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RESEARCH ARTICLE

THE INTER-RELATIONSHIP BETWEEN DEFORESTATION, CARBON DIOXIDE EMISSIONS AND INCOME POVERTY: EVIDENCE FROM SUDAN (2000-2021)

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Abstract: This paper aims to investigate the inter-relationship between environmental degradation and income poverty, implies time series data for Sudan published on the World Bank-World Development Indicators Database, covering the period 2000-2021. A recursive model made up of three behavioral equations has been built and used as a means of analyzing the data, the functional equations expressed deforestation and carbon dioxide emissions as facets of environmental degradation and income poverty from an economic perspective. The results reveal that deforestation and carbon dioxide emissions are positively related to the incidence of poverty, likewise poor people found to be environmental degrader. Moreover, increasing in per capita gross domestic product lead to higher rates of both deforestation and carbon dioxide emissions. Nonetheless, increasing in per capita gross domestic product is not sufficient means to reduce income poverty. The negative association between deforestation and carbon dioxide emissions stem from the direct link between agriculture expansion into forest area, and increasing in energy use simply increasing emissions. The study concludes environmental degradation and poverty are inter-related in the sense that both are causally related and hence explainable in the light of macro-socio economic variables such as per capita gross domestic product and energy use.

Keyword: *Carbon dioxide emissions, Deforestation, Environmental degradation, Income poverty, Sudan.*

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INTRODUCTION

Environmental degradation has unequivocally been recognized as a major factor breeding and aggravating poverty. In response to this, the concept of sustainable development has come into being. Sustainable development as a philosophy and policy-guiding framework is based upon three integrative and interactive components namely, economic efficiency, social equity and environmental conservation.

On the one hand, alleviation of poverty will be instrumental in the way of realizing sustainable development while on the other, the role of poverty as a counter force and process to environmental conservation will be widely accepted. As such, reduction and alleviation of poverty has been central to the operationalization and hence achievement of sustainable development (World Bank, 1997). Environment provides goods and services used for food production, the harvesting of wild products, energy, and raw materials. The environment is also a recipient and partial recycler of waste products from the economy and an important source of recreation, beauty, spiritual values, and other facilities (World Summit on Sustainable Development, 2002). Environmental services encompass a wide range which can be summed up as: provision of production factors and inputs in the form of renewable and non-renewable resources; acting as a sink tank whereby the wastes produced as a result of biological, physical and economic activities can be disposed of.

Out of the debate on the "Limits to Growth" the concern over environmental degradation emerged to become a highly prioritized developmental concern. Such a concern has revealed the pressing need to manage global resources in a way, which would cater for human, ecological and economic considerations. Pre-occupation with economic growth as a sole and over-ridding objective of

economic activity in both the developed and the developing countries has dominated since World War II for over three decades. However, since then, evidence started to accumulate that unrestrained economic growth in the developed world and the dominance growth in the developing countries had negative repercussions on the natural environment. The Paris Agreement on climate change started during 2016, to combat climate change and adapt to its effects. Such repercussions, which are generally referred to as environmental degradation, would highly reduce the ability of the environment to provide its indispensable services.

Environmental degradation in the developing countries has been thought of as a major contributing factor to the pervasive spread of poverty. Indeed, the two have been conceived as reinforcing and reciprocally inter-related. The rise in poverty in poorer countries reflects economies that are more informal, social protection systems that are weaker, and financial systems that are less developed. This highlights the magnitude of poverty, which overwhelms despite the immense technological progress the world has made following World War II.

Low-income countries have yet to see a full recovery. Various gatherings, declarations and conventions such as Stockholm conference on human development of early 1972s, the world environment strategy of early 1980s and the world conference on environment and development of mid 1980s were held to address the poverty related issues. Temporal and spatial spread of poverty would be dealt with in this study by way of defining the nature and scale of the problem.

Rural poverty-environment relationship stated that, environmental resources make a significant contribution to average rural incomes and poorer households also depend heavily on these resources. Hence, degradation of natural resources would hurt the poorest most (Cavendish, 2000). In Africa, however, deforestation and forest degradation are still major concerns, and are depleting the region's wealth, environmental problems of Sub-Saharan Africa include pollution of air and water supplies, massive deforestation, loss of soil and soil fertility and a dramatic decline in biodiversity throughout the region (Energy Information Administration, 2000).

The relationship between humans and forests is subject to complex, dynamic and sometimes opposing forces (Busch and Ferretti-Gallon, 2017) Identifying the causal pathways between social and economic variables and environmental outcomes is a formidable challenge (Ferraro *et.al.*, 2019) Studies by (Alix-Garcia *et.al.,* 2013) in Mexico and by (Hes *et.al.,* 2019) in the Gambia to determine the causal impact of income growth on deforestation showed that income growth induced by a conditional cash transfer programme and a community-driven development programme, respectively, increased forest loss.

By contrast, other studies in Mexico and Uganda suggest that programmes offering payments in compensation for conservation activities have successfully reduced rates of deforestation (Alix-Garcia *et. al.,*2015; Jayachandran *et.al.,* 2017) from other side, the role of forests in poverty alleviation is also increasingly well implicit (Miller *et.al.,* 2020*).*

Actions to combat deforestation have gathered pace over the past decade, primarily because of awareness that the loss of forests and the use of fire to clear land is having negative impacts on the global carbon cycle. In order to reduction of emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries as a recommended action in the Paris Agreement.

A recent analysis of 31 national strategies and action plans (Food and Agriculture Organization, 2023) highlights priority actions to reduce deforestation and forest degradation. A number of international initiatives have provided support to these efforts, including the United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation, programme jointly operated by FAO, the UNDP and UNEP, the Forest Carbon

Partnership Facility and the Forest Investment Program of the World Bank. The New York Declaration on Forests, a voluntary and non-binding international declaration to take action to halt global deforestation launched in 2014, now has over 200 endorsers, including national and subnational governments, multinational companies, groups representing indigenous communities and None-Governmental Organizations.

The new (Food and Agriculture Organization, 2023) estimates, based on a simple carbon stock change approach, update published information on net emissions and removals from forests in relation to net forest conversion and forest land. Results show a significant reduction in global emissions from net forest conversion over their study period, from a mean of 4.3 in the 1991–2000 to 2.9 in 2016–2020, at the same time, forest land was a significant carbon sink globally.

Moreover, the findings of their study indicate that in the decade just concluded the net contribution of forests to the atmosphere, representing the combination of emissions from net forest conversion and removals on forest land, was very small. Sudan is very rich country in terms of natural resources. The country is awarded with huge and varied natural resources, fertile land, natural forests, fresh water, biodiversity, wild and domestic animal stock, marine ecosystems, mineral and soil resources.

It has been faced with several environmental problems including: deforestation, desertification and land degradation, water pollution, soil erosion and deterioration in biodiversity. The environmental state in the Sudan is sorrow from a stern process of degradation, which could be irreparable. Most of the once abundant and varied wildlife has disappeared, and agroastoral development is constrained by increasing desertification, erratic seasonal rainfall and successive dry spells. Decline in biodiversity and pressures on habitats are growing with more areas opened to development and stakeholders.

The impact of petroleum prospecting, drilling and transport on habitats, especially that of produced water on migratory birds is very disturbing.

More than half the area of the country is affected by desertification as a result of inappropriate land use method, over-grazing and deforestation (Ministry of Welfare and Social Security, 2010).

Massive land areas of the country currently stand unadorned after being deforested through various causes and as a consequence of extensive and intensive agricultural use pastures and rangelands have also worsened from over use. The general picture given by the various studies of the forest extent in the country indicate that the forest cover is decreasing at an alarming rate.

While (Harrison and Jackson, 1958) estimated the forest cover of the Sudan to be (34 %) the forest cover as estimated by (FRA, 2005) is 67546000 hectares, equivalent to 27% of the country area. Most common causes of deforestation as identified by stockholders include expansion of agriculture onto forest areas, unsustainable felling of valuable trees, weak institutional protection, conversion of tree based crops such as gum Arabic into intensive agriculture schemes, illegal cutting by armed forces, tree removal for oil development, and illegal commercial cutting for brick-making.

Another important cause of deforestation is the tree removal for production of fuel-wood, charcoal and for housing construction together with other causes on which people's wellbeing and food security are substantially dependent.

Poverty as envisaged by the study is a multifaceted process, which impacts on the economic and social aspects of household, communities and nations at large. Low incomes, which fall short of subsistence requirements; inequitable access to factors of production and inadequacy or sheer lack of health care and education services are viewed as salient features of poverty as an appalling socio-economic phenomenon. More people today live healthier and more productive than at any time in history.

But the gains have been inadequate and uneven, as for instance, during the peak of the covid-19 crisis in the second quarter of 2020, the incomes of the poorest 40 percent of the world's population likely fell by 4 percent in 2020.

As a result, the number of people living in extreme poverty likely increased by 11 percent in 2020 from 648 million to 719 million. This increase pushed the extreme poverty rate 1.2% higher than projections going into the year. Given current trends, it became clear that the global goal of ending extreme poverty by 2030 would not be achieved. Of the world's 8.2 billion people, that is, 574 million people live on less than US$2.15 a day in 2030, with most in Africa. In 2020 alone, the number of people living below the extreme poverty line rose by over 70 million. That is the largest one-year increase since global poverty monitoring began in 1990 (World Bank, 2022).

Sudan is a lower middle-income country in Sub-Saharan Africa with Gross National Income per capita between US$1,026 and US$4,035, the Human Development Index for Sudan stood at 0.490 in 2015, which puts the country in the low human development category, positioning it at 165 out of 188 countries and territories. Money metric poverty is high in Sudan, with 46.5% of the population living below the national poverty line in 2009 National Baseline Household Survey (NBHS) [17]. As of 2014, 12.2% of the population was living on less than $1.90 a day (World Bank, 2020) and 52.3% were multidimensional poor according to Multidimensional Poverty Index (MPI) in the same year as reported by (Oxford Poverty and Human Development Initiative, 2020).

Agriculture still accounts for about one-third of Sudan's gross domestic product. According to (Food and Agriculture Organization 2023) nearly 65% of Sudan's population of 49 million is engaged in the agricultural sector The worsening conditions for farmers suggests a looming hunger crisis could be even worse. The United Nations estimated that the number of people going hungry in Sudan would rise to 19.1 million from 16.2 million last estimated prior to the conflict, which started in April 2023.

Shortages of key staples would further worsen a hunger crisis that has been steadily building in recent years. It could also cripple livelihoods and deprive Sudan of foreign currency needed to import basic commodities, as cash crops such as sesame and peanuts accounted for $1.6 billion in export revenues in 2022, according to central bank figures.

The problems of poverty and environmental degradation in Sudan are highly stereotyped. Over the past 30 years, Sudan has been among the most rapidly warming locations on the globe, with air temperatures increasing by 1.0° Celsius since the 1970s. In addition to a 30-year trend of declining precipitation, there is evidence that rainfall is becoming more erratic. Natural disasters, such as desertification, drought, and flooding, also contribute to the deteriorating socio-economic situation of communities and households. Desertification has been a significant stress factor on pastoralist societies and has also contributed to inter-communal tensions (United Nations Children's Fund-Sudan, 2020).

Environmental management is instrumental to sustained poverty alleviation. Therefore, the problem statement of the present paper emphasized rural poverty and environmental degradation as a reinforcing process. Then, the rural poor are expected to be the most affected by diminishing environmental quality. Moreover, the dual role of the poor as agents and victims of environmental degradation will be raised as a research question, that must be attended to analyses and comprehend the linkage between poverty and environmental degradation.

The question is how environmental problems such as deforestation and emissions of carbon dioxide affects the of the poor, what causes the emissions. On equal footing –but even more significant to poverty alleviation is provision of an objective understanding to deforestation. The latter which is widely spread in the study area is a major threat to sustainable livelihoods and hence to the aggravation of poverty. The main objective of the research is to investigate the inter-relationship between the pervasiveness of environmental degradation and spread of poverty in Sudan.

To pursue the above objectives, secondary objectives are considered, which are as follows: to examine the factors contributing to environmental degradation as expressed in terms of deforestation per capita (GDPC) and emissions of carbon dioxide (CD) and to analyze the effect of macro-economic factors on poverty. The researcher puts forward the following as its working hypotheses: deforestation as environmental degrading

parameter is explainable by a set of socio-economic variables such as economic poverty (PE), illiteracy rate (IR), CD, net enrolment in secondary school (NER) and GDP per capita (GDPC). Environmental degradation measured in terms of CD is affected by PE and number of factors namely, IR, GDPC and energy use (EU). Whereas, PE measured in terms of number of poor people living in poverty is functionally related to key macro-economic variables such as GDPC, AS, DFC, food production index (FPI) and Gini index (GI).

In order to explore the inter-relationship between environmental degradation and poverty, secondary data on the environment and poverty for period 2000-2021, the database available at World Development Indicators of World Bank (World Bank. World Development Indicators Database, 2000-2021) will be used. The term poverty is defined as the number of poor people living below poverty line (less than US $1.9 a day 2017 purchasing power party [PPP]).

For the purpose of this article, environmental degradation is peroxided by carbon dioxide emissions and deforestation. The research will also have scope for environmental awareness among poor people through improvement in the level of education. The findings and conclusions of the study can help in understanding the link between rural poverty and the degradation of their environmental resources.

The significance of the study due to environmental problems require serious and urgent attention. Specified, (World Summit on Sustainable Development 2002) tackling environmental degradation is an integral part of effective and lasting poverty reduction, moreover, environmental degradation harms human health and reduces economic productivity.

The rest of this is article is organized in the following form. Section one provides the link between rural poverty and environmental degradation, problem statement, objectives, hypothesis, scope and the significance of the study. Section two provides a description of the features, population, socio-economic development and state of environment of Sudan, the area of the study. Section three dwells on the methodology. Section four outlines the results and discussion and conclusion of the study in Section five.

REVIEW OF LITERATURE

Sudan is the third largest African country by area after Algeria and the Democratic Republic of the Congo, covering 1.88 million square kilometers. The secession of South Sudan in 2011 reduced its size by 24.7 per cent (Sudan National Survey Authority, 2017).

The secession, compounded by economic sanctions imposed on the country, led to a significant decline in the country's Gross Domestic Product per capita from 2034.46 USD in 2011 to 1698.08 and 816.54 USD in 2015 and 2018, respectively (Statista, 2019).

The country's population is estimated at 44.43 million, based on a projection from the 2008 census, and is predicted to increase to 57.3 million by 2030 (Central Bureau of Statistics, 2018). Despite being a largely desert and semi-desert country, natural resources are the backbones of the economy. The agricultural sector contributes around 30-35 per cent to the nation's GDP, constitutes a source of livelihood for about 65 per cent of the population (World Bank and Sudan's Ministry of Agriculture, 2016).

Sudan is a country with a highly diverse vegetation cover and ecological zones where, the rainfall varies from zero in the northern desert to more than 1,200 mm in the High Rainfall Woodland Savannah in the far south-western part of the country. Five distinct ecological zones representing biomes with different ecological conditions and different vegetation cover, desert, semi-desert, woodland Savanah, flood region and montane vegetation.

Sudan's forests cover is about 10.3% of its total land surface, with an estimated annual rate of net forest area loss of about 174,400 hectors, or about 0.8% (Food and Agriculture Organization of the United Nations, 2016) .This deforestation rate is not comparable to the rate of 0.4 -0.7 million hectare reported in Sudan's Second National Communication 2013. The deforestation rate in the Sudan's Second National Communication is estimated based on (FRA, 2005) which was based on the

forest statistics before the cessation of Sudan in year 2011, into two states Sudan and South Sudan. Forests have been facing encroachment by agriculture, urbanization, and subjected to unsustainable wood fuel extraction for several decades, since late 1970s after the so-called mechanized rain-fed agriculture was introduced in east and central Sudan. The lack of integrated land use planning and coordination across institutions has resulted in uncontrolled land use changes and conversion of vast forest tracts into agricultural areas over the past 40 years.

Forests play a significant role in the current land use systems in Sudan in terms of their socioeconomic Ministry of Agriculture and Forests, 2020), development and environmental protection functions. In addition, forests meet the needs of the various dependent stakeholder groups and supporting their livelihoods. 70% of Sudan's total population 33.4 million is rural and nomadic and considered as forest-dependent for livelihood, wood energy and on round timber for buildings.

Contribution of forests sector to the national economy is under-estimated, the formal national accounts estimation of the forest sector contribution to the GDP is about 3%. The 1994 energy consumption study confirmed that the per capita consumption of fuel wood is 0.73 cubic metre per annum which, when converted into Ton/Oil Equivalent, could be valued at nearly 2.0 Billion US dollars. Moreover, Non-Wood Forest Products are rich and diverse and have substantial direct contribution to the livelihood of rural people at the local (household) level as well as to the national economy in terms of exports.

METHODOLOGY

Data Source and Description of Variables

In order to capture the dynamic relationship between Environmental degradation and poverty, the study uses annual time series secondary data on its selected variables covering the period 2000-2021. An empirical model of three equations has been built. The state of the environment is measured in terms of CD and indices of agricultural productivity, poverty is measured as the number of people living below the international poverty line of $1.90 a day (PPP 2017), and its indicators include such variable as education. The study uses data in the GDPC, AS, DFC, MS and GI. Given hereby definitions for the variables employed by the empirical model both as dependent and explanatory variables.

Annual deforestation is the permanent conversion of forest area to other uses, including shifting cultivation, permanent agriculture, ranching, settlements and infrastructure development; FPI: covers food crops that are considered edible and that contain nutrients; GI: measures the deviation of income distribution among individuals or households with respect to a perfectly equal distribution; IR: number of people age 15 and above who cannot read and write in an effective way; MS: is the net output of manufacturing sector after adding up all outputs and subtracting intermediate inputs.

CD: refer to those stemming from the burning of fuels and the manufacturing. These emissions include carbon dioxide produced during consumption of solid, liquid and gas fuel and from gas flaring; EU: it is apparent consumption measured by adding the indigenous production to imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transportation. Commercial energy use is designed as the domestic primary energy use before transformation to other end-use energy sources; NER: is the ratio of the number of children of official school age who are enrolled in school to the population of the corresponding official school age.

The PE: is measured by the number of population living below $1.90 per capita per day level of consumption or income at 2017 prices, total population: includes all residents regardless of their legal status or citizenship and excluding the refugees not permanently settled in their country of asylum; GDP: is measured by gross value added, at purchase prices, by all resident producers in the economy plus any taxes and minus any subsidies not included in the value of the products; GDPC: is calculated by divided GDP and total population mention above; AS: corresponds to the International Standard Industrial Classification divisions 1-5 and includes forestry and fishing. Due to the

difficulties in collecting, recording and compiling of data, a combination of methods is used to estimates the outputs, yields and area under cultivation to predict the agricultural production; DFC: is calculated by dividing annual deforestation per one thousand square kilometers by total population.

Empirical Model

A recursive regression model has employed as a means of analysing the data and hence arriving at results, findings and conclusions with regard to the inter-relationship between environmental degradation and poverty. A resort to the recursive has been made to avoid the problems following the analysis when we used Ordinary Least Square (OLS) method namely, bias, inconsistent and the interdependent between the explanatory variables. The model which has been designed to analyses the environmental degradation- poverty nexus is made up of three behavioral equations as follows:

Deforestation weighted by every country population to yield a per capita deforestation variable (DFC) as a proxy of environmental degradation has been used as a dependent variable. We would have expected positive relationship between DFC and PE, the higher PE, the higher DFC. As well as, positive relationship between DFC and IR, the higher IR, the higher DFC. Likewise, positive relationship between DFC and CD, the higher CD, the higher DFC. Negative relationship would be anticipated between DFC and NER, the higher NER, the lower DFC. And positive relationship between DFC and GDPC, the higher GDPC, the higher DFC. This equation takes the following form:

$$DFC = f\ (PE, IR, CD, NER, GDPC) \quad (1)$$

Environmental degradation as a dependent of poverty: This equation envisages environmental degradation as a resultant of poverty. In relation to the form of energy sources, used by the poor people, the most serious problems faced by developing countries are the local effects of emissions of particular matter, the use of leaded fuels and the indoor air pollution arising from use of biomass fuels. We would expect a positive relationship between CD and PE, the higher PE, the higher will be CD. As well a positive relationship between CD and IR would be expected, the higher IR, the higher CD. Likewise, positive relationship would be expected between CD and GDPC, the higher GDPC, the higher CD. Positive relationship would be expected between CD and EU, the higher EU, the higher CD. Hence, this equation shall take the following form:

$$CD = F\ (PE, IR, GDPC, EU) \quad (2)$$

PE as a function of macro-economic variables: This equation depicts poverty as an outcome of explanatory variables made up from macro-economic variables. We would expect that negative relationship between PE and GDPC, the higher GDPC, the lower PE. Also negative relationship between PE and AS, the higher AS, the lower PE would be expected. Positive relationship would be anticipated between PE and DFC, the higher DFC, the higher PE. Negative relationship would be expected between PE and FPI, the higher FPI, the lower PE. GI can be positive or negative from the fact that inequality worsens at first with development and improved only later (World Bank, 1990). Thus, this equation shall take the following structure:

$$PE = F\ (GDPC, AS, DFC, FPI, GI) \quad (3)$$

The OLS is used as a model of estimation and SPSS has employed as software. The t-test has been used to test the significance of the relationship between the dependent and the independent variables. The model will be validated on the merits of its explanatory power as measured by the magnitude of R^2 which will also provide the measure of goodness of fit. R^2 can range in value between 0 and 1, with a value of close to 1 indicating a good fit.

RESULTS

The results of the present study as provided for by the econometric estimation of the three equations, which together make up the empirical model that has been used for testing the hypotheses of the study. The SPSS output for (1), (2) and (3) have been tabulated in Appendixes A, B and C.

One of the empirical model, analyses environmental degradation measured as per capita deforestation as a function of selected socio-economic variables and single environmental quality variable. The estimation of (1) is as follows:

DFC = 39.089 + 2.830PE – 3.681IR – 44.664CD + 0.131NER + 0.098GDPC
(1.771) (0.859) (-0.961) (-2.548) (0.205) (2.323)
R^2 = 0.634 D-W = 1.790

The estimation results indicate a good explanatory power and goodness of fit as it can be concluded from R^2 with a magnitude of 0.634, and F value, which is significant at 0.006 points out that all of the explanatory variables are functionally related to-alternatively associated with DFC as a dependent variable. Poor people are positively affected the deforestation phenomena in Sudan, negative effects of deforestation need no further description.

However, it is worthwhile mentioning that deforestation very frequently becomes a source of conflict among users particularly pastoralists and farmers. Carbon dioxide emissions show a negative coefficient; this implies that higher rates of carbon dioxide emissions are associated with less deforestation. In other words, less rates of carbon dioxide emissions are associated with high rates of deforestation.

Agricultural production is a major economic activity and income generator. However, because of the significant of traditional farming –which virtually uses no fossil fuel- in relation to modernized and such contributes to carbon dioxide emissions. GDPC proves to be statistically significant with a positively signed coefficient.

This would reveal a direct relationship between economic growth measured in terms of GDPC and deforestation a principal indicator of environmental degradation in the study area. This entails that economic growth, particularly at the early stages of development, would result in higher rates of deforestation.

Second models environmental degradation expressed as CD, as a function of PE, IR, GDPC, EU and DFC. The estimation of (2) is as below:

CD = 0.289 + 0.013PE – 0.015IR + 0.002GDPC + 8.220EU– 0.010 DFC

(0.906) (0.271) (–0.254) (5.948) (0.082) (–3.543)
R^2 = 0.720 D-W = 1.277

Good fit and high explanatory power for equation has been obtained as evidenced by R^2 at 0.720. All the independent variables are significantly related to carbon dioxide emissions, as indicated by the F value significant at 0.001.

The PE variable is positively related to carbon dioxide emissions. However, such a finding is plausible on the basis that increased carbon dioxide emissions is in general a consequence of high rates of urbanization and manufacturing which reflect conditions prevalent in the developed countries and least in the developing ones. The coefficient of EU has been found to be statistically significant at 0.05 level and positively related to environmental degradation. This implies that an increase in energy use automatically leads to environmental degradation.

Third Models economic poverty as a function of a set of macro-economic variables, estimation of (3) is presented as follows:

PE= –19.332 + 0.002 GDPC + 0.006AS _ 0.011 DFC + 0.155FPI +0.105GI
(-1.666) (0.845) (10.001) (_0.639) (1.599) (0.131)
R^2 = 0.907 D-W = 1.849

Good fit and high explanatory power for equation has been obtained as evidenced by R^2 at 0.907 and F value significant at 0.000. All explanatory variables coefficients proved to be statistically significant at 0.05 level different from zero as indicated by the t-values in the parentheses. Such a result supports the finding that poverty expressed in economic terms - as number of persons living below a specific poverty line- is functionally related and hence is readily explainable in terms of macro-economic indicators. Moreover, all of the regresses have shown a significant functional relationship with the dependent variable as indicated by the F value, a measure of how well the data fit into the equation as a model.

The coefficient of GDPC has been found to be statistically significant at 0.05 level and positively related to PE, this implies increases of PE as GDPC increases. AS proves to be statistically significant and positively related to economic poverty. This result runs opposite to what to be expected of agricultural development as an engine of

socio-economic in developing countries and hence as a major contributor to alleviation of poverty. DFC bears a negative sign and is significant, this highlights the role to be shouldered by actions aimed at environmental quality improvement as a means of poverty reduction. It is worth making the point that DFC, an environmental degradation variable embedded into this equation which mainly seeks an explanation for poverty from a macro-economic perspective.

DISCUSSION AND CONCLUSION

This study aimed to investigate the interrelation between environmental degradation and poverty in Sudan. The empirical results from the estimation of three equations show that deforestation in the study area dramatizes environmental degradation in Sudan which degrade soils, result in low and declining incomes and as such in the predominance of low standards of living and hence the spread of poverty.

Deforestation, as the study result show, taken as a dependent factor is positively related to the incidence of poverty. This highlights the ways by means of which the poor may turn out to be environment degraders. The explanation for the positive proportionality between deforestation as environment degrading factor and prevalence of poverty is the poor in their quest to earn living would be inclined on what-so-ever forest or other vegetative cover lands. This would spawn deforestation which would accelerates over time to result in desertification. The latter which is indiscriminately affects Sudan at varying magnitudes is a principal factor which underlies diminishing productive capacity of agricultural land which ultimately result in the spread of poverty. Similar findings have been concluded on the inter-relationship between deforestation and economic growth.

The analysis also concludes that, deforestation as an environmental hazard has been found to be negatively associated with literacy rate and carbon dioxide emissions. Such a finding is explainable on the following grounds. Literate people would be expected to be more aware of the consequences of environmental degradation and hence of preserving the environment intact.

Carbon dioxide emissions are likely to be on the high level as country venture more towards manufacturing. Such state of affairs would bring into play less dependence on agricultural expansion and as thus less deforestation. The link between environmental awareness and deforestation is direct, the more the population is oriented towards environmental conservation as a result of them being well aware of the significance of the natural environment to their well-being, the less will be deforestation.

Carbon dioxide emissions a measure of environmental degradation proves to be negatively associated with environmental awareness. This would lead to the inference that environmentally degraded environments would perhaps contribute to less environmental awareness. The linkage here can be thought of in the way how specific modes of development would be expected to affect the lives of the poor. As such, the poor were found to be less aware of environmental problems which are bound to affect their lives. This suggests a positive role for raising the profile of environmental awareness – expressed as availing more educational opportunities- as a means of improving environmental awareness.

Agricultural expansion –in general- contributes less to carbon dioxide emissions. The negative association between carbon dioxide emissions and deforestation stems from the nature of agricultural growth in the country, which relies on encroaching on forest lands rather than improving resource use efficiency. By contrast (Mohamed, 2022), found positive relation between carbon dioxide emissions in and land changes Sudan, carbon dioxide emissions are largely stemming from the agricultural practice and land use changes. Data compiled by (Food and Agricultural Organization, 2020) evident that given that agricultural expansion is the main driver of deforestation.

This would stem from the impact of services such as agricultural extension as a means of enlightening rural communities as to the misgivings of environmental degradation and the potential opportunities inherent in environmental conservation and quality promotion.

The most recent data for carbon dioxide emissions in 2021 clearly show a rebound in emissions compared to 2020, which was strongly affected by covid-19 globally. Global carbon dioxide emissions in 2021 increased by 5.3% compared to 2020 and were just 0.36% smaller than in 2019. The covid-19 crisis slowed down the global economy in the first half of 2020, resulting in an interruption in the global growth in carbon dioxide emissions.

However, the positive relation between income poverty and share of Agriculture in GDP signifies the predominance of agricultural development programmes in enhancement of the interests of the poor when it comes to the distribution of the benefits of such agricultural development programmes.

From other hand, a paradoxical role for increased GDPC on poverty is readily explainable on the grounds that GDPC as macro-economic indicators is a measure which weights GDP by population size without giving what–so-ever attention to actual income distribution as amongst various socio-economic strata that make up every society. This reveals that whilst per capita GDP increases, not parallel allocations to income of population are made to the extent which result in per capita GDP improvements being a cause for deteriorated poverty measured in economic term.

Valuable contribution by International Monetary Fund, an improving living standards and potential growth, particularly in resource intensive countries, boosting income per capita will require wide-ranging structural reforms, including investment in education, better natural resource management, improved business climate and digitalization, and a commitment to trade integration (International Monetary Fund, 2023).

The findings indicate that affecting development at the national level is a necessary condition for alleviation of poverty. However, it is significantly relevant to point out the well-known shortcomings of GDPC as a measure of social welfare in general and as an indicator of income distribution as amongst the various socio-economic group which make up every society.

Impressive gains in GDPC may materialize, yet the lot of the poor might well go down, however the result as it applies to this study on the association between poverty alleviation and economic growth expressed as per capita gross domestic product is encouraging as well as the positive prospects for national development programmes as a means of poverty reduction.

To drive this point home, national development plans and actions which prioritizes manufacturing though are expected to speed up economic growth, yet such development programmes by relying more on intensive labour technologies as opposed to capital intensive ones, would not affect a parallel expansion is social services which ultimately raises the capacity and capability of the population in question. As such, it is highly likely that imbalanced development which does not attend to promote the production base of the economy as well as raising the profile of social services availability will adversely affect environmental awareness.

To sum up, deforestation and carbon dioxide emissions as aspects and manifestation of environmental degradation are functionally related more or less to the same set of socio-economic variables. The poverty measured in economic terms as persons living on less than US $1.9 a day is well explained by socio-economic variables at the macro level. For instance, the variables like per capita GDP, share of agriculture and manufacturing in the GDP.

On other hand, this leads to the conclusion that environmental degradation and poverty are inter-related in the sense that both are causally related and hence explainable in the light of macro-socio economic variables such as the ones incorporated by the study. This would make plausible the inference that socio-economic factors at the macro level as made by this study provide for sound investigation of the inter-relationship between environmental degradation and poverty.

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APPENDICES

Appendix A

SPSS Output of Equation 1
Regression

Descriptive Statistics

	Mean	Std. Deviation	N
DFC	69.9810	95.72273	21
PE	8.8808	18.44523	21
IR	8.2033	15.73830	21
CD	.7286	1.57897	21
NER	13.3637	46.17759	21
GDPC	6.7885E2	949.02038	21

Correlations

		DFC	PE	IR	CD	NER	GDPC
Pearson Correlation	DFC	1.000	-.169	-.210	-.090	.659	.504
	PE	-.169	1.000	.967	-.034	-.060	-.154
	IR	-.210	.967	1.000	.017	-.071	-.117
	CD	-.090	-.034	.017	1.000	.158	.682
	NER	.659	-.060	-.071	.158	1.000	.720
	GDPC	.504	-.154	-.117	.682	.720	1.000
Sig. (1-tailed)	DFC	.	.231	.181	.349	.001	.010

	PE	.231	.	.000	.442	.398	.252
	IR	.181	.000	.	.471	.381	.306
	CD	.349	.442	.471	.	.246	.000
	NER	.001	.398	.381	.246	.	.000
	GDPC	.010	.252	.306	.000	.000	.
N	DFC	21	21	21	21	21	21
	PE	21	21	21	21	21	21
	IR	21	21	21	21	21	21
	CD	21	21	21	21	21	21
	NER	21	21	21	21	21	21
	GDPC	21	21	21	21	21	21

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	GDPC, IR, CD, NER, PE[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: DFC

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.796[a]	.634	.513	66.83402	.634	5.205	5	15	.006	1.790

a. Predictors: (Constant), GDPC, IR, CD, NER, PE

b. Dependent Variable: DFC

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	116255.035	5	23251.007	5.205	.006[a]
	Residual	67001.797	15	4466.786		
	Total	183256.832	20			

a. Predictors: (Constant), GDPC, IR, CD, NER, PE

b. Dependent Variable: DFC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	39.089	22.068		1.771	.097	-7.947	86.125
	PE	2.830	3.295	.545	.859	.404	-4.193	9.852
	IR	-3.681	3.830	-.605	-.961	.352	-11.845	4.482
	CD	-44.664	17.530	-.737	-2.548	.022	-82.028	-7.300
	NER	.131	.637	.063	.205	.840	-1.226	1.488
	GDPC	.098	.042	.975	2.323	.035	.008	.189

a. Dependent Variable: DFC

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	5.4695	351.4631	69.9810	76.24140	21
Residual	-7.65293E1	1.93701E2	.00000	57.87996	21
Std. Predicted Value	-.846	3.692	.000	1.000	21
Std. Residual	-1.145	2.898	.000	.866	21

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	5.4695	351.4631	69.9810	76.24140	21
Residual	-7.65293E1	1.93701E2	.00000	57.87996	21
Std. Predicted Value	-.846	3.692	.000	1.000	21
Std. Residual	-1.145	2.898	.000	.866	21

a. Dependent Variable: DFC

Appendix B

Output of Equation 2

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
CD	.7286	1.57897	21
PE	8.8808	18.44523	21
IR	8.2033	15.73830	21
GDPC	6.7885E2	949.02038	21
EU	1.4128E4	28393.46168	21
DFC	69.9810	95.72273	21

Correlations

		CD	PE	IR	GDPC	EU	DFC
Pearson Correlation	CD	1.000	-.034	.017	.682	-.101	-.090
	PE	-.034	1.000	.967	-.154	.617	-.169
	IR	.017	.967	1.000	-.117	.632	-.210
	GDPC	.682	-.154	-.117	1.000	-.167	.504
	EU	-.101	.617	.632	-.167	1.000	-.083
	DFC	-.090	-.169	-.210	.504	-.083	1.000
Sig. (1-tailed)	CD	.	.442	.471	.000	.332	.349
	PE	.442	.	.000	.252	.001	.231
	IR	.471	.000	.	.306	.001	.181
	GDPC	.000	.252	.306	.	.235	.010
	EU	.332	.001	.001	.235	.	.360
	DFC	.349	.231	.181	.010	.360	.
N	CD	21	21	21	21	21	21
	PE	21	21	21	21	21	21
	IR	21	21	21	21	21	21
	GDPC	21	21	21	21	21	21
	EU	21	21	21	21	21	21
	DFC	21	21	21	21	21	21

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	DFC, EU, GDPC, PE, IR[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: CD

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.289	.319		.906	.379	-.392	.970
	PE	.013	.048	.151	.271	.790	-.089	.115
	IR	-.015	.058	-.147	-.254	.803	-.138	.109
	GDPC	.002	.000	.991	5.948	.000	.001	.002
	EU	8.220E-7	.000	.015	.082	.935	.000	.000
	DFC	-.010	.003	-.594	-3.543	.003	-.016	-.004

a. Dependent Variable: CD

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.849[a]	.720	.627	.96392	.720	7.733	5	15	.001	1.227

a. Predictors: (Constant), DFC, EU, GDPC, PE, IR

b. Dependent Variable: CD

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	35.926	5	7.185	7.733	.001[a]
	Residual	13.937	15	.929		
	Total	49.863	20			

a. Predictors: (Constant), DFC, EU, GDPC, PE, IR

b. Dependent Variable: CD

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.6857	5.3333	.7286	1.34026	21
Residual	-1.23900	1.98567	.00000	.83477	21
Std. Predicted Value	-1.801	3.436	.000	1.000	21
Std. Residual	-1.285	2.060	.000	.866	21

a. Dependent Variable: CD

Appendix C

SPSS Output of Equation 3

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
PE	8.8808	18.44523	21
GDPC	6.7885E2	949.02038	21
AS	2.3521E3	3794.16866	21
DFC	69.9810	95.72273	21
FPI	1.1035E2	16.55598	21
GI	42.7762	13.16176	21

Correlations

		PE	GDPC	AS	DFC	FPI	GI
Pearson Correlation	PE	1.000	-.154	.941	-.169	.503	.144
	GDPC	-.154	1.000	-.209	.504	-.161	.204
	AS	.941	-.209	1.000	-.155	.418	.121
	DFC	-.169	.504	-.155	1.000	-.092	-.063
	FPI	.503	-.161	.418	-.092	1.000	.031
	GI	.144	.204	.121	-.063	.031	1.000
Sig. (1-tailed)	PE	.	.252	.000	.231	.010	.267
	GDPC	.252	.	.181	.010	.243	.188
	AS	.000	.181	.	.251	.030	.300
	DFC	.231	.010	.251	.	.346	.393
	FPI	.010	.243	.030	.346	.	.447
	GI	.267	.188	.300	.393	.447	.
N	PE	21	21	21	21	21	21
	GDPC	21	21	21	21	21	21
	AS	21	21	21	21	21	21
	DFC	21	21	21	21	21	21
	FPI	21	21	21	21	21	21
	GI	21	21	21	21	21	21

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	GI, FPI, DFC, AS, GDPC[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: PE

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.952[a]	.907	.876	6.49995	.907	29.211	5	15	.000	1.849

a. Predictors: (Constant), GI, FPI, DFC, AS, GDPC

b. Dependent Variable: PE

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6170.794	5	1234.159	29.211	.000[a]
	Residual	633.740	15	42.249		
	Total	6804.534	20			

a. Predictors: (Constant), GI, FPI, DFC, AS, GDPC

b. Dependent Variable: PE

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-19.332	11.604		-1.666	.116	-44.066	5.402
	GDPC	.002	.002	.082	.845	.411	-.002	.006
	AS	.004	.000	.890	10.001	.000	.003	.005

DFC	-.011	.018	-.059	-.639	.533	-.050	.027
FPI	.155	.097	.139	1.599	.131	-.052	.362
GI	.015	.117	.011	.131	.898	-.233	.264

a. Dependent Variable: PE

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-2.5482	80.7566	8.8808	17.56530	21
Residual	-1.26274E1	6.29143	.00000	5.62912	21
Std. Predicted Value	-.651	4.092	.000	1.000	21
Std. Residual	-1.943	.968	.000	.866	21

a. Dependent Variable: PE

