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MINERAL PRODUCTION AND ENVIRONMENTAL POLLUTION IN NIGERIA

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ABSTRACT

This study empirically determined the effect of mineral production on environmental pollution in Nigeria from 1985 to 2022. The research utilised time series data obtained from the Central Bank of Nigeria (CBN) data bulletin and the World Development Indicators (WDI) of the World Bank. The data analysis methodologies utilised include descriptive statistical analysis, ADF Unit Root test, ARDL Bound Co-integration test, and ARDL methodology. The result of the ADF unit root test indicated the presence of a combination of stationary and non-stationary elements. That is a mixture of I(0) and I(1). Furthermore, the ARDL limits co-integration test has shown the presence of a long-term link between the variables. Finally, the ARDL estimation revealed that crude petroleum and natural gas production, likewise mining and quarrying had significant and positive implication on emission of CO2 in both long and short runs. Coal production had positively significant impact on CO2 emission in the long run but positively insignificant impact in the short run. In addition, metal ores positively and insignificantly impacted on CO2 emission in both the long and short runs. The study's results indicated that mineral mining in Nigeria resulted in a rise in environmental contamination. The report proposed that the Nigerian government should thoroughly evaluate and revise current environmental laws and regulations in order to effectively address the environmental consequences of mineral development. This should include establishing clear standards, guidelines, and permits for mining operations, waste management, pollution control, and rehabilitation of mining sites.

KEYWORDS: *Mineral Production, Environmental Pollution, CO2 Emission*

1.0 INTRODUCTION

Mineral production encompasses activities as mining, quarrying, drilling, and processing of minerals for various purposes, including energy generation, construction, manufacturing and agriculture. The natural ecosystem is often times disrupted by the release of pollutants into the environment in the process of the aforesaid operations for extracting raw materials from the Earth's crust and processing same. Consequently, habitat loss, soil contamination, water contamination, and air pollution are among ways mineral extraction and processing may harm the ecosystem (Hartman, Mutmansky & Wang, 2018). Pollution from mineral production has far-reaching consequences that affect not just the local environment but also ecosystems, animals, human health, and economic prosperity. Natural minerals like coal, gold, limestone, iron ore, tin, and oil are among Nigeria's vast natural resources. Degradation and contamination of ecosystems; water resources, air quality, and human health have often resulted from the mining and processing of these minerals. The production of oil has a substantial role in the Nigerian economy, since the nation is a major oil producer. But oil extraction has led to serious environmental contamination, especially in the Niger Delta area via exploration, drilling, and refining. The contamination of water bodies, soil, and air by oil spills, gas flaring, and pipeline vandalism have had devastating effects on aquatic life, farmlands, and the lives of local residents. The pollution from oil activities has been a subject of international concern and has led to social unrest and conflicts in the region.

Also, mining operations, including artisanal and small-scale mining (ASM) have led to environmental degradation and pollution in various parts of Nigeria. Pollutants are released into the air, water, and soil during activities including mining processing, blasting, and excavation. Damage to the ecosystem has worsened due to illegal mining methods and a lack of governmental control. In states such as Zamfara and Niger, for instance, uncontrolled artisanal gold mining has been linked to mercury contamination, forest loss, and soil deterioration. The unregulated outflow of wastewater from mining sites typically contaminates water bodies with acids, heavy metals, and other harmful compounds. The contamination of water and fish supplies endangers human health and has impact on aquatic ecosystems. There are health issues and decreased agricultural output in regions where mining is common because people in such areas typically have trouble of access to clean water for many uses, including drinking and irrigation. Pollutants like Sulphur dioxide, nitrogen oxides, particulate matter, and greenhouse gases are released into the air by both solid mineral and oil extraction processes. Air pollution has the potential to harm biodiversity, alter global climate, and exacerbate respiratory health issues. Finally, gas flaring, which is widespread in Nigeria's oil sector, adds to environmental problems on a local and global scale by releasing pollutants and greenhouse gases into the air.

Interestingly, some studies have been carried out to determine the effect of mineral production on economic growth/development while other studies were carried out to determine the effect of environmental pollution on economic growth/development across the globe, Nigeria inclusive. Regrettably, there are paucity of empirical literature that examined mineral production - environmental pollution nexus, especially in the Nigeria context. This created a gap in literature/knowledge that this study sought to fill. Hence, this study as its aim empirically determined the effects minerals production had on environmental pollution in Nigeria. More specifically, its purposes are to evaluate how the production of crude petroleum and natural gas, mining and quarrying, coal production, and metal ores had impacted on carbon dioxide emission in Nigeria.

This research is organised in a manner that the subsequent section is devoted to the review of related literature. This review included the theoretical literature, conceptual clarification and empirical literature. The methods will be discussed in depth in the third section. Following the analysis of the data and the discussion of the established results in the fourth part, the conclusion and policy suggestions are presented in the fifth section.

2.LITERATURE REVIEW

2.1 Review of Theoretical Literature

This study presents the theory of Energy Transition as the theoretical leaning and guiding hypothesis that steers the shift of energy systems from conventional, fossil fuel-based sources to more sustainable, low-carbon, and environmentally friendly alternatives. The motivation for this transformation stems from the acknowledgement of the need to tackle urgent global issues as climate change, energy security, and environmental sustainability. The concept of energy transition originated from multidisciplinary research and discussions about the need to transition from fossil fuel-dependent energy systems to cleaner, renewable energy sources in order to assuage environmental pollution, tackle climate change, and accomplish long-term environmental sustainability objectives. Researchers from several fields, including energy economics, environmental economics and sociology, political science, and engineering, have made valuable contributions to the advancement and improvement of energy transition theory. They have done so via conducting empirical researches, developing theoretical frameworks, and analysing policies. Energy transition theory provides useful insights into the correlation between mineral extraction and environmental degradation by analysing the dynamics of energy systems, technical advancements, and socio-economic shifts towards more sustainable energy sources and practices. This theory helps elucidate how mineral production, particularly of fossil fuels and critical minerals, influences environmental pollution and the imperative for transitioning to cleaner, renewable energy sources. Energy transition theory recognizes the historical reliance on fossil fuels like coal, oil, and natural gas for energy generation, transportation, and industrial processes. The extraction, processing, and combustion of fossil fuels contribute to environmental pollution through emissions of greenhouse gases (GHGs), air pollutants, and toxic substances, leading to climate change, air pollution, and ecosystem degradation. Also, mineral production, including mining and processing of minerals (coal, metals, and rare earth elements), can have significant environmental impacts on air, water, soil, and ecosystems. Mining activities release pollutants ranging from particulate matter, heavy metals, acids, and toxic chemicals into the environment, leading to air and water pollution, soil contamination, and habitat destruction.

2.2 Review of Conceptual Literature

Mineral Production

Mineral production refers the entire process of converting mineral resources into mineral reserves through exploration, development, and extraction activities. It involves the identification, evaluation, and exploitation of mineral deposits to meet the demands of domestic and international markets for raw materials and finished products. Mineral production refers to the process of extracting and processing minerals from natural deposits for commercial purposes. This includes activities as exploration, mining, beneficiation, and refining of minerals to obtain raw materials utilised in various industries like mining, construction, manufacturing, and energy production (Otto, Cordes, Andrews-Speed,

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Davison & Guj, 2006). The process of mineral production was defined by Hartman, Mutmansky, and Wang (2018) as the mining of Earth's crust for the purpose of extracting commercially valuable minerals or ores. It encompasses surface mining, underground mining, and in-situ recovery methods to recover minerals which include coal, metals, gemstones, and industrial minerals. In congruent with Habashi (2009), mineral production involves the beneficiation and processing of minerals to extract valuable metals and minerals for further refining and manufacturing processes. It includes physical and chemical processes involving crushing, grinding, flotation, smelting, and refining to separate and purify desired minerals from ore concentrates. Todani (2012) defined mineral production as the utilization of mineral resources to generate economic value through extraction, processing, and utilization in various industries and sectors. It encompasses the entire value chain of mineral exploitation, including exploration, mining, processing, marketing, and distribution of mineral products to domestic and international markets.

Classification of Mineral Production
Mineral production activities are diverse and can be classified into different types owing to the nature of the minerals, the methods of extraction, and the stages of production:
Exploration: This entails the initial phase of mineral production, where geologists and exploration companies search for mineral deposits and assess their economic viability. This stage involves geological mapping, remote sensing, geophysical surveys, geochemical analysis, and drilling to identify potential mineral targets. Techniques include satellite imagery, aerial surveys, ground-based geophysical surveys (e.g., magnetic, gravity, electromagnetic), and geochemical sampling are utilised to detect anomalies indicative of mineralization. Exploration companies invest in exploration activities to discover new mineral deposits and expand their resource base for future development.

Mining: Mining is the practice of extracting valuable minerals from Earth's crust by use of a variety of processes that are adapted to the specific geological features of the deposit likewise the commodity that is sought for. The two primary types of mining techniques are surface mining and underground mining. The process of surface mining entails exposing shallow mineral resources close to the Earth's surface by removing overburden, which may include soil, rocks, and plants. Quarrying, surface mining, open-pit mining, and strip mining are some of the most common processes. Coal, aggregates, iron ore, limestone, bauxite, and surface mining are all methods utilised to extract these minerals. However, when surface techniques fail to reach deep mineral resources, underground mining becomes the preferred method of extraction. Building passages, tunnels, and shafts under the surface of the Earth to reach ores that lie deeper is what this process is all about. Ways to mine underground range from drifting to utilising shafts, slopes, rooms, pillars, and longwalls. Minerals including uranium, gold, silver, copper, zinc, and lead are extracted by underground mining.

Processing and Beneficiation: Beneficiation and processing are crucial steps in mineral production because they prepare raw mineral ores for future processing and use by extracting rich metals and minerals. Physical and chemical procedures are often utilised in processing techniques to isolate and concentrate precious minerals from the ore matrix. The specific techniques utilised to do this vary with the kind of ore and the final product that is sought for. A common first stage in mineral processing is crushing and grinding the ore into smaller pieces. This increases the surface area, which in turn facilitates the subsequent release of precious minerals. Crushing reduces the size of the ore to a manageable size, while grinding further reduces the particle size to facilitate mineral separation. Also, gravity separation methods, as jigging, shaking tables, and spirals, rely on the differences in density between minerals to separate them. Heavy minerals settle faster under gravity, while lighter gangue minerals are carried away by water or air currents.

Refining and Smelting: These are the final stages in mineral production, where purified metals and alloys are obtained from concentrate or intermediate products through high-temperature processing and chemical treatments. Smelting involves the extraction of metal from ore or concentrate by heating it to high temperatures in the presence of reducing agents (e.g., coke, charcoal) and fluxes. Smelting reactions convert metal oxides into molten metal and slag, which are separated owing to density and chemical composition. Smelting is utilised to produce base metals as iron, copper, lead, and zinc. Conversely, refining processes further purify metals obtained from smelting to remove impurities and achieve desired product specifications. Refining techniques include electrolysis, distillation, solvent extraction, and precipitation. Refining is utilised to produce high-purity metals for industrial applications and manufacturing processes.

Manufacturing and Utilization: The final stage in mineral production involves the manufacturing and utilization of refined metals, minerals, and mineral-based products for various industrial, commercial, and consumer applications.

Metals like steel, aluminum, copper, and titanium are utilised in construction, transportation, electronics, machinery, and consumer goods. Minerals such as limestone, gypsum, clay, and silica are utilized in cement production, glass manufacturing, ceramics, and refractories. Other mineral-based products include fertilizers, abrasives, pigments, and chemicals utilised in agriculture, mining, and manufacturing industries. In conclusion, mineral production encompasses a series of interconnected stages, from exploration and mining to processing, refining, and utilization. Each stage involves specialized techniques and technologies tailored to the characteristics of the mineral deposit and the desired end product. By understanding the different types of mineral production and their associated processes, stakeholders can optimize resource utilization, minimize environmental impacts, and promote sustainable development of mineral resources.

Environmental Pollution

The term "environmental pollution" refers to the introduction of dangerous compounds or pollutants into the natural environment, which may have a negative externality on ecosystems, animals, human health, and the overall quality of life. Air pollution, water pollution, soil contamination, and noise pollution are all aspects of pollution that may be caused by a variety of sources, including industrial activity, transportation, agriculture, and waste disposal. Pollution can also take on a variety of forms, including noise pollution, soil contamination, and air pollution. In their study published in 2002, Smith and DeSombre defined environmental pollution as the contamination of the environment in terms of air, water, and soil with contaminants that originate from human activities, industrial processes, and natural sources. Because pollution offers enormous challenges to the preservation of biodiversity, public health, and environmental sustainability, it is necessary to make concerted efforts at the local, national, and global levels in order to address the underlying causes of pollution and to lessen the negative ramifications. In congruent with Agarwal (2010), environmental pollution is defined as the loss of environmental quality that occurs as a result of the release of dangerous compounds, pollutants, and contaminants into the air, water and soil. This release poses dangers to ecosystems, biodiversity, and human health. Pollution results from unsustainable resource use, industrialization, urbanization, and inadequate pollution control measures, necessitating effective regulatory frameworks and enforcement mechanisms to prevent and mitigate its adverse effects. Daly and Farley (2011) conceptualized environmental pollution as the unintended consequences of economic activities that generate harmful externalities in the form of pollution, resource depletion, and environmental degradation. Pollution represents a market failure where the costs of environmental damage are not internalized by polluters, leading to overexploitation of natural resources and negative impacts on ecosystem services, human well-being, and future generations.

Causes of Environmental Pollution

The major causes of environmental pollution include the following:

Industrial Activities: A lot of pollution in the environment comes from industrial operations including generating electricity, processing chemicals, and manufacturing. Through their emissions, effluents, and waste disposal, industries contribute to the contamination of our air, water, and land with pollutants such particulate matter, Sulphur dioxide (SO_2), nitrogen oxides (NOx), heavy metals, VOCs, and dangerous chemicals. Industrial pollutants endanger ecosystems, biodiversity, and human health by contaminating air, water, and soil. While most of the time industrial pollution is concentrated in and around cities and other industrial regions, it may nevertheless affect air quality and climate change on a regional and even global scale.

Transportation: A lot of the air pollution and greenhouse gas emissions come from the transportation industry, which includes things like cars, aircraft, ships, and trains. Engines that run on fossil fuels emit harmful gases into the air as they burn. These gases include carbon monoxide (CO), Sulphur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM), and greenhouse gases (e.g., carbon dioxide, methane). Urban smog, acid rain, respiratory disorders, and climate change are all caused by emissions from vehicles. These factors have consequences for public health, environmental quality, and the resilience of ecosystems. Vehicle emission requirements, fuel efficiency upgrades, alternative fuels, and public transit programs are all part of the fight to lessen pollution from transportation.

Agricultural Practices: Crop cultivation, animal rearing, and the use of agrochemicals are all examples of agricultural operations that may lead to environmental contamination. Agricultural runoff containing pesticides, fertilizers, and animal waste can contaminate surface water and groundwater, leading to water pollution and eutrophication of aquatic

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ecosystems. Also, pesticides and fertilizers can also leach into soil, affecting soil quality, biodiversity, and ecosystem functioning. Agricultural practices like deforestation, land conversion, and monoculture farming contribute to habitat destruction, loss of biodiversity, and soil erosion, exacerbating environmental degradation and pollution.

Waste Generation and Disposal: The generation, treatment, and disposal of solid waste, hazardous waste, and electronic waste contribute to environmental pollution and degradation. Improper waste management practices, including open dumping, landfilling, and incineration, can release pollutants into the air, water, and soil, posing risks to human health and the environment.

Mining and Resource Extraction: Mining activities, including surface mining, underground mining, and quarrying, can cause environmental pollution through habitat destruction, soil erosion, water contamination, and air pollution. Tailings, runoff, and mining waste all contribute to environmental pollution from acidity, heavy metals, and sedimentation.

Urbanization and Land Use Changes: Urbanization, land development, and land use changes alter natural landscapes, fragment habitats, and disrupt ecosystems, leading to environmental pollution and degradation. Urban areas are sources of air pollution, noise pollution, light pollution, and heat islands, affecting air quality, biodiversity, and human health.

Review of Empirical Literature

Examining the ramifications of solid minerals production on environmental pollution in Nigeria, Akidi, Cookey and Oladosu (2024) employed time series data for period 1986 to 2022. The applied Autoregressive Distributive Lag analytical procedure established that in the short run and long run, the production activities of mining and quarrying, metal ores and coal production substantially increased carbon emission in the Nigerian environment. Thus, concluding that solid minerals production significantly contributes to environmental pollution in Nigeria.

Zhang, Wang, Liu, and Li (2023) conducted empirical research on the effects that mining operations have on the quality of the air in Shanxi Province, which is located in China. The data on air quality were acquired by the researchers from monitoring stations that were situated in close proximity to coal mines. These data were then compared to background levels and air quality requirements. In order to determine the level of air pollution caused by coal mining activities, they conducted an analysis of the amounts of particulate matter (PM2.5 and PM10), Sulphur dioxide (SO2), nitrogen dioxide (NO2), and volatile organic compounds (VOCs). The empirical study established that activity related to coal mining in Shanxi Province was a substantial contributor to air pollution. The study also indicated that higher levels of particulate matter, Sulphur dioxide and nitrogen dioxide were observed in the vicinity of mining sites.

Nwogwugwu, Nwokoye, and Ebenebe (2022) conducted research to determine the extent to which the solid mineral industry contributes to the expansion of the economy in Nigeria. For the purpose of this research, a CCR (canonical cointegrating regression) model evaluating the relationship between solid minerals and economic development in Nigeria was calculated by utilising time data spanning from 1980 to 2020. following the outcome from the CCR estimate, it was determined that production of solid minerals has a large and favourable impact on the expansion of the economy. A rise in the output of solid minerals leads to an increase in investments in intermediate and capital goods, which in turn leads to an increase in aggregate demand.

Molly, Richard, and Edwin (2022) conducted an analysis to determine how the production of gas influences expansion of the Kenyan economy. 2008-2020 was the time frame for the research. Secondary data were obtained from the database maintained by the World Bank. This model, known as the General Method of Moments (GMM), was chosen. It was found in the research that the use of petrol has an effect on the development of economy in Kenya.

In the study by Muftau and Onaopemipo (2022), the ARDL Approach was utilised in order to unearth the impact that development of solid minerals had on expansion of the economy in Nigeria. During the course of the research, time series data ranging from 1981 to 2019 were utilised. Test were conducted to determine whether or not the time series were stationary, and all of the data were examined at a 5% level. As outcome of the investigation, it was discovered that Solid Mineral Development had marginally beneficial impact on expansion of the economy under investigation.

Between the years 1981 and 2020, Nwinyodee and Kerebana (2022) focused their attention on the ways trade openness has influenced expansion of the solid mineral sub-sector in Nigeria. ARDL, which stands for ARDL was the modelling approach utilised in this investigation. Solid mining sub-sector (SLM) was employed as the dependent variable while Trade openness (TPN), Foreign direct investment (FDI), Foreign portfolio investment (PFI), Remittances (RMT) comprised the independent variables. The cheque variable that was utilised was the exchange rate (EXR). The research established that TPN, FPI, RMT, and EXR had a disadvantageous impact on the solid mineral sub-sector. The connection between FDI and SLM remained favourable throughout.

Ighosewe, Akan, and Agbogun (2021) conducted an empirical study investigating the influence that fluctuations in crude oil output have had on the economy of Nigeria. They utilised a resource-dependence method to investigate the phenomenon, which covered a study period of 35 years (1984-2018). The information was obtained from the Central Bank of Nigeria Statistical Bulletin, the World Bank Report, and the Annual Report of Oil Producing Exporting Countries. The ARDL Model was utilised to analyse the data. Numerous diagnostic examinations demonstrated that the model is suitable for the investigation. Production and fluctuations in oil prices per barrel (FOBP) and kerosene pump prices (KPPF) both contribute to a major improvement in the economy of Nigeria over the course of a longer period of time.

Over the years 1998 and 2017, Foye and Benjamin (2021) conducted an investigation of the impact natural gas had on the economic performance of a number of countries located in sub-Saharan Africa. For the purpose of data analysis, both the lag augmented vector autoregressive method developed by Toda and Yamamoto for heterogeneous mixed panels, as described by Emirmahmutoglu and Kose, and the dynamic heterogeneous approaches are utilised. The study established considerable association between real gross domestic product and the use of natural gas over the long term. The research also show that the use of natural gas has a considerable and favourable impact on the functioning of the economy in the short term.

Nwatu and Ezenwa (2020) provided an estimation of the connection between use of natural gas, expansion of the economy, and emission of carbon (IV) oxide. In addition to the standard preliminary analysis and formal tests that were carried out on the data, a co-integration test was carried out by utilising Johansen's approach. Additionally, the Akaike information criterion (AIC) was utilised, and a lag value of one was chosen. In the short term, the results coefficients associated with the multi-directional interactions between natural gas consumption, economic growth, and carbon dioxide emission were produced for Nigeria.

Ajie, Okoh, and Ojiya (2019) conducted an empirical study about the influence of Nigeria's natural resources on the nation's economic development. The variables were examined for stationarity utilising a variety of econometric instruments of analysis, and it was determined that all of the variables became stationary at first difference. In the same line, the evidence showed that the series in the model display a long-run equilibrium association, which may be deduced from the result of the Johansen co-integration. An increase of one billion naira in the development of solid minerals, which include quarrying, bauxite, metal ores, iron ore, coal, and so on, would add 0.26 billion naira to the gross domestic product of Nigeria, in consonance with the most important results from the output of the OLS.

Employing the ARDL analytical model on sample period 1982-2018, Musa, Maijama'a, Shaibu, and Muhammad (2019) conducted an investigation into the influence that crude oil and exchange rate have on the expansion of the Nigeria’s economy. There was a considerable favourable influence on economic growth in both the long-run and the short-run periods, agreeing with the result which suggested that crude oil and currency rate had a notable impact. Both the long-term and the short-term effects of crude oil and exchange rate, which are the key areas of the research, were shown to have potential to influence economic development as noticed from the results.

Using ordinary least squares (OLS) regression, Acquah-Andoh, Gyeyir, Aanye, and Ifelebuegu (2018) analysed the sustainability of petroleum production in light of the Ghana Shared Growth and Development Agenda (GSGDA), which is a policy framework that is intended to be implemented over a medium-term period. After taking into account the contributions made by other areas of the economy, the data revealed that petroleum does not constitute major contributor to Ghana's GDP at the present levels of output when adjusted. Between the years 2010 and 2013, Ghana's

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real effective exchange rate had a constant appreciation, which resulted in decline in the contribution of the agriculture sector to the nation's GDP and a decline in the competitiveness of the non-oil sector.

3.0 METHODOLOGY

Research Design

The term "research design" describes the procedures utilised by the researchers to integrate the many parts of the study in a way that makes sense in order to solve the issue. The adopted research design for this study is the ex-post facto variant. This design is suitable as the research aims to examine the causal link between the study's dependent variable (environmental pollution) and independent variable (mineral output) utilising previously available data. The selected variables for the study with their relevant sources are described in Table 3.1 below.

Table 1: Variables Description and Data Sources

Variable Name	Identifier	Source of Data	Definition and Measurement
CO_2 emissions	CO_2	WDI	CO_2 emissions are largely generated by solid and liquid minerals production and the combustion of fossil fuels in vehicles i.e automobiles, automobiles, vessels, trains, and aircraft. It is measured in kiloton.
Crude petroleum and natural gas production	CPP	CBN Statistical Bulletin	Crude petroleum and natural gas production include the worldwide activities of searching for, extracting, purifying, transporting, and selling petroleum products. Fuel oil and petrol are the industry's most significant volume products. It is measured in barrels.
Mining and quarrying	MAQ	CBN Statistical Bulletin	Mining and quarrying are industrial processes that include the retrieval of rich solid minerals, rocks, and other geological substances from the ground. These activities are essential for economic growth since they provide raw materials for many sectors. It is measured in grams.
Coal production	CPT	CBN Statistical Bulletin	Coal production include the activities of separating, extracting, acquiring, and manufacturing coal with the intention of selling, generating profit, or utilising it for commercial purposes. It is measured in metric tons.
Metal Ores	MOS	CBN Statistical Bulletin	Metal ores are indigenous formations of rocks or minerals that contain metallic elements or compounds that may be recovered. These ores often have significant amounts of the required metal, making it economically feasible to extract and refine the metal for diverse industrial uses, usually measured in metric tons.

Note: WDI = World Development Indicators; CBN = Central Bank of Nigeria (CBN),

Model Specification

From an empirical standpoint, the research shall use a multiple regression model to enhance the efficiency of economic estimations. This is due to the additional degrees of freedom and decreased collinearity. Both independent and dependent variables will be part of the model. Owing to the data, a regression equation is utilised to represent the connection between the independent (X) and dependent (Y) variables in this study. This multiple linear regression model may be expressed in the form of general equations as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + u \quad (3.1)$$

Where:

Y = dependent variable (environmental pollution)

a = intercept parameter (where the regression surface crosses the y-axis)

β_1 - β_n = Slope parameters (measures the degree of responsiveness of dependent variables to independent variables)

X_1 - X_n = independent variables (proxies of mineral production)

u = stochastic error term

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Owing to the above, the study specifies a functional relationship between mineral production and environmental pollution thus:

$$ENVP = f(mineral\ production) \quad (3.2)$$

$ENVP$= Environmental pollution measured in terms of CO_2 emissions

Model 3.2 is disaggregated as follows:

$$CO2_t = f(CPP_t,\ MAQ_t, CPT_t, MOS_t) \quad (3.3)$$

The functional relationship in Equation 3.3 is stated in explicit form to enhance its estimation thus:

$$CO2_t = \beta_0 + \beta_1 CPP_t + \beta_2 MAQ_t + \beta_3 CPT_t + \beta_4 MOS_t + u_t \quad (3.4)$$

Equation 3.4 is stated in log form as follows:

$$CO2_t = \beta_0 + \beta_1 InCPP_t + \beta_2 InMAQ_t + \beta_3 InCPT_t + \beta_2 InMOS_t + u_t \quad (3.5)$$

Expressing the model in its ARDL form, we have:

$$\Delta \text{In}(CO2_t) = \beta_0 + \sum_{t=1}^{p} \beta_{1i} \Delta In(CO2_t) + \sum_{t=1}^{q} \beta_{2i} \Delta In(CPP_{t-1}) + \sum_{t=1}^{q} \beta_{3i} \Delta In(MAQ_{t-1}) + \sum_{t=1}^{P} \beta_{4i} \Delta In(CPT_{t-1}) + \sum_{t=1}^{P} \beta_{5i} \Delta In(MOS_{t-1}) + \alpha_{1i} \Delta(CO2_{t-1}) + \alpha_{2i} \Delta \ln(CPP_{t-1}) + \alpha_{3i} \Delta(MAQ_{t-1}) + \alpha_{4i} \Delta \ln(CPT_{t-1}) + \alpha_{5i} \Delta(MOS_{t-1}) + u_{ti} \quad (3.6)$$

Where,

CO_2 = CO_2 emissions, CPP = Crude petroleum and natural gas production, MAQ = Mining and quarrying, CPT = Coal production, MOS = Metal Ores, Δ = Difference operator, P= Lag of dependent variable, q = Lag of independent variables, t = Time, In = Natural log, β_0 = Constant variable; $\alpha_1 - \alpha_5$ = Coefficient of long run equilibrium; $\beta_1 - \beta_5$ = Coefficient of short run dynamic model, u_{ti} = Stochastic term.

Estimation Techniques

To prevent the occurrence of misleading results, it is crucial to establish the sequence of series integration in modelling. The ADF method was utilised to examine the series' integration characteristics in this research. Consequently, to find out the link between the independent and dependent variables in the long and short term, the ARDL model was utilised.

4.0 ANALYSIS AND DISCUSSION OF RESULTS

Descriptive Analysis

Performing summary statistics on the model variables is the first phase of the data analysis in this research. The analysis is conducted utilising descriptive statistics, and the outcomes are shown in Table 2:

Table 2: Descriptive Statistics

	CO2	CPP	MAQ	CPT	MOS
Mean	45.63280	6801.331	6851.943	7.719474	2.780526
Median	46.06860	6730.865	6791.440	5.040000	1.980000
Maximum	54.46350	9294.050	9323.750	27.50000	9.660000
Minimum	33.15260	4231.900	4391.420	1.710000	0.620000
Std. Dev.	5.444738	1353.969	1341.931	7.428726	2.315983
Skewness	0.181692	0.118911	0.130054	1.514945	1.503228
Kurtosis	2.448091	2.205525	2.194321	4.149514	4.259449
Jarque-Bera	0.691364	1.088938	1.134893	16.62756	16.82289
Probability	0.707738	0.580150	0.566971	0.000245	0.000222
Sum	1734.046	258450.6	260373.8	293.3400	105.6600
Sum Sq. Dev.	1096.871	67829539	66628803	2041.881	198.4598
Observations	38	38	38	38	38

Source: ***Authors' Computation, 2024.***

Table 2 shows that for each series, there were 38 observations. CO_2 emissions, a surrogate for environmental pollution, range from a low of 33.15 to a high of 54.46, with an average value of 45.63 and a median of 46.07. Crude petroleum and natural gas production (CPP), mining and quarrying (MAQ), coal production (CPT) and metal ores (MOS), which were utilised as proxies for minerals production, have average values of 6801.33, 6851.94, 7.719 and 2.780 with median values of 6730.87, 6791.44, 5.04 and 1.98 with maximum values of 9294.05, 9323.75, 27.5 and 9.66 and minimum values of 4231.9, 4391.42, 1.71 and 0.62 respectively. The analysis of standard deviation values reveals that

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mining and quarrying, likewise crude petroleum and natural gas production (CPP), are highly volatile sectors, with values of 1353.97 and 1341.93 respectively. Conversely, coal production (CPT) is the least volatile component, with a value of 7.428726. Furthermore, the standard deviation for CO_2 emissions is 5.44, whereas for metal ores (MOS) it is 2.32. The table demonstrates that all the variables (CO_2 emissions, crude petroleum and natural gas output, mining and quarrying, coal production) are skewed positively.

Pre-Estimation Tests

a. Correlation Analysis

In econometrics, the correlation matrix is a popular tool for examining the relationships between variables. It gives a correlation coefficient matrix that quantifies the degree of linear relationship between variables. For the purpose of this study, correlation matrix is utilised to detect multicollinearity. Detecting multicollinearity utilising a correlation matrix involves examining the correlation coefficients between pairs of independent variables. The result of the correlation matrix is presented in Table 3:

Table 3: Correlation Matrix

	$InCO2_t$	$InCPP_t$	$InMAQ_t$	$InCPT_t$	$InMOS_t$
$InCO2_t$	1				
$InCPP_t$	0.376146	1			
$InMAQ_t$	0.369447	0.599535	1		
$InCPT_t$	-0.467400	-0.741810	-0.743760	1	
$InMOS_t$	-0.442430	-0.36124	-0.33699	0.267557	1

Source: ***Authors' Computation, 2024.***

The correlation test result reported in Table 3 shows that crude petroleum and natural gas production (CPP), mining and quarrying (MAQ), coal production (CPT), metal ores (MOS) all have mixture of positive and negative values but weak relationships with CO_2 emissions over the research period. This gives us the green light to go on with our econometric study as it suggests that the independent variables are not subject to multicollinearity.

b.Unit Root Test

In order to prevent spurious regression from occurring in any time series analysis, the first step that has always been performed is to determine the order in which the variables are integrated. Due to the fact that the testing of the unit roots of a series is a prerequisite for the presence of a co-integration connection, this research first utilised the well-known ADF unit root test in order to ascertain the stationarity status of each adopted variable. Thus, following the diagnosis, the outcomes of the unit root test are detailed in Table 4 as detailed below:

Table 4: Augmented Dickey-Fuller (ADF) Test Results

	At Levels		At 1st Difference		
Variables	**ADF Statistic**	**5% Critical Value**	**ADF Statistic**	**5% Critical Value**	**Order of Integration**
$InCO2_t$	-0.911169	-2.943427	-4.706324	-2.945842	I(1)
$InCPP_t$	-0.805339	-2.943427	-4.618432	-2.945842	I(1)
$InMAQ_t$	-3.044471	-2.943427	-	-	I(0)
$InCPT_t$	-2.389127	-2.945842	-3.507366	-2.945842	I(1)
$InMOS_t$	2.803731	-2.948404	-11.61268	-2.945842	I(1)

Source: ***Authors' Computation, 2024.***

The unit root pretests of the variables as displayed above, showed the levels and first difference analyses results. In the event that the t-statistic is lower than the critical value at a significance level of 5% or if the probability value is lower than 0.05, then the variable in question is considered to be stationary. The results of the ADF model indicate that metal ores (MOS) are stationary at level, which is indicated as order I(0). Conversely, CO2 emissions (CO2), crude petroleum and natural gas production (CPP), mining and quarrying (MAQ), and coal production (CPT) are stationary at first different, which are indicated as order I(1). As a result of the combination of the order of integrations as order I(0) and I(1), an ARDL bound test is utilised to determine whether or not there is a co-integration or a long-run link among the variables.

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c. ARDL Bounds Co-integration Test

Table 5: ARDL Bounds Co-integration Test

	Critical Value Bound		F-Statistics
Significance	I(0) Bound	I(1) Bound	
10%	2.2	3.09	
5%	2.56	3.49	6.392664
2.5%	2.88	3.87	
1%	3.29	4.37	
Note: K = 4.			

Source: ***Authors' Computation, 2024.***

The ARDL Bounds co-integration test was utilised to determine the long-term connection between the independent and dependent variables in this research. Table 5 shows that the test's output established that, at the 5% level of significance, the null hypothesis of no co-integration is rejected since the F-Statistics value of 6.392664 is higher than the upper limit value of 3.49. this suggests that, there is enough statistical evidence to aver that the variables in question which are CO2 emissions, mining and quarrying, coal production, metal ores, crude petroleum and natural gas production are related over the long term. Thus, in order to corroborate the variables' long-term dynamics, it is necessary to estimate the extent of the effect of the independent variables on the regressand applying in principle the ARDL model.

Autoregressive Distributive Lag (ARDL) Long-Run and Short-Run Dynamics

The long run and short run dynamic relationship between proxies of mineral production and the indicator of environmental pollution in Nigeria was estimated utilising ARDL method. The upshots are presented in Table 6:

Table 6: Estimated Long-Run Coefficients of ARDL

Dependent Variable = $InCPP_t$				
Long-Run Results				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
$InCPP_t$	4.342496	1.640578	2.646930	0.0164
$InMAQ_t$	9.925805	2.825084	3.513455	0.0025
$InCPT_t$	0.146102	0.059996	2.435217	0.0255
$InMOS_t$	0.414835	0.222494	1.864480	0.0786
EC = In(CO2) - (4.3425*In(CPP) + 9.9258*In(MAQ) + 0.1461*In(CPT) + 0.4148*In(MOS) + 4.9209)				
Short-Run Results				
$D(InCPP_t)$	20.01742	8.335520	2.401460	0.0241
$D(InCPP_{t-1})$	-4.257926	15.23212	-2.795360	0.0098
$D(InMAQ_t)$	-0.711092	0.276859	-2.568429	0.0193
$D(InMAQ_{t-1})$	0.047472	0.053779	0.882727	0.3858
$D(InCPT_t)$	3.873106	2.022961	1.914572	0.0716
CointEq(-1)*	-0.549254	0.110097	-4.988841	0.0000
R^2 = 0.774297; Adjusted R^2 = 0.666352; Durbin-Watson stat = 2.086119				

Source: ***Authors' Computation, 2024.***

Interpretations of Long-run and Short-run ARDL Model Results

Crude Petroleum and Natural Gas Production (CPP) and CO_2 Emissions

Table 6 displays the ARDL model's long-run and short-run estimations. The study established that in both long-term and short-term, the relationship between CO_2 emissions and the production of crude oil and natural gas were found to be positive and statistically significant. Crude petroleum and natural gas production's positive coefficient value and p-value (less than 0.05) prove this. That means both the short-term and long-term increases in CO_2 emissions in Nigeria is partly owing to increases in the production of crude oil and natural gas. This discovery is in consonance with the study outcome of Odoh, Akpi, and Anyah (2017), who also discovered that the extraction of crude petroleum and natural gas in Nigeria has harmful implication on the environment.

Mining and Quarrying (MAQ) and CO_2 Emissions

Table 6 also suggests from the displayed results that mining and quarrying are positively and significantly implicated on CO_2 emissions in the long and short terms. The fact that the p-value for mining and quarrying is less than 0.05 and that the coefficient value is positive are indicators of this. This means that both the short-term and long-term increases in CO_2 emissions in Nigeria are also contributed by mining and quarrying industry's activities. This corroborates with Muftau and Onaopemipo (2022) conclusions, as they established that solid mineral development like mining and quarrying positively affects the economy and its environment.

Coal Production (CPT) and CO_2 Emissions

In accordance with the presentations in Table 6, the long-run and short-run estimates of the ARDL model suggests that coal production is positively and significantly related to CO_2 emissions in the long run, whereas in the short run, the ramification is positive but not significant. Consequently, both the long-term and short-term effects of increasing coal output incrementally impacted CO_2 emissions in Nigeria over the sampled period. This confirms what Aigbedion and Iyayi (2017) have discovered: that coal production is a major source of pollution in Nigeria's ecosystems.

Metal Ores (MOS) and CO_2 Emissions

In similar manner, Table 6 displays the estimates from the ARDL model which revealed metal ores as positively and insignificantly influenced CO_2 emissions in Nigeria. This is substantiated by the fact that the p-value is larger than 0.05 and the coefficient value for metal ores is positive. As a result, both the long-term and short-term effects of an increase in metal ores escalated CO_2 emissions in Nigeria during the data period. This confirms what Akidi, Cookey and Oladosu (2024) have discovered: that metal ores, a proxy for solid mineral exploration and processing causes deterioration in environmental quality via contribution to CO_2 emissions in Nigeria.

Interpretation of CointEq(-1) Result

In addition to the long-run relationships derived from the error correction model, Tabe 6 also displays the generated short-run dynamic coefficients. There is link between the indicators of the long-term estimates and those of the short-term changes. A rapid return to equilibrium after shock is established by the sufficiently significant and correctly signed estimate of the error correction coefficient of -0.549254 (p-value = 0.0000). This means that yearly, about half of the disequilibria caused by the shocks in the preceding year return to long-term equilibrium.

Interpretation of Adjusted R-Squared (Adj. R^2) Value

Following the estimates' outcomes of the ARDL model as displayed in Table 6, the fitting power of the model is well explained with an Adjusted R-squared value of 0.666352. This is because about 67% of the systematic variations in CO_2 emissions are due to changes in the explanatory variables (Crude petroleum and natural gas production, mining and quarrying, coal production, and metal ores) with the remaining 33% being blamable on factors not captured in the model.

Interpretation of Durbin-Watson Statistic Value

Lastly, Durbin-Watson statistic value of 2.086119 which is greater than 2 indicates that the error terms are not uncorrelated, thus, suggesting absence of serial autocorrelation problem.

Diagnostic Tests of CO_2 Model

Tabulated and discussed below are the results of the diagnostic tests analyses:

Table 7: Post-Estimation Test Results

Test	Null Hypothesis	X^2 Value	X^2 Prob	Remark
Jarque-Bera	Normal distribution exists	0.368699	0.831645	Normal residuals
Breusch-Godfrey LM	Serial correlation does not exist	0.383893	0.6873	Serial independence
Breusch-Pagan-Godfrey	Homoscedasticity exists	1.144981	0.3880	Constant Variance
Ramsey RESET	Model is stable	0.367170	0.5502	correctly specified model

Source: ***Authors' Computation, 2024.***

To make sure the ARDL model doesn't have any problem associated with traditional linear regression like normality, serial dependency, heteroscedasticity, or stability, it was tested utilising post diagnostic tools. As presented in Table 7 above, the post-tests' outcomes revealed that the examined model of the effects of mineral extraction on environmental pollution in Nigeria is normally distributed in variables' residuals, serially independence in error terms, homoscedastic in constant variance, and correctly specified.

5.0 CONCLUSION AND RECOMMENDATIONS

Conclusion

This research utilised the Autoregressive Distributive Lag (ARDL) estimate approach to conduct an empirical analysis of the impact of mineral extraction on environmental pollution in Nigeria from 1985 to 2022. The study's outcomes revealed that production of crude petroleum and natural gas, mining and quarrying activities, coal production, and extraction of metal ores in Nigeria had a direct correlation with increased CO_2 emission. The study's results indicated that mineral extraction and mining in Nigeria has resulted in a rise in environmental contamination.

Recommendations

The following suggestions for policy are proposed on the basis of the research outcomes and conclusion:

i. The Nigerian government should review and update existing environmental laws and regulations to address the environmental impacts of mineral production comprehensively. This should include establishing clear standards, guidelines, and permits for mining operations, waste management, pollution control, and rehabilitation of mining sites.

ii. Government should strengthen enforcement mechanisms and monitoring systems to ensure compliance with environmental regulations and permit conditions by oil and mining companies.

iii. Government should encourage the adoption of environmentally sustainable mining practices and technologies that minimize the environmental footprint of mineral production.

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