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Understanding Farmers' Vulnerability to Environmental Change in Semi-Arid Region: A Key to Agricultural Sustainability

Jude Nwafor Eze[1], **Patience Chinyelu Onokala**[2]

[1]Farming System Research Programme, National Cereals Research Institute, Badeggi, Niger State, Nigeria
[2]Department of Geography, University of Nigeria, Nsukka Enugu State, Nigeria

✉**Corresponding author:**
Farming System Research Programme, National Cereals Research Institute, Badeggi, Niger State, Nigeria
E-mail: jn.eze@ncribadeggi.org.ng
Phone: +2348067199525

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ABSTRACT

The study assessed the extent of farmers' vulnerability to environmental change in the semi-arid region of Nigeria. The research seeks to proffer a solution to farmers' vulnerability to environmental change and promote Agricultural sustainability in the face of climate change in dryland areas. The study classified biophysical and socio-economic indicators of vulnerability into exposure, adaptive capacity, and sensitivity to determine the level of farmers' vulnerability to environmental change, which is important to agricultural sustainability. The study adopted a survey design and the method utilized for the study was a questionnaire administered to 400 farmers in the study area. The levels of farmers' vulnerability identified in this study were 4. The vulnerability levels identified include very high with a mean index of 1.20, high with a mean index of 2.44, low with a mean index of 4.00, and very low with the mean index of 6.94. Thus, the extent of farmers' vulnerability to environmental change could be attributed to the availability of infrastructural facilities which is more in some areas than the other. The availability of infrastructural facilities which drives economic growth in the study area, enhance the coping capacity of the farmers to environmental change. Consequently, there is a need to integrate adaptation options into the community development process for Agricultural sustainability. These measures are poverty reduction, good agricultural practices and development of cattle ranches.

Keywords: Agricultural Sustainability, Farmers' Vulnerability, Adaptive Capacity, Exposure, Sensitivity, Environmental change

1. INTRODUCTION

Human activities for over 100 years on the earth surface have intensely changed the environment. Consequently, the environmental changes due to human interference have resulted in environmental pollution, land degradation, desertification, climate change, drought and biodiversity loss (Arora et al, 2018). These issues have directly affected the quality and sustainability of Agriculture. Desertification constitutes severe environmental and socio-economic threats to the world. United Nation Convention to Combat Desertification (2016), states that desertification directly affects 2.5×10^8 people and one-third of the Earth surface (over 4.0×10^7 km^2). Desertification ranks highest among the barriers (extreme poverty, drought, land degradation, floods) to sustainable development (Liu, *et al*., 2018). Desertification, land degradation and drought (DLDD) processes have increased in the last century, affecting more than 20% of all cultivated areas, 30% of natural forests, and 25% of grasslands (UNCCD, 2016). Each year an estimated 24 billion tons of fertile soil is lost due to erosion in the world's croplands (UNDP, 2016).About 500 million hectares of farmland globally has been abandoned due to drought and desertification resulting in major social, environmental, and agricultural constraint (UNEP, 2017). Moreover, severe drought due to climate change exacerbates crop production, by causing nutrient immobilization and salt accumulation in soils making them dry, unhealthy, saline and finally infertile (Arora, 2019).

Africa is among the most affected by desertification, drought and land degradation. Over a billion hectares are affected by desertification in Africa. UNEP has estimated that Africa loses approximately $ 9 billion a year as a result of desertification. Human interference such as overgrazing, over-cultivation and deforestation practices undermines the productivity of the lands (Eze and Onokala, 2020). These causes and effect of desertification are proven major socio-economic and environmental problems for farmers dwelling in dryland regions of the world (Hooke and Sandercock, 2017). Desertification is the predominant player in the collapse of agricultural systems in areas where environmental changes and disturbances do not allow balance in the ecosystems (Masoudi et al., 2018). Such imbalance in the ecosystem contributes to farmers' vulnerability to environmental change.

The vulnerability is the extent a system is prone to, or unable to adapt to the negative effect of climate or environmental change (IPCC, 2014). The vulnerability concept differs based on researchers' disciplines, the method used, and the objectives the researcher intends to achieve. Therefore, the study made use of existing methodology and concepts as a guide to analysing the vulnerability of farmers to environmental change in the semi-arid region of Nigeria. The approaches to assessing vulnerability to ecological problems were divided into three. These are the biophysical (climate science point of view), socioeconomic (social science point of view) and integrated assessment approach. The biophysical vulnerability assesses the extent of damage on human society or ecological structure caused by environmental change. It was assessed from the perspective of the amount of loss. For instance, the impacts of climate change can be analysed by modelling the relationships between crop yields and climatic variables (Kaiser et al. 1993). The main disadvantage of the biophysical approach is that it concentrates only on physical changes, such as a reduction in crop production, vegetation decrease, migration. Thus, the biophysical approach gives the quantities of crop loss as a result of a hazard that occurred. However, the approach does not provide what that particular quantities lost means to different farmers.

Socio-economic vulnerability is described as a set of socio-economic factors that determine community's ability to adapt to stress or change in the environment (Allen, 2003). Moreover, the social vulnerability can be determined using adaptive indicators such as assets, inequality, housing quality, income, access to insurance (Blaikie et al., 1994). The main disadvantage of socio-economic vulnerability approach is that it concentrates on differences among individuals or farmers in relation to socio-economic factors. However, communities differ both on environmental and socio-economic factors. Two communities with the same socio-economic characteristics but have different environmental characteristics can have different levels of vulnerability (Eze et al., 2018b).

Integrated vulnerability assessment approach: This approach assesses the vulnerability of communities by combining social, economic and biophysical indicators. Thus, the integrated vulnerability approach was in the (IPCC, 2014) definition, which describes vulnerability as a function of sensitivity, exposure and adaptive capacity. The main limitation of this approach is that there is no generally accepted way of combining the indicators of biophysical vulnerability and socio-economic vulnerability (Deressa et al.

2008). Despite the limitation, its results can serve as a guide to policy-makers in decision making (Deressa et al. 2008). Moreover, the integrated assessment approach takes care of the weaknesses of socio-economic and biophysical approaches (Eze et al. 2018a). Thus, we adopted this method to analyse the vulnerability of farmers' to environmental change in the semi-arid region of Nigeria. Consequently, poor continents of the world, such as Africa, that are predominantly dependent on farming have been as one of the most vulnerable regions to the impacts of environmental changes, particularly desertification (Reid and Vogel, 2008).

Desertification is significantly noticeable in the extreme northern states in Nigeria. It is the most pressing environmental problem in Northern Nigeria, particularly in the semi-arid region. The sign of desertification in the semi-arid region of Nigeria is the gradual shift in vegetation from grasses, bushes, and occasional trees, to expansive areas of desert-like sand (Musa, 2012). Oladipo, (1993), states that about 140,000km2 of Nigeria is predisposed to desertification. Moreover, Northern Nigeria forms a grazing area for about 90% of the cattle population in the country (Oladipo, 1993). Thus, the survival of farmers particularly, crop and livestock farmers are endangered by desertification in the States of extreme northern Nigeria (Nyong et al., 2003), thus increasing the vulnerability of farmers to environmental change. The region experiences annual rainfall as low as 200 mm and as high as 600 mm (Odjugo, 2003).

Studies on vulnerability to environmental change have been undertaken in various parts of arid and semi-arid regions of the world (Emordi, 2013; Nneji, 2013; Molinari, 2014; Sepehr et al. 2014; Hosseinizadeh et al. 2015, Olagunju, 2015, Eze, 2018). Majority of the studies concentrated on land vulnerability, causes and effects on the land, mitigation and the extent of environmental change. There is little or no work done on the degree of vulnerability of farmers to environmental change which has much to offer in terms of policy decisions. Policies on adaptation to hazard in the semi-arid region of the country were prepared without experimental foundations placed on the degree of farmers' vulnerability to environmental change. Against this background, this research assesses the degree of farmer's vulnerability to environmental change to show the level of farmers' vulnerabilities to changes in the environment, hence to highlight the implications of these variations in the degree of vulnerability and underlines the need to come up with the option to combat some of the environmental changes such as desertification and how to integrate these options into the national development process. The figure produced from the cluster analysis can be used as a basis by the government/policymakers, in planning, in terms of communities that need specific or urgent attention during the implementation of programmes to combat environmental hazards in the study area.

2. MATERIALS AND METHODS

Study Design

A survey design was used in this work. The study area consisted of 443,375 households. However, agriculture is the mainstay of the economy of the study area. Several individuals are engaged in one form of farming activities or the other. Over 80% of the households in the study area are farmers, with only a few households particularly in the large urban centres who are engaged in non-farming activities (Musa and Shaib 2010). However, the study adopted Yamane (1967) sampling size method. Thus, 80% of 443,375 (households) is 354, 7500 (farmers) in the study area. Since 354,7500 farmers in the study area were more than 100, 000 according to Yamane (1967) sampling size, therefore, 400 farmers were proportionally selected and interviewed based on the relative population of each LGA in the study area. Purposive sampling technique was employed to select the communities, key informants, and farmers studied. Two key informants were selected for in-depth interviews in each LGA giving a total of 34 respondents.

Moreover, the farmer's vulnerability indicators such as adaptive capacity (access to irrigation, practice of crop rotation, cover crop, elimination/reduction in soil tillage, use of improved seed, practice of agroforestry, have access to extension workers etc),sensitivity (farmers that were affected due to climate and environmental change leading to crop failure, reduction in crop yield, etc)and exposure (farmers exposed to over-grazing, over-cultivation, drought, dunes etc)were carefully selected to determine the ability of farmers to cope with environmental change, how farmers were affected positively or adversely by the inconsistency in climate (Eze *et al*, 2018a), and the extent to which farmers were prone to environmental change (IPCC, 2014, Eze et al 2018a). Consequently, the higher the percentage of the total farmers is with more adaptive capacity, the lesser the vulnerability. Also, the higher the percentage of the total farmers exposed to drought, dunes erosion etc the higher the vulnerability. Besides, the higher the percentage of the total farmers affected due to change in the environment resulting to crop failure, etc the higher the vulnerability.

Data Analysis

The data collected on farmers' adaptive capacity, sensitivity and exposure to environmental change were analysed using Percentages, Principal Component Analysis (PCA), Correspondence Analysis (CA), Farmers' Vulnerability Index and Cluster Analysis.

PCA was run on adaptive capacity, sensitivity and exposure to extract the component scores. The result of the component scores of the first principal component was taken to serve as a weight because it explains the majority of the variations in the dataset and also used in the computation of the vulnerability index of the farmers in different communities. Consequently, the correspondent analysis was also run on adaptive capacity, sensitivity and exposure variables for data reduction. Consequently, the results of both PCA and CA were used to compute the Farmers' Vulnerability Index (FVI) adopted from Deressa et al 2008, which states that Vulnerability= (adaptive capacity) - (sensitivity-exposure)……………………………………………………………………………………1

Based on the methodology adopted in this work, the equation was modified to accommodate the vulnerability variables used as follows

$FVI=[(wt_{a1}ac_1+wt_{a2}ac_2...wt_{an}ac_n)]-[(wt_{s1}st_1+wt_{s2}st_2...wt_{sn}st_n)+(wt_{e1}ex_1+wt_{e2}ex_2...wt_{en}ex_n)$……………………………2

FVI represents farmers' vulnerability index. wt_{ase1}-wt_{asen} represents the weight obtained from the first principal component scores. ac_1-ac_n represents the adaptive variables, st_1-st_n sensitivity variables and ex_1-ex_n exposure variables. Thus, vulnerability of farmers increases with a lower index values and decreases with a higher index values. Cluster analysis was performed on the farmers' vulnerability indices. The analysis was carried out to cluster the communities according to their level of vulnerability using the Ward Method of Agglomeration.

3. RESULTS

Table 1, shows the percentage of respondents that have access to extension workers (31.6%), practice agroforestry (36.5%), cover crop (31.5%),crop rotation (36.3%,), use of irrigation (35.6%), practice reduction/elimination of soil tillage (34.9%) and use improved crop varieties (34.1%). The results indicate that majority of the farmers in the study area have low adaptive capacity to cope with environmental change in the study area.

Table 1: Farmers' Adaptive Capacity Indicators

LGA	Have access to extension workers (%)	Adoption of agroforestry (%)	Practice cover crop (%)	Practice of crop rotation. (%)	Use of irrigation (%)	Reduction/ Elimination of soil tillage (%)	Use of improved crop variety (%)
Bade	54	56	36	55	20	51	41
Busari	13	19	18	13	15	18	20
Damaturu	76	70	58	85	57	57	58
Fika	53	54	36	33	57	25	36
Fune	28	36	22	22	63	27	24
Geidam	08	19	13	24	11	31	26
Gujba	42	52	47	52	61	48	50
Gulani	41	36	44	57	64	53	53
Jakusko	15	20	13	16	13	20	19
Karasuwa	09	20	10	15	11	21	20
Machina	07	15	16	18	9	30	17
Nangere	09	15	24	26	55	28	21
Nguru	73	70	61	74	28	65	60
Potiskum	86	75	68	77	74	54	65
Tarmuwa	11	35	44	28	50	20	29
Yunusari	6	20	11	9	8	22	21
Yusufari	07	09	14	13	10	24	19
Mean	31.6	36.5	31.5	36.3	35.6	34.9	34.1

Source: Fieldwork 2019 (Computed by the author)

The result on Table 2, which shows sensitivity indicators, reveals the percentage of the respondents that lost their livestock to a shortage of pasture (74.4%), relocated due to shortage of rainfall amount (22.1%), experienced vegetation decrease (80.4%,) had reduction in crop yield due to land degradation (78.4%), relocated due to dunes encroachment (14.1%) and affected by crop failure due to drought (77.3%).

Table 2: Farmers' Sensitivity Indicators

LGS	Lost livestock due to shortage of pasture (%)	Relocated due to due to low rainfall amount)	Vegetation decreasing (%)	Reduction in crop Yield due to land degradation (%)	Relocated due to sand dune (%)	Affected by crop failure due to drought (%)
Bade	75	20	68	68	16	60
Busari	86	23	97	96	23	97
Damaturu	48	0	42	45	0	44
Fika	77	6	75	71	0	64
Fune	81	53	90	86	0	68
Geidam	60	34	97	97	12	97
Gujba	80	0	76	68	0	70
Gulani	77	0	77	69	0	66
Jakusko	69	34	96	84	31	97
Karasuwa	75	30	98	95	36	95
Machina	79	33	95	97	24	93
Nangere	76	48	85	73	0	97
Nguru	55	5	45	53	6	48
Potiskum	44	0	44	51	0	35
Tarmuwa	89	4	89	85	5	91
Yunusari	97	42	96	96	42	94
Yusufari	96	44	97	98	44	98
Mean	74.4	22.1	80.4	78.4	14.1	77.3

Source: Fieldwork 2019 (Computed by the author)

The results indicate that majority of the farmers were highly sensitive to climate and environmental change, except for the impact of dunes and rainfall amount.

Table 3 shows the percentage of respondents exposed to environmental change. Such hazards include farmlands affected by droughts (75.1%), over-cultivation (73.1%), dunes (18.5%), soil erosion (67.1%), land conflict (68.6%) and overgrazing (67.6%). The results indicate that the majority of the farmers were highly exposed to the indicators of environmental change, except on loss of farmlands to dunes.

Table 3: Farmers' Exposure Indicators

LGA	Farmlands affected by drought (%)	Farmlands affected by over-cultivation (%)	Farmlands lost to dunes (%)	Farmlands affected by soil erosion (%)	Farmers Affected by land conflict (%)	Affected by over-grazing (%)
Bade	69	76	6	59	67	72
Busari	95	97	49	92	76	81
Damaturu	45	38	0	36	44	37
Fika	59	56	0	47	68	40
Fune	79	75	0	87	91	93
Geidam	94	97	12	68	69	75
Gujba	50	47	0	55	54	38
Gulani	53	48	0	46	53	46

Jakusko	98	96	35	80	76	82
Karasuwa	97	98	40	64	86	86
Machina	95	94	53	74	70	79
Nangere	75	80	0	80	85	76
Nguru	64	49	5	51	65	70
Potiskum	40	36	0	34	28	31
Tarmuwa	70	64	0	76	75	74
Yunusari	96	97	59	97	78	83
Yusufari	98	96	55	96	81	86
Mean	75.1	73.1	18.5	67.1	68.6	67.6

Source: Fieldwork 2019 (Computed by the author)

Table 4 shows the farmers' vulnerability indices in all the 17 communities that make up the study area. Thus, farmers in Yunusari have the highest vulnerability with an index of0.88, while farmers in Potiskum have the least vulnerability with an index of 7.29.

Table 4: Indices of Farmer's Vulnerability to Environmental change in the Study Area

Communities	Index	Rank
Bade	4.13	6
Busari	1.45	13
Damaturu	6.97	2
Fika	3.65	7
Fune	2.39	11
Geidam	2.51	8
Gujba	4.17	5
Gulani	4.25	4
Jakusko	1.46	12
Karasuwa	1.42	14
Machina	0.94	16
Nangere	2.41	10
Nguru	6.56	3
Potiskum	7.29	1
Tarmuwa	2.46	9
Yunusari	0.88	17
Yusufari	1.06	15

Source: Fieldwork 2019 (Computed by the author)

The result of the Cluster Analysis shows four clusters representing different vulnerability levels in the study area (Table 5). The dendrogram (Figure 1) reveals that there were six communities in the first cluster with a mean index of 1.20, four communities in the second cluster with a mean index of 2.44, three communities in the third cluster with a mean index of 6.94and four communities in the fourth cluster with a mean index of 4.00.

Table 5: A Summary of Results of the Cluster Analysis on Farmers' Vulnerability in the 17 Communities of the Study Area

Very High Vulnerability (Mean Index = 1.20) (First cluster)	**High Vulnerability (Mean Index = 2.44) (Second cluster)**	**Very Low Vulnerability (Mean Index = 6.94) (Third cluster)**	**Low Vulnerability (Mean Index = 4.00) (Fourth cluster)**
Yunusari, Karasuwa, Machina, Yusufari Busari, Jakusko	Fune, Nangere, Geidam, Tarmuwa	Damaturu, Potiskum Nguru	Gujba, Gulani, Bade, Fika

Source: Fieldwork 2019 *(*Computed by the author)

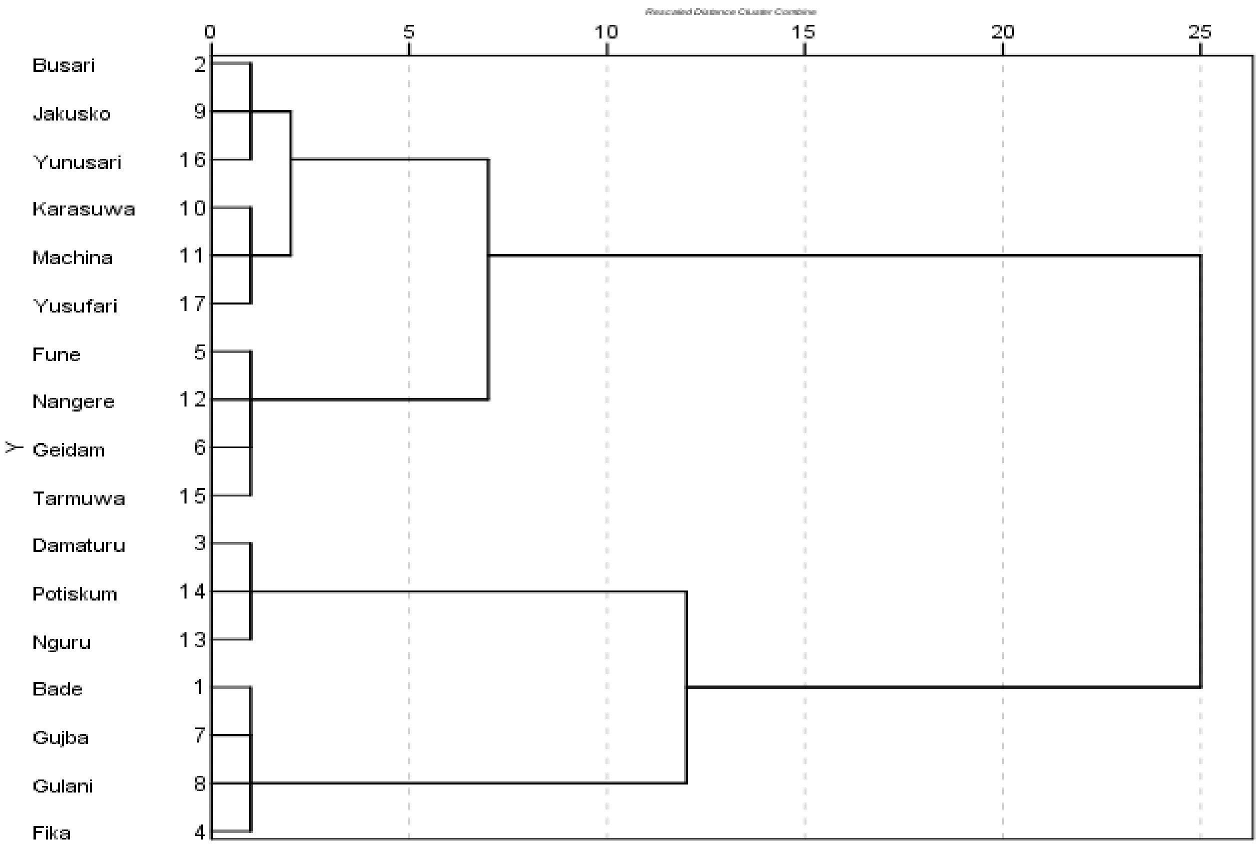

Figure 1: Dendrogram showing hierarchical clustering of the vulnerability indices of the farmers in the semi-arid region of Nigeria

4. DISCUSSION

The degree of farmers' vulnerability to environmental change in the study area varies from place to place. The farmers in Yunusari, Karasuwa, Machina, Yusufari Busari, Jakusko, were the most vulnerable with the mean index of 1.20. Also, farmers in Fune, Nangere, Geidam, and Tarmuwa were second to the most vulnerable communities with a mean index of 2.44. Many scholars have argued that the higher the percentage of the total population with low adaptive capacity (Table 1), high sensitivity (Table 2) and exposure (Table 3) in a given area, the higher the vulnerability of the population (O'Brien et al. 2006; Deressa Hassan and Riggler, 2008; Eze et al. 2018a). Thus, the vulnerability of farmers in the communities with a mean index of 1.20 and 2.44 was high. Predominant farmers have poor access to improved seed, extension services, irrigation facility, soil management practices resulted in low adaptive capacity. Moreover, increased crop failure, low crop yield, high loss of livestock, high rate of migration gave rise to high sensitivity and high exposure (farmers affected by drought, over-grazing, over-cultivation, soil erosion, land conflicts and dunes) to environmental change in semi-arid. Conversely, the farmers in Damaturu, Potiskum, and Nguru communities were the least vulnerable with the mean index of 6.94 whereas the farmers in Gujba, Gulani, Fika and Bade communities have low vulnerability with a mean index of 4.00 (Table 5). Deressa, Hassan and Riggler, (2008) argued that the higher the percentage of the total farmers with high adaptive capacity, low sensitivity and exposure, the lesser the vulnerability. Thus, the vulnerability of farmers in Damaturu, Potiskum, Nguru, Gujba, Gulani, Fika and Bade communities were low because the greater percentage of the sampled population has the high adaptive capacity (have access to improved seed, extension services, irrigation facility, good soil management practices), low sensitivity (low crop failure, high crop yield, low rate of livestock mortality, low rate of farmers' migration), low exposure (fewer farmers exposed to over-grazing, over-cultivation, drought, and dunes) to environmental change in the semi-arid.

Therefore, the ability of a given population to cope with or affected positively or adversely by ecological change depends on the availability of infrastructural facilities (Eze et al. 2018a), and the extent to which farmers were prone to environmental change (IPCC, 2014; Eze et al. 2018a). Therefore, the extent of vulnerability of farmers to environmental change in the study area could also be the availability of infrastructural facilities which are more in some communities than the other. The availability of infrastructural facilities which drives economic growth in an area, enhance the coping capacity of the farmers (Deressa, Hassan and Riggler, (2008). The communities such as Bade and Nguru, Damaturu, Fika, Gujba, Gulani, and Potiskum have government establishments, good markets, schools, banks and industries than other communities, hence making the farmers have access to extension services, irrigation facilities, loan facilities, improved crop varieties etc. Therefore, the availability of infrastructural facilities provided the farmers with high ability to cope with the hazards. The result of this study, therefore, is in line with the work carried out by O'Brien et al. 2006; Deressa Hassan and Riggler, 2008; Eze et al. 2018a). They used an integrated vulnerability assessment approach and their calculations of vulnerability indices were able to show the variations in vulnerability levels in their various study areas.

Recommendations

The vulnerability of Farmers to environmental change can be reduced through local management and macro policy approaches that promote the sustainability of land resources (Eze et al 2020). Thus, the following should be adopted to reduce the adverse effect of environmental change on farmers and promote environmental sustainability in the semi-arid region of Nigeria.

Poverty Reduction

Rural poverty can be reduced through livelihood diversification. These can be made possible by establishing industries, capacity building and giving loans to farmers. Giving finance and technical assistance to farmers will encourage them to go into small and medium scale businesses such as poultry farming, fish farming, trades and services.

Adoption of Ranching System

In the study area, the predominant grazing type is continuous. This is a grazing type where cattle graze freely from one place to the other. This continuous grazing has contributed to over-grazing and communal clashes. Therefore, there is need to adopt silvopasture. Silvopasture ranching involves integrating grazing of animals and forestry in a mutually beneficial way in a given area. This type of ranching system maintains the biodiversity, soil fertility and increase animal production and income. The development of cattle ranches will also remove the problems of overgrazing and communal clashes in the study area and Nigeria in general.

Adoption of Good Agricultural Practices

This study shows that the total respondents involved in the practice of agroforestry, cover crop, crop rotation, irrigation etc were below 40%. Therefore, to enhance environmental sustainability and reduce environmental hazards in the semi-arid region, there is need to adopt good agricultural practices.

5. CONCLUSION

The predominant farmers in the semi-arid region of Nigeria are highly vulnerable to environmental change. Moreover, the interaction of hazards with the socio-economic status has contributed to the high level of farmers' vulnerability to environmental change. Thus, there is a need for integrated rural development schemes aimed at alleviating poverty and increasing the adaptive capacity of farmers to environmental change in the semi-arid region of Nigeria. Finally, the study has successfully used integrated vulnerability assessment approach to determine the extent of farmers' vulnerability to environmental change, which has much to offer in terms of policy decisions on how to reduce the farmers' vulnerability to environmental change and promote environmental sustainability in semi-arid region of Nigeria.

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Author's Contributions

Jude Nwafor Eze is the principal investigator. His contributions were encompassing (study design, data collection, statistical analysis and the general compilations).

Patience Chinyelu Onokala is a co-investigator. Her contribution was on literature review.

Conflict of Interest

We, write to attest that the article submitted to *Climate Change* Journal for consideration has not been published previously. It is not under consideration for publication elsewhere and that its publication is approved by us (Jude Nwafor Eze and Patience Chinyelu Onokala) and openly by the authorities in charge where the research work was conducted. However, if the article is accepted for

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All data associated with this study are present in the paper.

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