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Original Article

The Role of Nature-Based Solutions in Building Resilience to Climate Change: An Analysis Based on the IPCC Vulnerability Framework in Kenya

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ABSTRACT

Adaptation to climate change is imperative given that it continues to pose severe and escalating risks to humanity and the ecological systems on which it depends. This calls for Nature-based solutions in climate adaptation since they involve the sustainable management and restoration of ecosystems while improving human livelihoods. However, despite their importance, the potential of Nature-based solutions in building resilience to climate change has not been rigorously studied. Also, no studies have done a joint analysis of the effect of Nature-based solutions on the three dimensions of vulnerability to climate change (exposure, sensitivity, and adaptive capacity. This study thus aimed to undertake a joint analysis of the role of nature-based solutions in building resilience to climate change based on its influence on the three dimensions of vulnerability. Data analysis was done using the multivariate analysis of variance (MANOVA). The study's multivariate and univariate tests found that nature-based climate solutions influenced the three dimensions of climate change vulnerability (Exposure, sensitivity, and adaptive capacity). The three dimensions of vulnerability were also found to be interconnected and have various relationships between them. The study will help understand how nature-based solutions build resilience to climate change and inform their design and implementation.

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INTRODUCTION

Adaptation to climate change is imperative given that it continues to pose severe and escalating risks to humanity and the ecological systems on which it depends (Masson-Delmotte et al., 2021). Given their interdependent nature, adaptation mechanisms that improve ecological systems also improve human systems (IPCC, 2022). This calls for Nature-based solutions in climate adaptation since they involve the sustainable management and restoration of ecosystems while improving human livelihoods. The International Union for Conservation of Nature (IUCN) defines Nature-based solutions as "actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits'' (IUCN, 2016). Nature-based solutions thus improve human well-being and protect biodiversity through the benefits that are provided by ecosystems, that is, ecosystem services (IUCN, 2016; Munang et al., 2013).

Nature-based solutions build resilience to climate change by influencing the three interconnected dimensions of vulnerability, including exposure and sensitivity (potential impacts) and adaptive capacity (Seddon et al., 2020; Anjum et al., 2024). In this process, Nature-based solutions act as the interface of the socioeconomic system and the ecological system through the protection, restoration, and sustainable management of ecosystems to improve the delivery of ecosystem services, which builds the resilience of the socioecological system (Seddon et al., 2020). This is aligned with the IPCC-formalised vulnerability framework for social-ecological systems, which integrates the vulnerability of ecosystems with the vulnerability of socioeconomic systems and recognises the three dimensions of vulnerability (Seddon et al., 2020). Thus, Nature-based solutions, if developed and implemented well, could help to reduce socioeconomic and ecological vulnerability by reducing exposure and sensitivity, and increasing adaptive capacity (Anjum et al., 2024; Seddon et al., 2020).

Nature-based solutions help address other challenges beyond climate change and biodiversity loss and are thus not only recognised as a climate change adaptation strategy (IUCN, 2020; European Commission, 2021). The seven societal challenges that Nature-based solutions can address include climate change mitigation and adaptation, Disaster risk reduction, Economic and social development, Human health, Food security, Water security, and reversing environmental degradation and biodiversity loss (IUCN, 2020; Dunlop et al., 2024). Nature-based solutions to climate change help to achieve many development goals in addition to climate change adaptation and the improvement of ecosystems (United Nations, 2022). Therefore, Nature-based solutions are a unique adaptation strategy since they address broader societal challenges and deliver diverse benefits within the paradigm of sustainable development (IUCN, 2016; European Union, 2023; Vassileva, 2023; Secretariat of the Convention on Biological Diversity, 2009).

Nature-based solutions encompass a wide range of activities, including landscape restoration, inclusion of green and blue infrastructure in urban areas, and applying ecosystem-based principles to agricultural systems (Seddon et al., 2020). By helping to protect, sustainably manage, and restore ecosystems, nature-based solutions sustainably increase the productivity of landscapes and seascapes, including agricultural production, which is directly dependent on the ecological services provided by natural ecosystems (Boyle and Kuhl, 2021). Nature-based solutions help to increase agricultural production by improving the quality of the environment (Boyle and Kuhl, 2021). This is achieved by the adoption of regenerative agricultural practices, which reduce production costs and sustainably increase yields, hence leading to higher revenues for farmers

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(Nair, 2016; Hawken, 2017; FAO, 2009). Farmers could also use the higher revenues to enhance their production, diversify their livelihood activities, or make savings, hence reducing their vulnerability to the impacts of climate change.

However, despite their importance, the potential of Nature-based solutions in building resilience to climate change has not been rigorously studied (Seddon et al., 2020). Also, no studies have done a joint analysis of the effect of Nature-based solutions on the three dimensions of vulnerability to climate change (exposure, sensitivity, and adaptive capacity), and how they influence each other regarding this, given their interconnected nature. This study thus aimed to undertake a joint analysis of the role of nature-based solutions in building resilience to climate change based on its influence on the three dimensions of vulnerability. The study will help understand how nature-based solutions build resilience to climate change and inform their design and implementation.

METHODOLOGY

Study Area

The study was undertaken in Kakamega County, Kenya. The county is in Western Kenya and has a surface area of 3,038 KM^2. The population of the county is 1,867,579 people, which includes 897,133 males, 970,406 females, and 40 intersex (Government of Kenya, 2019). The country has uniformly distributed rainfall, although the heaviest rainfall occurs from March to July, and the least occurs from December to February. The annual precipitation ranges from 1280.1 mm to 2214.1 mm. Temperature ranges between 18 ˚c and 29 ˚c. The hottest months are from January to March, while the coldest are July and August (Government of Kenya, 2023). The county has an average humidity of 67 percent (Government of Kenya, 2023). There are three main ecological zones in the county, namely, the Upper Medium (UM) and the Lower Medium (LM) (Government of Kenya, 2023).

The county has been experiencing an increasing trend in minimum and maximum temperature since the 1960s is projected to persist in the future. In addition, projections in precipitation show increasing inter-annual rainfall variability, an increase in the number of episodes of consecutive days without rainfall, and a decrease in episodes of consecutive days with rainfall. Rainfall periods are becoming shorter and intense, leading to extreme rainfall events, while there is a marked increase in dry periods (Government of Kenya, 2023).

Research and Sampling Design

A descriptive study design was used in carrying out the study. Besides, a multistage sampling design was used in collecting the data for the study. This first involved proportionately deciding the number of households to be studied per the three locations identified for the study through stratified sampling. The households to be studied per study location were then decided using a systematic sampling technique. The 385 households identified for the study were determined using Cochran’s (1963) method.

Data Collection

Data collection was done using a household questionnaire survey. Moreover, data were also collected using focused group discussions and key informant interviews. These helped to gain deeper insights regarding the study’s subject and shed more light on the observation based on analysis of data collected using the household survey questionnaire. Field-based observation was also used, especially regarding the identification of the various nature-based solutions practised in the study area.

Data Analysis

Data analysis was done using descriptive statistics. Moreover, data analysis was done using a general linear model. This involved the use of the multivariate analysis of variance (MANOVA) to undertake a joint analysis of the role of nature-based solutions in building resilience to climate variability.

The adoption of nature-based solutions was measured using a composite index, which is the nature-based solutions adoption index. The

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components used in developing the nature-based solutions adoption index included the various on-farm nature-based practices undertaken to address climate change impacts, including practices related to organic agriculture, soil conservation, water harvesting, and forest landscape restoration. Firstly, composite indices were calculated for the four components, and the average was used to determine the nature-based solutions adoption index. In developing the composite indices, the indicators were allocated weights using principal component analysis. The composite index was tested for certainty using the propagation of standard errors approach. Also, it was tested for sensitivity based on the coefficient of determination (R2) in multiple regression analysis. The adoption of nature-based solutions was then categorised by grouping the nature-based solutions adoption index values into four groups that is very low, low, high, and very high.

Moreover, the level of resilience of households to climate variability was measured based on the IPCC vulnerability framework. In doing this, a household's exposure to climate change was measured based on their perception of the occurrence of climatic hazards, including droughts, floods, and others. Moreover, sensitivity to climate change was measured based on the perception of the level of severity of the effect of climate change on a household's livelihood. Further, a household's adaptive capacity to the impacts of climate change was measured based on the level of a household's perception of its capacity to address the impacts. Data encoding was used to convert the categorical variables used in measuring a household's perception of climate change exposure, sensitivity, and adaptive capacity to continuous variables.

RESULTS

Descriptive Statistics

The descriptive statistics found the levels of adoption of nature-based solutions to be very low (25%), low (27%), high (24%), and very high (24%).

Households that had very low adoption of nature-based solutions for climate change were found to have a higher average score of climate change exposure (0.42844) compared to those who had a low adoption (0.38345), high adoption (0.35815), and very high adoption (0.36776). However, the households that had very high adoption of nature-based solutions had a slightly higher exposure to climate change compared to those who had a high level of adoption.

Households that had a very low adoption of nature-based solutions for climate change were found to have a higher average score of climate change severity (0.51220) compared to those that had a low adoption (0.45842) and high adoption (0.44115). However, households that had very high adoption of nature-based solutions for climate change had a higher severity of climate change compared to those who had a high level of adoption.

Further, households that had very low adoption of nature-based solutions for climate change had a lower average score of climate change adaptive index (0.37996) compared to those who had a low adoption (0.40095), and high adoption (0.42490). However, households that had a very high adoption of nature-based solutions for climate change had a higher adaptive capacity compared to those who had a high level of adoption. This is as in Table 1.

Table 1: Descriptive Statistics of the Study

Descriptive Statistics				
	Nature-based solutions adoption	**Mean**	**Std. Deviation**	**N**
Climate change exposure index	Very Low	0.42844	0.172194	96
	Low	0.38345	0.157724	102
	High	0.35815	0.167720	93
	Very High	0.36776	0.164094	94
	Total	0.38473	0.166911	385
	Very Low	0.51220	0.214965	96

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Descriptive Statistics				
	Nature-based solutions adoption	**Mean**	**Std. Deviation**	**N**
Climate change severity index	Low	0.45842	0.178748	102
	High	0.44115	0.211256	93
	Very High	0.52310	0.172335	94
	Total	0.48345	0.197263	385
Adaptive capacity index	Very Low	0.37996	0.171284	96
	Low	0.40095	0.167828	102
	High	0.42490	0.160712	93
	Very High	0.34983	0.172763	94
	Total	0.38902	0.169792	385

Box's Test of Equality of Covariance Matrices

The Box's Test of equality of covariance matrices statistical test was found to be non-significant (*P* = 0.591>0.05), meaning that the test of homogeneity had been met since the matrices are equal. This is as in Table 2.

Table 2: Box's Test of Equality of Covariance Matrices

Box's Test of Equality of Covariance Matrices	
Box's M	16.256
F	0.890
df1	18
df2	507915.556
Sig.	0.591

Bartlett's Test of Sphericity

Furthermore, Bartlett's Test of Sphericity statistical test was found to be significant (P = 0.000<0.05), meaning that the three variables that represented the dimensions of climate vulnerability are correlated enough such that the observed correlation matrix diverges significantly from the identity matrix. This is as shown in Table 3.

Table 3: Bartlett's Test of Sphericity

Bartlett's Test of Sphericity	
Likelihood Ratio	0.000
Approx. Chi-Square	375.253
Df	5
Sig.	0.000

Multivariate Test

The multivariate test found the *F*-Ratios of all the test statistics (i.e., Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root) to be significant. That is Pillai's Trace (P = 0.002 < 0.05), Wilk's Lambda (P = 0.002 < 0.05), Hotelling's Trace (P = 0.002 < 0.05), and Roy's Largest Root (0.001 < 0.05). This shows that the adoption of nature-based solutions for climate change had a significant effect on households' resilience to climate change. This is as in Table 4.

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Table 4: Multivariate Test of the Effect of Nature-based Solutions on Household's Climate Change Exposure, Sensitivity, and Adaptive Capacity

Multivariate Tests						
	Effect	**Value**	**F**	**Hypothesis df**	**Error df**	**Sig.**
Intercept	Pillai's Trace	0.973	4553.39	3.000	379.000	0.000
	Wilks' Lambda	0.027	4553.39	3.000	379.000	0.000
	Hotelling's Trace	36.043	4553.39	3.000	379.000	0.000
	Roy's Largest Root	36.043	4553.39	3.000	379.000	0.000
Nature-based solutions adoption	Pillai's Trace	0.068	2.945	9.000	1143.000	0.002
	Wilks' Lambda	0.933	2.955	9.000	922.537	0.002
	Hotelling's Trace	0.070	2.953	9.000	1133.000	0.002
	Roy's Largest Root	0.042	5.332	3.000	381.000	0.001

Univariate Tests

To further understand the effect of the adoption of nature-based solutions for climate change on the household's resilience to climate change, univariate tests were undertaken. This was done to understand the effect of the adoption of nature-based solutions for climate change on the three dimensions of climate change vulnerability. This first involved undertaking the Lavene's Test to find out if all the dependent variables met the assumption of homogeneity. The Lavene's Test was found to be non-significant for all the dependent variables, meaning that they all met the assumption of homogeneity. This is as in Table 3.5.

Table 5: Lavene's Test of Equality of Error Variances

Levene's Test of Equality of Error Variances				
	F	**df1**	**df2**	**Sig.**
Climate change exposure index	0.069	3	381	0.977
Climate change severity index	5.535	3	381	0.111
Adaptive capacity index	0.678	3	381	0.566

The analysis of ANOVA for each of the dependent variables found that there was a significant difference between the adoption of nature-based solutions for climate change and all the dimensions of climate change vulnerability, that is, exposure, sensitivity, and adaptive capacity. The univariate results are thus in agreement with the multivariate statistics, which found that there was a significant difference between the adoption of nature-based solutions for climate change and the three dimensions of climate change vulnerability. That is exposure ($P = 0.019 < 0.05$), sensitivity ($P = 0.008 < 0.05$), and adaptive capacity ($P = 0.019 < 0.05$). This is as in Table 6.

Table 6: Univariate Tests of the Effect of Nature-based Solutions on Households' Climate Change Exposure, Sensitivity, and Adaptive Capacity

Tests of Between-Subjects Effects						
Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	Climate change exposure index	0.276	3	0.092	3.368	0.019
	Climate change severity index	0.458	3	0.153	4.012	0.008
	Adaptive capacity index	0.287	3	0.096	3.374	0.019
Intercept	Climate change exposure index	56.831	1	56.831	2077.682	0.000

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Tests of Between-Subjects Effects						
Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
	Climate change severity index	89.968	1	89.968	2366.460	0.000
	Adaptive capacity index	58.157	1	58.157	2054.719	0.000
Nature-based solutions for climate change adoption	Climate change exposure index	0.276	3	0.092	3.368	0.019
	Climate change severity index	0.458	3	0.153	4.012	0.008
	Adaptive capacity index	0.287	3	0.096	3.374	0.019
Error	Climate change exposure index	10.422	381	0.027		
	Climate change severity index	14.485	381	0.038		
	Adaptive capacity index	10.784	381	0.028		
Total	Climate change exposure index	67.683	385			
	Climate change severity index	104.926	385			
	Adaptive capacity index	69.335	385			
Corrected Total	Climate change exposure index	10.698	384			
	Climate change severity index	14.942	384			
	Adaptive capacity index	11.070	384			

Residual Sum of Squares and Cross Products (SSCP) Matrix

Based on the residual sum of squares and cross products (SSCP) Matrix, climate change exposure had a negative correlation with climate change adaptive capacity and a positive correlation with climate change sensitivity. Moreover, climate change sensitivity was found to have a negative correlation with climate change adaptive capacity. Therefore, climate change adaptive capacity had a negative correlation with climate change exposure and climate change sensitivity. This is as in Table 7.

Table 7: Residual Sum of Squares and Cross Products Matrix

Residual SSCP Matrix				
		Climate change exposure index	**Climate change severity index**	**Adaptive capacity index**
Sum-of-Squares and Cross-Products	Climate change exposure index	10.422	6.859	-4.074
	Climate change severity index	6.859	14.485	-8.294
	Adaptive capacity index	-4.074	-8.294	10.784
Covariance	Climate change exposure index	0.027	0.018	-0.011
	Climate change severity index	0.018	0.038	-0.022
	Adaptive capacity index	-0.011	-0.022	0.028
Correlation	Climate change exposure index	1.000	0.558	-0.384

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Residual SSCP Matrix				
		Climate change exposure index	Climate change severity index	Adaptive capacity index
	Climate change severity index	0.558	1.000	-0.664
	Adaptive capacity index	-0.384	-0.664	1.000

DISCUSSION

The study found that those who have a higher exposure to climate change had a lower adoption of nature-based solutions to climate change. However, at a certain threshold of very high exposure, adoption tends to increase. This could be due to individuals at very high levels of exposure being more perceptive to climate and thus being more aggressive in taking responsive actions. Also, individuals with higher severity were found to have lower adoption of nature-based solutions to climate change. But like the case of exposure, at a certain threshold of very high sensitivity, adoption tends to increase. This again could be due to individuals who are highly affected by climate change taking more drastic action to respond to climate change. Moreover, individuals having higher adaptive capacity had higher adoption of climate-smart solutions to climate change. However, at a certain threshold of very low adaptive capacity, adoption of climate-smart solutions for climate change tended to increase, which could be due to individuals at that level being more sensitive and exposed to climate change and thus taking greater action to respond. This affirms the observation by Gonzalez-Zuniga et al. (2018) that through the conservation of ecosystems, nature-based solutions can positively influence all three dimensions of socioeconomic vulnerability.

The joint analysis undertaken through multivariate tests in the study found that nature-based solutions had a significant effect on climate across the three dimensions of vulnerability, including sensitivity, exposure, and adaptive capacity. This observation was also confirmed by the univariate tests, whereby nature-based solutions were found to influence each dimension of climate change vulnerability, including sensitivity, exposure, and adaptive capacity individually. This shows that nature-based solutions indeed are a solution for addressing climate change. This aligns with (Anjum et al., 2014), who noted that when properly implemented, nature-based solutions could help reduce ecosystem and socioeconomic vulnerability by reducing exposure and sensitivity and increasing adaptive capacity. Moreover, (the Inter-American Development Bank, 2020) and (Seddon et al., 2020) noted that nature-based solutions can play an important role in increasing climate change resilience through the delivery of sustainable solutions that at the same time improve biodiversity and increase ecosystem services.

Moreover, the study found that there were interdependencies between the various dimensions of climate change vulnerability. Firstly, it was found that climate change exposure led to an increase in climate change sensitivity. This means that an increase in climate hazards enhanced the effect of climate change on people's livelihoods. Also, climate change sensitivity led to an increase in climate change exposure, meaning that those who were more sensitive to climate change were more exposed to climate hazards. However, climate change adaptive capacity was found to have a negative effect on exposure and sensitivity. This means that an increase in adaptive capacity reduces exposure to climate hazards and the effect it has on households' livelihoods. This is confirmed by Seddon et al. (2020), who noted that potential impacts of climate change, that is, exposure and sensitivity, are moderated by adaptive capacity. Besides, the vulnerability framework for socio-ecological systems affirmed by the IPCC (Marshall et al., 2010; Thiault et al., 2017) stipulated the critical role of nature-based solutions in addressing the impacts of climate change, that is, exposure and sensitivity, and enhancing adaptive capacity.

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The fact that the study mainly studied climate change vulnerability at the household level, hence socioeconomic level and the confirmation by the study that nature-based solutions offered a response confirmed the interrelated nature of ecological socioeconomic systems. And that an effect of climate change on the natural systems influences human systems, while an effect on the human system influences the natural system. This also confirmed that the vulnerability of ecosystems to climate change could be alleviated by socioeconomic actions and that the vulnerability of socioeconomic systems to climate change could be addressed by ecologically related actions. According to (IPCC, 2022), climate change problems related to ecosystems and those related to human systems can't be tackled independently because the systems are highly interdependent. Also, both can contribute to increasing or addressing climate change (Hamilton and Friess, 2018; Johnson et al., 2021). Nature-based solutions thus stand at the interface of the socioeconomic and ecological systems to reduce the vulnerability of the social-ecological system to climate change (Seddon et al., 2020).

CONCLUSION AND RECOMMENDATIONS

Nature-based solutions are effective in adaptation to climate change, given the fact that they influence the three dimensions of vulnerability, including exposure, sensitivity, and adaptive capacity. In doing this, nature-based solutions not only improve ecological systems but also improve human systems, given their interconnected nature. Based on the results of the study, there is a need for policymakers and developers to design and implement effective nature-based solutions not only to build resilience to climate change but also to gain other multiple benefits associated with them.

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