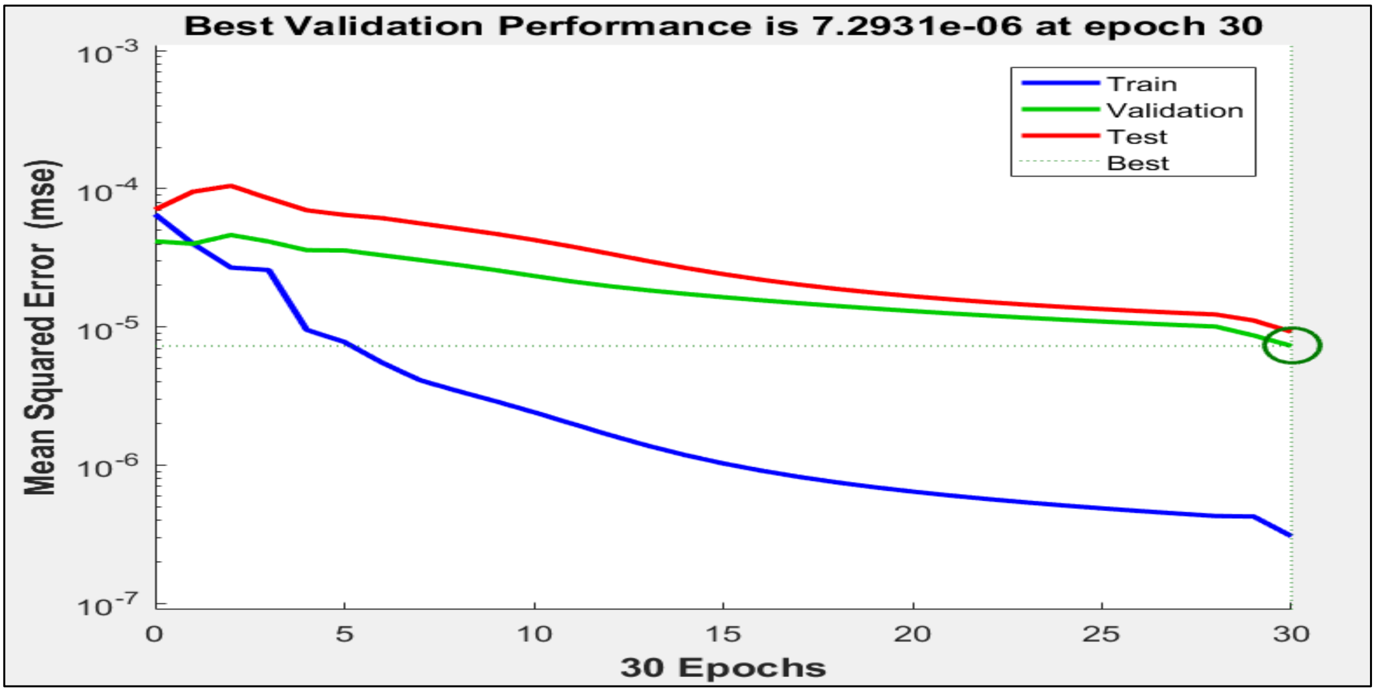

Fig 8: Best Validation Performance

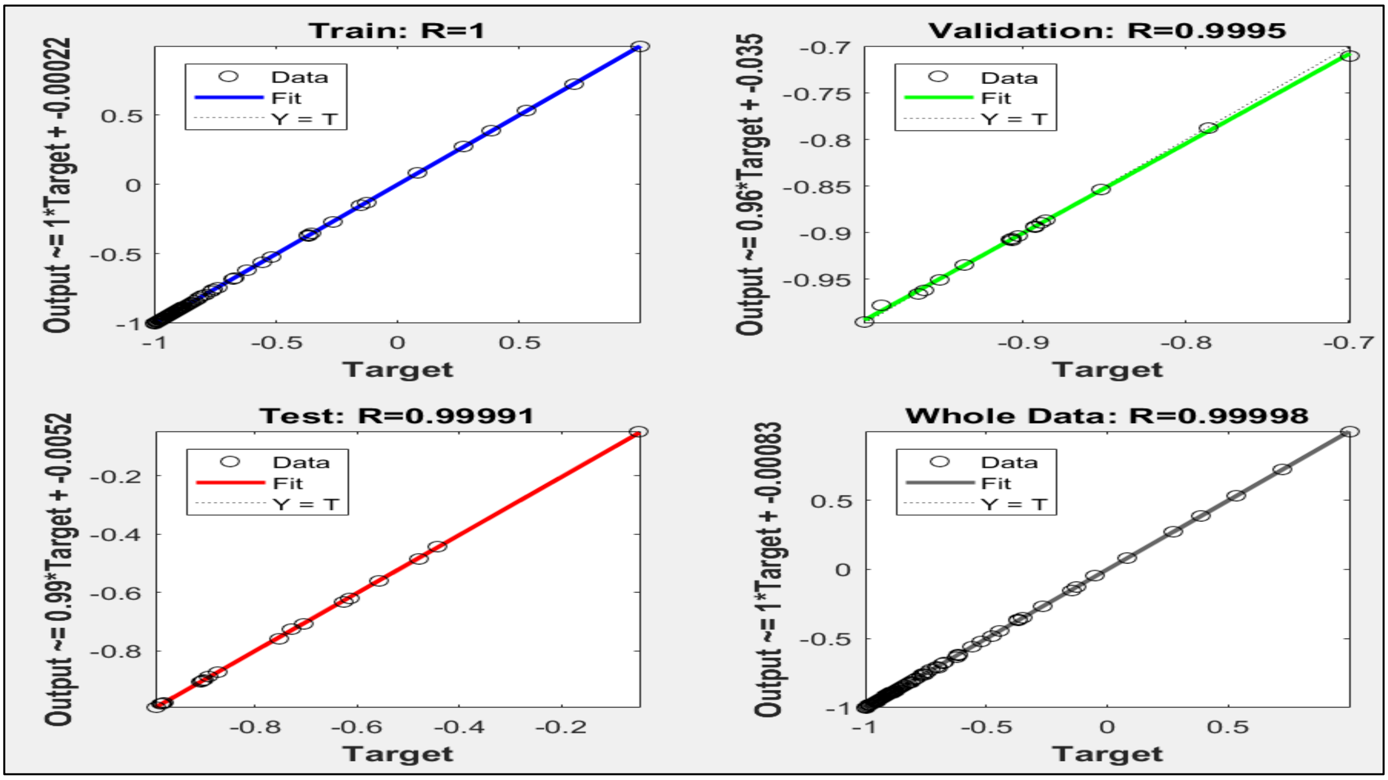

Fig 9: Obtained ANN Result

Table 4: Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	30	30
Elapsed Time	-	00:00:00	-
Performance	6.54e-05	3.06e-07	0
Gradient	0.00445	0.000483	1e-07
Mu	0.001	1e-07	1e+10
Validation Checks	0	30	30

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

B. Model Performance Evaluation

The proposed ANN based model for predicting the NPV of selected deposits is subjected to performance evaluations using key statistical performance indicators such as coefficient of determination, root mean square error, and mean absolute error as presented in Equations (7) to (8). The outcome of this evaluation is presented in Table 5. It can be seen from the Table 5 that for the training phase, the R^2, RMSE and MAE values are 0.9922, 4.8833, and 1.837. while for the testing phase, they are 0.9999, 1.605 and 1.266. For the validation case, the R^2, RMSE and MAE values are 0.9999, 1.957 and 1.457. The results of the statistical indicators for the three phases which are training, testing and validation are close to the actual values as the R^2 value is close to 1 while RMSE and MAE are small.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(\Delta_{meas} - \Delta_{pred})^2}{\sum_{i=1}^{n}(\Delta_{meas} - \bar{\Delta}_{meas})^2} \quad (7)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\Delta_{meas} - \Delta_{pred})^2}{n}} \quad (8)$$

$$MAE = \frac{\sum_{i=1}^{n} abs(\Delta_{meas} - \Delta_{pred})}{n} \quad (9)$$

Table 5: Model Performance Evaluation

	R^2	RMSE	MAE
Training	0.9922	4.883324	1.837378
Testing	0.9999	1.605416	1.266306
Validation	0.9999	1.957052	1.456748

C. Formulation of ANN based NPV

The extracted weights and biases from the developed ANN model for predicting the NPV using price and discount as the independent variables are presented in Table 5. Using Table 5, the obtained equation is as presented in Equation (10). The procedures adopted in developing this ANN based mathematical model agree with Lawal *et al.* (2021b)

$$NPV = 543.57443[tanh(\textstyle\sum_{i=1}^{n} Y_i - 0.520496093677691)] + 492.44788 \quad (10)$$

Where Y_1 to Y_{15} can be computed using Table 5 as demonstrated are in Equations (10) while the x1 to x7 in Equation (10) can also be derived using Table 4.14 as presented in Equations (12) to (12).

$$Y_1 = -0.54326819926 tanh(0.765722444x_1 - 1.33251878772x_2 - 0.7915063157271x_3 - 0.415409642051483x_4 + 0.455448971193x_5 + 0.265024657451x_6 - 0.88036595347x_7 - 2.45032127) \quad (11)$$

$$x_1 = tanh(3.2239267266Pr + 0.4269328279Dc - 4.0528532) \quad (12)$$

$$x_2 = tanh(0.803715Pr - 6.17083185Dc - 3.62001237) \quad (13)$$

$$x_3 = tanh((-2.102684235Pr + 2.564628929Dc + 1.298057541) \quad (14)$$

$$x_4 = tanh(2.42414135Pr - 2.51288149Dc - 0.11405290183) \quad (15)$$

$$x_5 = tanh(2.065682Pr - 3.6481559Dc - 0.338248798) \quad (16)$$

$$x_6 = tanh(-2.52454223\mathrm{Pr} + 3.1670509133021Dc - 2.380861695) \quad (17)$$

$$x_7 = tanh(-3.1512592Pr - 0.70346113Dc - 3.082020797) \quad (18)$$

Table 6: Extracted Weight and Bias

W_1	W_2								W_3	b_1	b_2	b_3
540.2344	781.8284	0.765722	-1.33252	-0.79151	-0.41541	0.455449	0.265025	-0.88037	-0.54327	-4.05285	-2.45032	-0.5205
625.1009	886.445	-0.94463	0.881045	-0.19001	0.902363	-0.63591	-1.14683	-0.10736	0.007543	-3.62001	1.607318	
746.1648	1035.79	-0.85116	-0.00376	0.144143	-1.28528	-0.47542	-0.38487	-0.53752	0.683346	1.298058	1.671418	
475.7481	702.3098	1.823671	-0.50699	0.156411	0.435354	-0.64054	0.20427	0.591698	-1.01287	-0.11405	-1.38696	
517.0407	754.5638	1.07186	-1.63561	-0.25993	0.933958	1.129923	1.260857	1.324024	0.798048	0.338249	-1.20616	
168.73	292.4235	0.998706	-1.44799	0.533814	0.519969	-0.13664	0.954947	1.006248	0.422706	-2.38086	-0.62465	
212.5925	346.406	0.433027	-0.149	-0.78915	0.738424	-0.38767	-0.77877	-0.51079	0.325442	-3.08202	-0.41244	
275.1635	422.7302	-1.31718	0.30693	-0.00283	0.124502	0.87454	0.107254	-0.38204	-0.54314		0.263207	
135.4007	250.9671	1.32427	-0.80846	0.49843	-0.89217	0.164778	0.057388	-0.81113	-0.03828		0.028897	
156.7424	278.5645	0.387481	1.687218	-0.6263	-0.8925	0.147893	-0.40166	0.457923	-0.12096		1.025011	
		0.154729	-0.49287	-1.04281	-0.62248	0.820467	0.20505	-0.55511	0.080625		1.01319	
		0.748287	-0.79161	-0.11399	0.911457	-0.1816	-1.28495	1.249897	-0.1633		1.009342	
		0.995658	0.357187	1.103025	-0.78963	0.745147	0.966377	0.322136	0.341089		1.494816	
		-0.3392	0.572343	-0.26175	0.787018	0.437134	-0.50134	1.483594	-0.63779		-1.88346	
		0.252229	1.720231	0.420192	0.044786	-1.05782	-1.04269	-2.22157	-1.6312		2.235364	

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

The developed ANN based NPV equation in Equation (10) is compared with the actual predicted NPV directly from the MATLAB as shown in Figure 10. It can be seen from Figure 10 that the developed ANN based NPV equation can mimic the simulated ANN result.

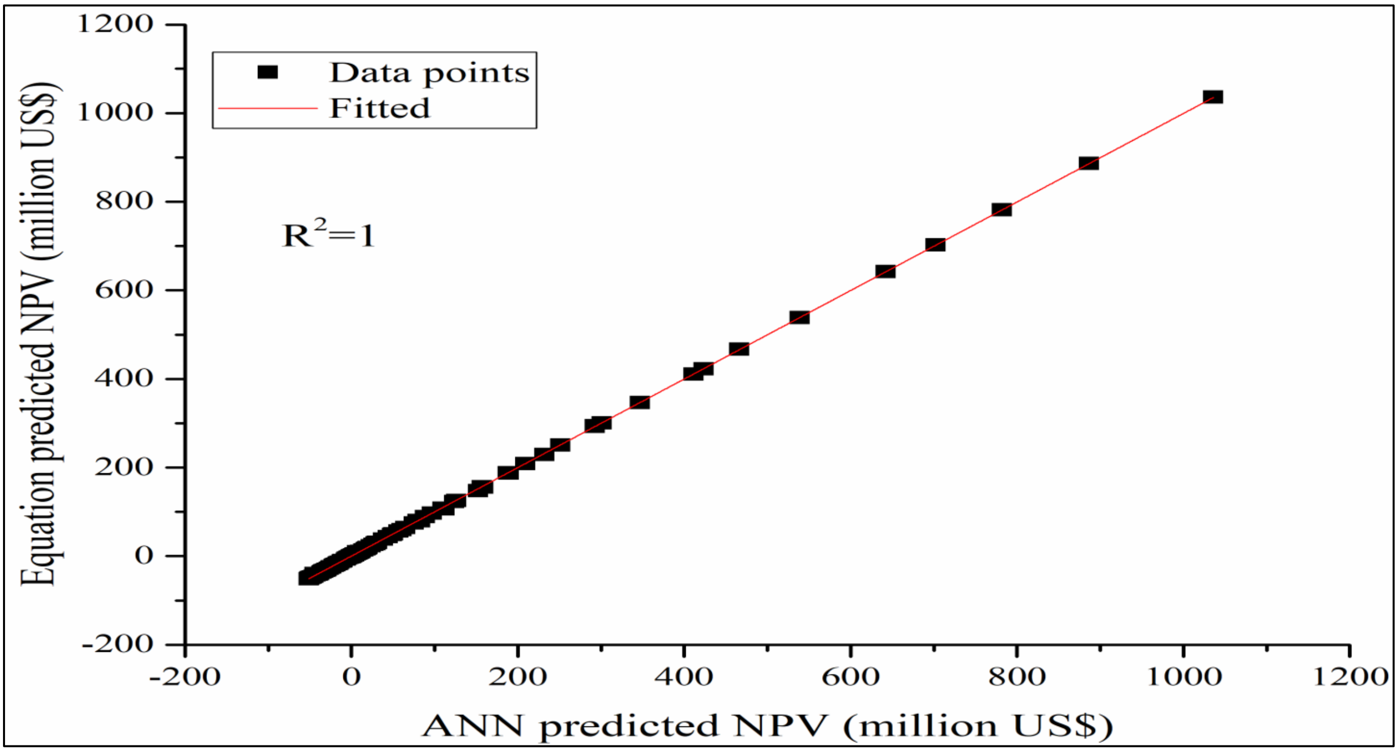

Fig 10: Equation (4.1) against ANN simulated NPV

D. Validation

To validate the model, some of the net present values were obtained through the economic models developed for the states. The discount rate and the price of commodities are randomly picked. Barite in Taraba State and iron ore in Kaduna State were used for this purpose. The obtained results are presented in Figure 11 for Taraba barite and Figure 12 for Kaduna iron ore. It can be seen from the Figures 11 and 12 that the R^2 value of 0.7674 is obtained for the barite while 0.9995 is obtained for the iron ore. Even though the data used are not part of those used in developing the models, the ANN models still give reasonable predictions with high R^2 value. In addition, the positive NPV values indicated that the projects are profitable just like the actual values.

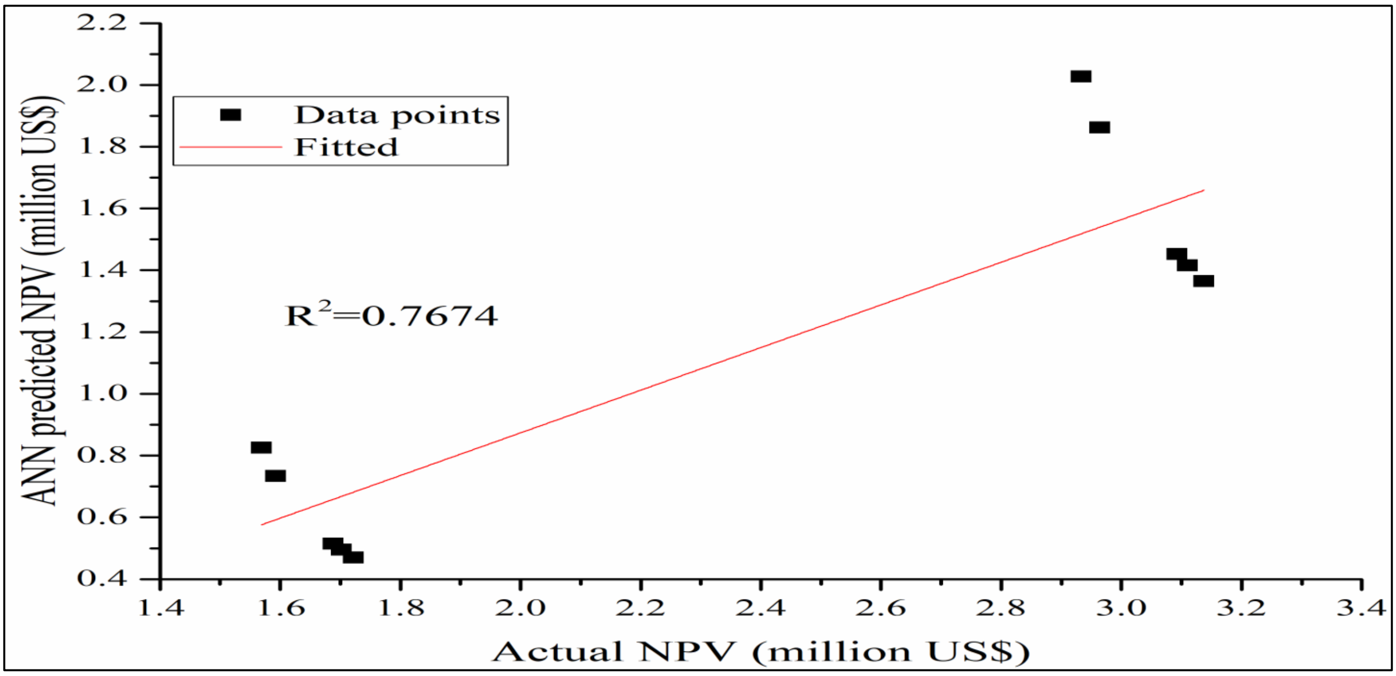

Fig 11: Predicted NPV against the Actual NPV for Barite Taraba State

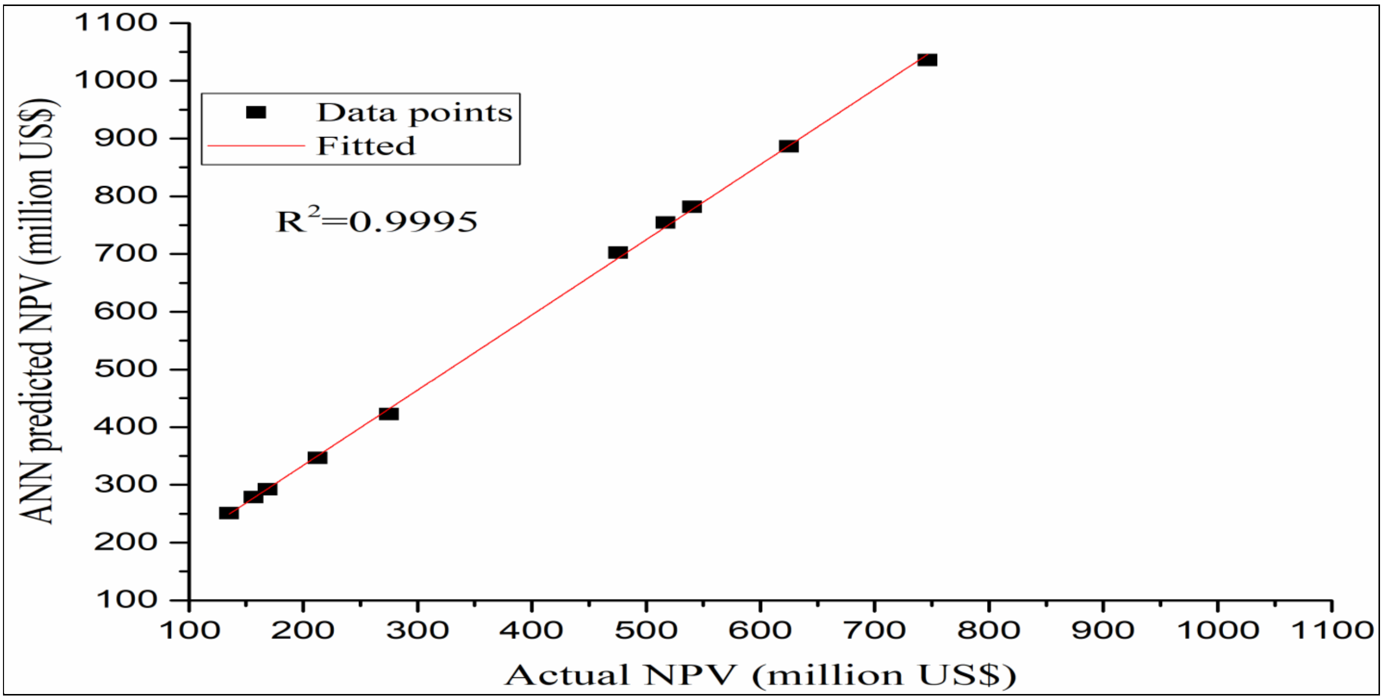

Fig 12: Predicted NPV Against the Actual NPV for Iron Ore Kaduna State.

VI. CONCLUSION

This study has been able to evaluates the potentials of Nigeria solid mineral resources as alternative means to her economic recovery. The research objectives were achieved using the data obtained from various sources which includes the reliable online source and on site. Different economic indices were computed to assess the economic viability of Nigeria mineral resources. Novel artificial intelligence method that is ANN was used to present the mathematically motivated ANN based model for the NPV prediction. The MATLAB was used in the development of ANN while the moving average method including the 'forecast' command in the Microsoft Excel Software were adopted in the forecasting. The outcome of the study can be concluded as follow:

- There are over 34 valuable minerals available in Nigeria out of which the lead/zinc, iron, barite, and limestone among others are actively mined
- The reserve estimates conducted using GIS approach for different minerals deposits for at least a deposit from each geopolitical zones reveal that there are enough quantities of those minerals capable of serving for many years. The GIS based results are also close to the existing proven and inferred reserves for the investigated locations.
- The NPV is sensitive to the price of the commodities and the discount rate and therefore, the discount rate increment should be a function of the market price.
- The import reliance index revealed that Nigeria depends largely on the importation of barite to meet its local demand
- Nigeria is not self-sufficient in terms of its exploitation of its mineral resources
- The IRR, NPV and PBP obtained for the investigated deposits are all favourable and can be mined at profit
- The developed ANN based model showed very high coefficient of correlation which is greater than 99% and capable of accurate prediction of NPV for minerals.

CONFLICT OF INTEREST

I declare that there are no conflicts of interest regarding the publication of this journal.

REFERENCES

[1]. Abaa, S.I., 1983. The structure and petrography of alkaline rocks of the Mada Younger Granite Complex, Nigeria. Jounal of African Earth Science 3, 107-113.
[2]. Abuntori, C. A., Al-Hassan, S. and Mireku-Gyimah, D. (2021), "Assessment of Ore Grade Estimation Methods for Structurally Controlled Vein Deposits – A Review", *Ghana Mining Journal*, Vol. 21, No. 1, pp. 31-44.
[3]. Adebimpe, R.A. and Akande, J.M. (2011). Engineering Economy Analysis on the Production of Iron Ore in Nigeria.Geomaterials, 1, 14-20.
[4]. Adu G. and Dramani J.B. (2018). Africa's mineral economies breaking their dependence on mining. https://nai.uu.se/.
[5]. Agusdinata, D.B., Liu, W. Eakin, H., and Romero, H. (2018). Socio-environmental impacts of lithium mineral extraction: towards a research agenda. Environmental Research Letters13(12)
[6]. Akongwale, S., Ayodele, O.S. and Udefuna, P.N (2013). Economic Diversification in Nigeria: Any Role for Solid Mineral Development? Mediterranean Journal of Social Sciences Published by MCSER-CEMAS-Sapienza University of Rome. Vol 4 No 6, pp. 691-703.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

[7]. Belhaj H.A. (2023). Economics and risk analysis of tight oil unconventional reservoirs. Chapter 8 in Tight Oil Reservoirs, 1, 251-276.

[8]. Black, R. (1980). *Precambrian of West Africa*. Episodes, 4(3), 3-8.

[9]. Bloodworth, A. J., Highley, D. E., & Mitchell, C. J. (1993). *Industrial Minerals Laboratory Manual: Kaolin*. British Geological Survey Technical Report WG/93/1.

[10]. Califf R.M., Rasiel E.B. and Schulman K.A. (2008) Considerations of net present value in policy making regarding diagnostic and theragnostic and therapeutic technologies. Am Heart J 156:879–8.

[11]. Central Bank of Nigeria (2018). 2018 Statistical Bulletin: Domestic Production, Consumption and Prices. https://www.cbn.gov.ng/documents/statbulletin.asp.

[12]. Chukwu, A. & Obiora, A. I. (2021). *Geochemical and Mineralogical Analysis of Pegmatite Belts in Nigeria*. Journal of African Earth Sciences, 172, 103992.

[13]. Cunningham, L. D. (2005). "Tantalum", USGS Mineral commodity Summaries; pp166-167.

[14]. Dada S.S. (2006). Proterozoic evolution of Nigeria. In: Oshin O. ed, The Basement Complex of Nigeria and its Mineral Resources (A Tribute to Prof. M.A.O. Rahaman). Akin Jinad & Co. Ibadan. 29-44.

[15]. Damulak D.D. (2017). Nigeria solid mineral resource potentials: An overview.

[16]. Ebunu A. I., Olanrewaju Y. A., Ogolo, O., Adetunji A. R. and Onwualu, A. P. (2021). Barite as an industrial mineral in Nigeria: occurrence, utilization, challenges and future prospects. Heliyon 7, e07365.

[17]. Elueze, A. A. (1983). *Petrology and Gold Mineralization of the Amphibolite Belt, Ilesha Area, Southwestern Nigeria*. Journal of Mining and Geology, 20(1), 17-22.

[18]. Enu, E. I., & Adegoke, O. S. (1986). *Industrial Mineral Potentials of the Nigerian Mid-continental Basement Complex*. Journal of African Earth Sciences, 5(5), 627-634.

[19]. Federal Republic of Nigeria (2010). Nigeria at 50: A Compendium: The Official and Throughtative Book About Nigeria.

[20]. Foster J.E and Tapan M. (2003). Ranking investment projects. Economic Theory 22:469–494.

[21]. Gandu, A.H., Ojo, S.B. and Ajakaiye, D.E. (1986). A gravity study of the Precambrian rocks in the Malum-fashi area of Kaduna State, Nigeria. Tectonophysics 126,181-194.

[22]. Hanafizadeh P. and Latif V. (2011). Robust net present value. J Math Comput Model 54:233–242.

[23]. Hosseini, S.; Lawal, A.I. and Kwon, S. (2023). A causality-weighted approach for prioritizing mining 4.0 strategies integrating reliability-based fuzzy cognitive map and hybrid decision-making methods: A case study of Nigerian Mining Sector. Resour. Policy 2023, 82, 103426.

[24]. Huang, P., Yudang, H., and Jingnan W. (2022). Exploring the Road toward Environmental Sustainability: Natural Resources, Renewable Energy Consumption, Economic Growth, and Greenhouse Gas Emissions. *Sustainability* 2022, *14*(3), 1579; https://doi.org/10.3390/su14031579

[25]. Hubbard, F.H. (1975). Precambrian Crustal Development in Western Nigeria: Indications from the Iwo Region. Geological Society of America Bulletin, 86, pp. 548 – 554.

[26]. Hustrulid W. and Kuchta M. (1995) Open pit mine planning and design, vol 1. Balkema, Rotterdam, pp 54–82, 47.

[27]. Infomine Inc. (2018). *CostMine: Industry Standard for Mining Cost Estimating*. [URL: https://www.infomine.com/costmine].

[28]. Jones, H. A., & Hockey, R. D. (1964). *The Geology of Part of Southwestern Nigeria*. Bulletin No. 31, Geological Survey of Nigeria, p. 87.

[29]. Jovanovic P. (1999). Application of sensitivity analysis in investment project evaluation under uncertainty and risk. Int J Proj Manag 17 (4):217–222.

[30]. Kohanpour, F., Gorczy, W., Lindslay, M.D. and Occhipinti, S. (2017). Examining tectonic scenarios using geodynamic numerical modeling: Halls Creek Orogen, Australia. Gondwana Research, 46, pp. 95 – 113. Doi: 10.1016/j.gr.2017.20.013.

[31]. Labe, N.A., Ogunleye, P.O. and Ibrahim, A.A. (2018). Field occurrence and geochemical characteristics of the barites mineralization in Lessel and Ihugh areas, Lower Benue Trough, Nigeria. J. Afr. Earth Sci. 142, 207–217.

[32]. Labe, N.A., Ogunleye, P.O., Ibrahim, A.A., Fajulugbe, T. and Gbadema, S.T. 2018. Review of the occurrence and structural controls of Baryte resources of Nigeria. J. Degrade. Min. Land Manage. 5(3): 1207-1216.

[33]. Lawal A.I and Kwon S. (2023b). Development of mathematically motivated hybrid soft computing models for improved predictions of ultimate bearing capacity of shallow foundations. Journal of Rock Mechanics and Geotechnical Engineering, 15(3), 747-759.

[34]. Lawal A.I., Onifade M., Bada S., Shivute A.P and Abdulsalam J. (2023a). Prediction of thermal coal ash behaviour of South African coal: A comparative application of ANN, GPR, and SVR. Natural Resources Research, 32 (3), 1399-1413.

[35]. Lawal A.I., Hosseini S., Minju K., Ogunsola N. and Kwon S. (2023b) Prediction of factor of safety of slopes using stochastically modified ANN and classical methods: a rigorous statistical model selection approach. Natural Hazards.

[36]. Lawal, A.I., Aladejare, A.E., Onifade, M., Bada, S., Idris, M.A. (2021a). Predictions of elemental composition of coal and biomass from their proximate analyses using ANFIS, ANN and MLR. International Journal of Coal Science & Technology 8, 124-140.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24SEP1304

[37]. Lawal, A.I., Olajuyi, S.I., Kwon, S. and Onifade, M. (2021b). A comparative application of the Buckingham π (pi) theorem, white-box ANN, gene expression programming, and multilinear regression approaches for blast-induced ground vibration prediction. Arabian Journal of Geosciences 14, 1073.
[38]. Lar, U.A., Agene, J.I. and Umar, A.I. (2015). Geophagic clay materials from Nigeria: a potential source of heavy metals and human health implications in mostly women and children who practice it. Environ. Geochem. Health 37, 363–375.
[39]. Lin G.C.I and Nagalingam S.V. (2000). CIM justification and optimization. Taylor & Francis, London, p 36.
[40]. Mallo, S.J. (2012). Base and precious metals development in Nigeria: challenges and prospects. Continental J. Applied Sciences 7 (1): 19-33.
[41]. Miller, G. L. (1959). *Tantalum and Niobium*. Butterworths Scientific Publications, London, p. 12 (SCIRP).
[42]. Mines Department, "Inventory of Nigerian minerals, mines and miners, "Federal Ministry of Petroleum and Mineral Resources. Lagos, 1993, pp. 1-10.
[43]. Nigeria Geological Survey Agency (2004). Map of Nigeria Showing Mineral Occurrences.
[44]. Nigeria Geological Survey Agency (2009). Existing ore reserves and production rates for Nassarawa State, Taraba State, and Cross River State.
[45]. Nigeria Geological Survey Agency (2011). Mineral Resources Inventory of Gold, Barites, Gypsum and Bentonite.
[46]. Nigerian Bureau of Statistics GDP report for Q3 2022. [URL]: https://nigerianstat.gov.ng/elibrary/read/1241259.
[47]. Nwosu, C., Okeke, N., & Uche, O. (2022). *Economic evaluation of barite resources in Nigeria*. Journal of African Earth Sciences, 45(3), 123-135.
[48]. Obassi, E., Gundu, D.T., Ashwe, A. and Akindele. M. (2015). Determination of Work Index of Enyigba Lead Ore, Ebonyi State, South-East Nigeria. Studies in Engineering and Technology 2(1), 103-110.
[49]. Okunlola O.A. (2005). Metallogeny of Ta-Nb mineralization of Precambrian pegmatites of Nigeria. Mineral Wealth 137: 38-50.
[50]. Onodugo, V. A. (2013). Can Private Sectors Facilitate Economic Growth and Realization of MDG in Developing Countries? Evidence from Nigeria. African Journal of Social Sciences, Vol. 3, No. 1.
[51]. Onunkwo, A.A. and Nwachukwu, M.A. (2005). Discovery, depth of occurrence and thickness estimation of PB-Zn-Fe(s) mineralization in Nigeria. A case study of Ndikpa, Ebonyi State, SE, Nigeria. Golabal Journal of Pure and Applied Sciences 11(4), 535-541.
[52]. Olalekan, D.O, Afees, N.O., and Ayodele, A.S. (2016). An empirical analysis of the contribuition of mining sector to economic development of Nigeria. Khazar Journal of Humanities and Social Sciences 2016, Vol. 19, № 1
[53]. Olayinka, A.I. (1992). Geophysical siting of boreholes in crystalline basement areas of Africa. Journal of African Earth Science 14, 197-207.
[54]. Onifade M., Lawal A.I., Abdulsalam J., Genc B., Bada S. and Said K.O. (2021). Development of multiple soft computing models for estimating the amount of organic and inorganic constituents in coal. International Journal of Mining Science and Technology, 31(3), 483-494.
[55]. Raw Materials Research and Development Council (RMRDC). (2003). *Report on Survey of Raw Materials in Nigeria: Kaolin*. RMRDC publication, Abuja, Nigeria.
[56]. Remer D.S. and Nieto A.P. (1995). A compendium and comparison of 25 project evaluation techniques, part 1: net present value and rate of return methods. Int J Prod Econ 42:79–96.
[57]. Roderick G. E. (2001). Mining and Economic Sustainability: National Economies and Local Communities. Division of Economics and Business, Colorado School of Mines, US.
[58]. Saint Simon de. (1999). *Historical Overview of Tantalum Mining in Nigeria*. International Journal of Mining, p. 45.
[59]. Saleh J.H. and Marais K. (2006). Reliability: how much is it worth? Beyond its estimation or prediction, the (net) present value of reliability. Reliab Eng Syst Saf 91:665–673.
[60]. Sayadi A.R., Tavassoli S.M.M, Monjezi M and Rezaei M. (2014). Application of neural networks to predict net present value in mining projects. Arab J Geosci (2014) 7:1067–1072.
[61]. Sharaky, A. M. (2014). Mineral Resources and Exploration in Africa Special Publication, Cairo University, 20p.
[62]. Small K.A. (1998). Project evaluation, Chapter 5 for transportation policy and economics. University of California Transportation Center, Berkeley.
[63]. Smith L.D. (1995). Discount rates and risk assessment in mineral project evaluations. CIM Bull 88(989):34–43.
[64]. Talens, P.L, Gara, V and Robert U. A. (2013). Lithium: Sources, Production, Uses, and Recovery Outlook. JOM: the journal of the Minerals, Metals & Materials Society 65(8)
[65]. Taylor, C.D, Schul, K.J. et al. (2005). Geology and Nonfuel Mineral Deposits of Africa and the Middle East USGS Open-File Report 2005–1294-E.
[66]. Torres T.F. (1998). Evaluating mineral projects: applications and misconceptions. Conference of Mining, Metallurgy and Exploration (SME), Denver, Colorado, USA.
[67]. USGS (United States Geological Survey). (n.d.). *Barite Statistics and Information*. [URL: https://www.usgs.gov/centers].
[68]. Wiesemann W., Kuhn D. and Rustem B. (2010). Maximizing the net present value of a project under uncertainty. Eur J Oper Res 202:356–367.
[69]. Funding source(s)