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Climate change, food security, and diarrhoea prevalence nexus in Tanzania

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The impact of climate change on food security and public health has hindered poverty reduction efforts in developing nations, including Tanzania, resulting in the impoverishment of millions and compromising both health and food production. To unravel these complex interactions, rigorous scientific research is indispensable. Leveraging three waves of the Agriculture Sample Census (2002/03, 2007/08, 2019/20), this study meticulously examines the interplay between climate change, food security, and diarrhoea prevalence in Tanzania. Employing Instrumental Variable Probit and Control Function Approach models to address endogeneity and heterogeneity, temperature anomalies serve as instrumental variables. The findings reveal a substantial impact of climate change on both food security (−0.331142, $p < 0.01$) and diarrhoea incidence (0.214602, $p < 0.01$). These results signify that climate change places significant stress on food security, rendering households more susceptible to insecurities, and heightens health concerns through increased diarrhoea prevalence. This underscores the urgency of prioritizing public health and well-being through an agricultural lens in climate change mitigation. A comprehensive strategy is imperative, entailing a synergy of sustainable agricultural practices, robust public health interventions, and targeted policies to fortify the adaptive capacity of communities. Special emphasis should be placed on cultivating climate-resilient agricultural systems, ensuring food security, and implementing health programs tailored to address the unique challenges posed by climate-induced factors. Moreover, community engagement and awareness initiatives play a pivotal role in fostering a collective understanding and commitment to sustainable practices, contributing to the overall resilience of societies amidst the challenges of climate change.

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Introduction

The global population, anticipated to reach 8.5 billion by 2030 and 10.4 billion by 2080, poses challenges for achieving Sustainable Development Goals, especially in the realms of Zero Hunger and Good Health and Well-Being (Andersen et al. 2023; UN 2022). The trajectory of this growth is significantly influenced by nine countries (United States, India, Democratic Republic of Congo (DRC), Indonesia, Nigeria, Ethiopia, Pakistan, Egypt, and Tanzania), which are expected to contribute more than half of the population increase by 2050 (UN 2022). This demographic shift intensifies the demand for food and healthcare, exposing the world to the complexities of achieving these goals, further compounded by the impact of climate change on agriculture and health (Folk 2019).

Climate change, a pervasive force affecting various aspects of human life, not only disrupts food production and agricultural systems but also compromises immunity, making populations more susceptible to diseases such as diarrhoea (Folk 2019). The intricate connection between infectious agent life cycles, transmission, and climate highlights the urgent need to explore these links comprehensively (Liang and Gong 2017). Extreme weather events and disruptions in food systems, coupled with rising zoonoses, food- and water-borne diseases, and mental health challenges, underscore the multidimensional impact of climate change (WHO 2022). Additionally, predictions by the World Health Organization (WHO) of increased deaths due to malnutrition, malaria, diarrhoea, and heat stress between 2030 and 2050 further emphasize the critical interplay between climate change, health, and food security (WHO 2021).

Diarrhoea, responsible for over 2.5 million global deaths annually, with children accounting for 21% of fatalities, is a significant public health concern (Abdullahi et al. 2022). In Tanzania, diarrhoea-related deaths reached 17,587 in 2020, constituting 5.96% of total deaths (Abdullahi et al. 2022). As climate change exacerbates the spread of diarrhoea, particularly in Sub-Saharan nations like Tanzania, the study aims to understand the intersectionality of climate change, food security, and diarrhoea prevalence (WHO 2020).

Globally, climate change has led to a decline in food production, resulting in increased food insecurity from 135 million in 2017 to 345 million in 2022 (Zeeshan 2022; WHO 2022). The impact is evident in Sub-Saharan Africa, where maize and wheat production declined by 3.8% and 5.5%, respectively, with nearly 30% of the population experiencing food insecurity in 2020 (WHO 2022). In Tanzania, the rising frequency of climate-related extreme events, coupled with a dense population and economic challenges, magnifies the vulnerability of both means of subsistence and health, particularly in rural areas (Munishi et al. 2010; Kibria et al. 2022). The effects on food and water quality, pathogen changes, and disease distribution patterns disproportionately affect rural populations, hindering poverty alleviation efforts (Ebi et al. 2018; Yasmin 2016; Kibria et al. 2022).

Despite the evident consequences of climate change on health and food security, limited attention has been given to its specific effects in Tanzania and other developing nations. Existing studies primarily focus on adaptation and resilience, leaving a knowledge gap in understanding the direct impacts on health and food security (Shemsanga et al. 2020; Mwakaje 2013). This study seeks to address this gap by unraveling the intricate relationships between climate change, food security, and diarrhoea prevalence, providing evidence-based insights crucial for policymakers. The findings are instrumental in shaping targeted policies and interventions to enhance resilience, fostering sustainable development, and improved public health outcomes.

Despite the complexity of the pathway leading to the effects of climate change on health, its effects on food security are direct and typically experienced immediately. In contrast, Fig. 1 demonstrates a bidirectional relationship between exposure pathways, vulnerability factors, and the capacity and resilience of the health system. The complexity can also be increased by the feedback effects of climate change on food security, as well as by the relationship between climate change and disease prevalence (Kitole et al. 2022).

Furthermore, Fig. 2 illustrates the change in the global average temperature, as reported by Scrafton (2020). The data reveals that a majority of African countries, including Tanzania, have experienced an additional increase of more than 1.00°C in temperature between 1956 and 2021. This rise in temperature has had significant repercussions, impacting not only crop production and food security across the continent but also leading to an increase in the prevalence of regional diseases, such as diarrhoea, over the past 50 years (Zeeshan 2022).

Literature reviews

Climate change has had a significant impact on global development efforts, particularly through its effects on agriculture and food security. The rise in temperature and changes in precipitation patterns have led to reduced crop yields and increased pest proliferation, threatening food security (Singh et al. 2023; Arora 2019). This has been further exacerbated by the increased frequency of extreme weather events, such as droughts and floods, which have caused economic losses and land degradation (Arora 2019). These changes have also contributed to the spread of diseases, such as diarrhoea, due to the deterioration of environmental conditions (Andersen et al. 2023; Kim et al. 2014). Therefore, addressing climate change is crucial for sustainable development and the well-being of communities worldwide.

In addition, climate change, particularly increases in temperature and changes in precipitation, has been consistently linked to an increase in the prevalence of diarrheal diseases (Malik et al. 2021, Chou et al. 2010). This is a significant concern, as diarrheal diseases are a leading cause of mortality and morbidity, particularly in developing countries. The impact of climate change on these diseases is particularly pronounced in older adults and children, making them more susceptible to the effects of climate variability. Therefore, it is crucial for countries to implement preventive measures and develop early warning systems to mitigate the impact of climate change on diarrheal diseases.

On the other hand, although the impact of climate change on diarrhoea is complex and uncertain, with a range of potential health impacts, Kolstad and Johansson (2011) highlights the need for empirical data to better understand these impacts, while Mellor et al. (2016) emphasizes the importance of mechanistic systems-based approaches to study climate change's effects on diarrhoeal diseases. Singh et al. (2023) and Chou et al. (2010) both provide evidence of a positive association between temperature and diarrhoea rates, as well as a negative association between water availability and diarrhoea rates. These findings suggest that climate change exacerbate diarrhoea illness, particularly in regions with water scarcity such as those in developing world including African countries.

Furthermore, climate change's profound impacts on food security and diarrhoea prevalence are evident in projections indicating reduced crop production and increased malnutrition in Sub-Saharan Africa (Opoku et al. 2021; Lechler, 2020). The negative repercussions are more pronounced in impoverished populations (Alpino et al. 2022). Established links between weather patterns and diarrheal diseases in Tanzania underscore the urgency of understanding climate change's implications for

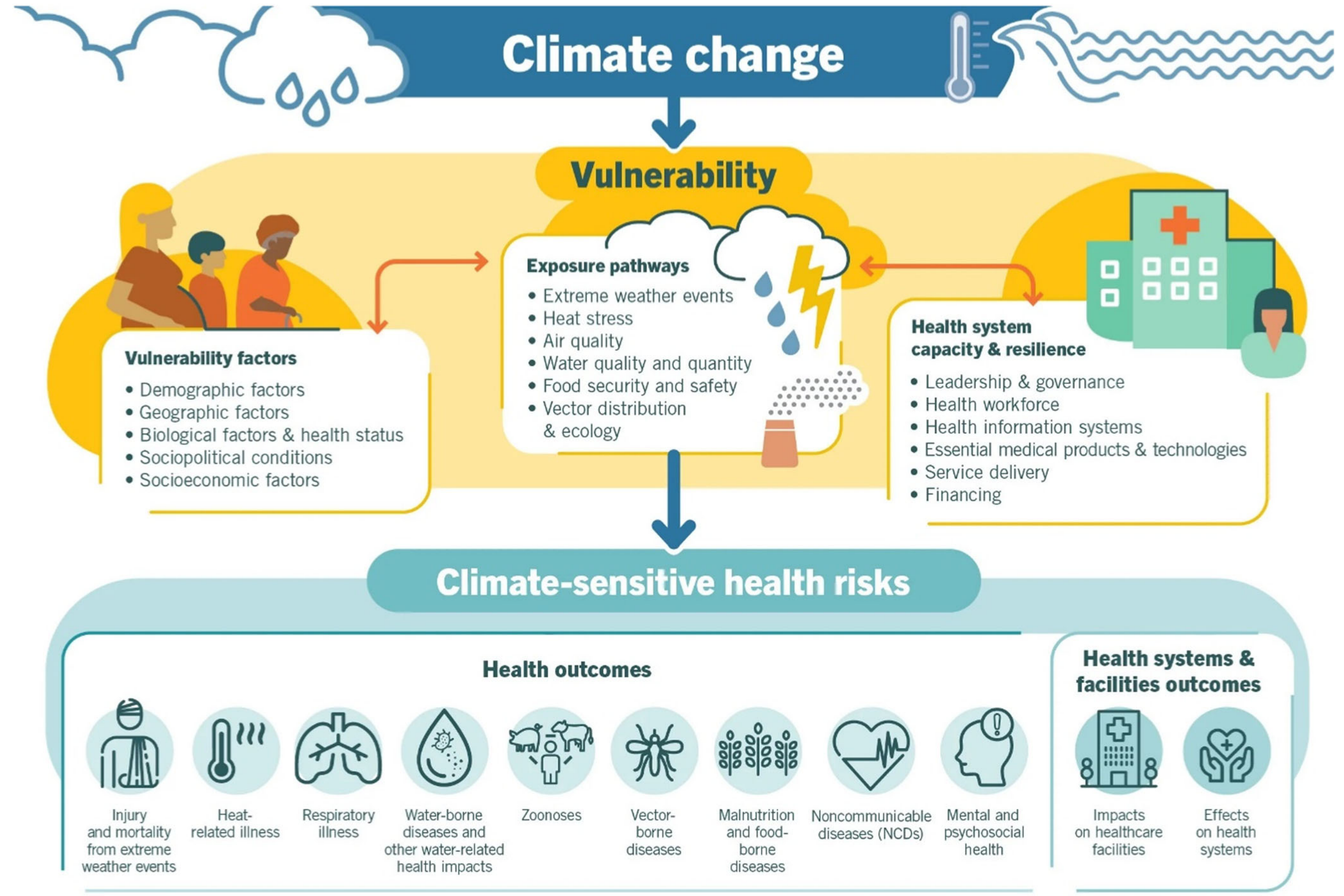

Fig. 1 Pathways through which climate change impacts health and food security. Source: Adopted from WHO (2021).

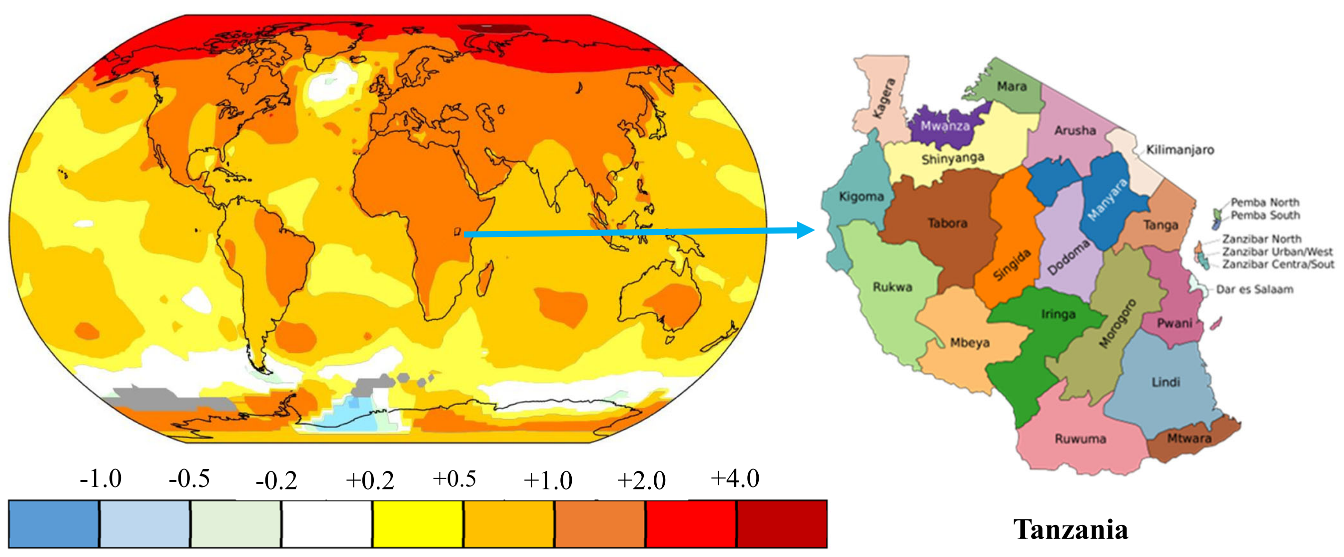

Fig. 2 Change in average global temperature (°C) in the past 50 years 1956–2021. Source: Scrafton (2020).

public health (Pasquini et al. 2020). While rising temperatures and altered rainfall patterns contribute to diarrhoeal incidence, climate variability's impact on food security in Tanzania raises concerns about stability and access to food supplies (Rocque et al. 2021; Gwambene et al. 2023; Masao et al. 2023; Dasgupta and Robinson 2022). Bhuyan et al. (2023) emphasizes the role of climate variables in decreasing food security, with temperature increases negatively impacting both short and long-term stability. Randell et al.'s (2022) study, employing the Tanzania National Panel Survey and climate data, reveals a 13-percentage point increase in simultaneous food insecurity risk during particularly dry years. Therefore, Vulnerability is higher in agriculturally dependent households with fewer working-age members due to double effects of food insecurity and diarrhoea as the result of climate change (Jones et al. 2023; Mboera et al. 2012; Shabani and Pauline 2023). Amid changing climate patterns, integrating resilience is proposed to address risks to food security and public health. Despite the escalating concerns, empirical evidence remains constrained (Scheelbeek et al. 2021; Trærup et al. 2011; Mboera et al. 2012). This study addresses the gap, employing instrumental variable models to estimate causal relationships and counteract simultaneity challenges in understanding the intricate dynamics among climate change, food security, and diarrhoea prevalence in Tanzania.

Methodology

This study used three rounds of National Agriculture Sample Census Survey comprising those collected in 2002/2003 (3rd round), 2007/2008 (4th round), and 2019/2020 (5th round) ([1]), of which the stratified multistage design was employed, and it remained the same across all rounds for the study's sample survey. The unit of analysis on the survey were smallholder farmers, however even details of the large scale farmers are normally included in the survey, however for the case of this study only sample of the smallholder farmers were included in the study because this is the largest group of agriculture producer in the Tanzania that constitute more than 75% of all people working in agriculture sector (NBS 2022a; [2]). The aim of using this group is to enhance uniformity (homogeneity) and reduce biases (Woodhill et al. 2022). Therefore, the used dataset contains information on the sociodemographic characteristics of smallholder farmers in Tanzania, as well as the challenges facing farming societies including climate change, and the health. Thus, the total of 32,560 smallholder farmers were used for various estimations purposes in the study.

Variables. In this study, however, the presence of diarrhoea (D), and food security (F) have been measured using categorical values given that diarrhoea presence in the household was captured in terms of presence of any member in the household who has been affected by diarrhoea for the period of twelve months, while food security was measured in terms of access to food, using the FAO components of food security.

Diarrhoea presence (D). D is categorized into two groups that $D = 0$ explaining the hosuehods with no recorded instances of diarrhoea, while $D > 0$ for hosuehods with at least one member affected by diarrhoea. Therefore, the general categorization of the diarrhoea presence across households is represented as:

$$Diarrhoea\ presence(D) = \begin{cases} No\ diarrhoea\ if\ D = 0 \\ Diarrhoea\ presence\ if\ D > 0 \end{cases}. \quad (1)$$

Food security (F). Food security (F) is categorized based on a threshold that distinguishes between households with adequate food accessibility and those facing challenges (*see* FAO[3]). A threshold value T is determined, and households are thereafter categorized as $F \geq T$ presenting food secured households, while $F < T$ presenting food insecured.

$$Food\ security(F) = \begin{cases} \text{Foodsecure if } F \geq T \\ \text{Foodinsecure if } F < T \end{cases}. \quad (2)$$

Moreover, these categorical representations enable a nuanced understanding of the prevalence and status of diarrhoea and food security within the studied households. Top of Form

Climate change. In addition, climate change was evaluated based on variations in precipitation, which were classified according to average precipitation thresholds. Thus, to calculate the precipitation thresholds which show the changes in climate conditions, let $P_{i,j}$ represents the monthly precipitation amount for every j months in every i year, whereas $j = 1, 2 \ldots 12$ (for each month). Therefore, the total annual precipitation P_i for i^{th} year is given by:

$$P_i = \sum_{j=1}^{12} P_{i,j}. \quad (3)$$

Assume the threshold value T represents an important departure from the P_i, thus there is two categories of departure $y = 1$ and $y = 0$. Therefore. For each year i if $P_i > T$, set $y_i = 1$ and if $P_i \leq T$, set $y_i = 0$. Mathematically, this can be presented as:

$$y_i = \begin{cases} 1\, if\, P_i > T \\ 0\, if\, P_i \leq T \end{cases}. \quad (4)$$

Therefore, this explains the categorical outcome of the variable y_i for every i^{th} year under the condition that the average annual precipitations P_i is below or above the T threshold. On the other hand, the study showed coverage of climate change, food security, and diarrhoea prevalence across household socioeconomic characteristics to understand effects of these three variables across different social groups:

Given that, climate change status is measured as a binary variable, where households are coded as 1 for 'yes' (indicating the presence of climate change impact) and 0 for 'no', The percentage change in climate change based on the household responses across various social groups can be calculated by comparing the proportion of households coded as 1 before and after the impact the percentage impact can be estimated using the following formula:

$$Impact\ of\ climate\ change = \left(\frac{Percentage\ change\ in\ climate\ change\ presence}{Initial\ percentage\ of\ climaet\ change}\right) \times 100\%$$

This formula provides a percentage measure of how much the presence of climate change has changed relative to its initial level.

On the other hand, for the diarrhoea which is also measured in binary (1 presence of diarrhoea, 0 no diarrhoea), the percentage impact can be estimated using the following formular:

$$Impact\ of\ diarrhoea = \left(\frac{Percentage\ change\ in\ diarrhoea\ presence}{Initial\ percentage\ of\ diarrhoea}\right) \times 100\%$$

This formula provides a percentage measure of how much the presence of diarrhoea has changed relative to its initial level. The same applied for the food security which was measured in terms of food accessibility based on the FAO's dimensions of food security. Therefore, these three (food security, climate change, and diarrhoea) were determined across social groups for all rounds 2002/03, 2007/08, and 2019/20. Moreover, other variables used in this study have been presented at Table 1.

Analytical modelling

In the first analysis on examining the effects of climate change on diarrhoea prevalence, the study employed Instrumental Variable (IV) Probit model which can capture the endogeneity or feedback effects during estimations of the diarrhoea prevalence model. Moreover with y_i as the binary outcome variable; β_1 is a $K \times 1$ vector and X is $n \times k$ matrix of covariates while μ_i is error term is expressed as;

$$y_i = \beta_0 + \beta_1 X_i' + \mu_i. \quad (5)$$

Therefore, as the result of endogeneity, the correlation between explanatory variables and the error term is not zero ($(E(X, \mu) \neq 0)$), thus we apply instrumental variables and Eq. 5 is reduced to:

$$y_{1i}^* = \beta y_{2i} + \gamma X_{1i} + \mu_i. \quad (6)$$

$$y_{2i} = X_{1i}\alpha_1 + X_{2i}\alpha_2 + \nu_i. \quad (7)$$

Table 1 Definitions and measurement of variables.

Variables	Description	Measurement
Climate Change	The annual precipitation status	y = 1 if annual average precipitation exceeds the threshold, 0 = Otherwise (Categorical)
Diarrhoea	The presence of diarrhoea affected members of household	1 = Yes, 0 = Otherwise (Categorical)
Food security	Household food security status	1 = food secured, 0 = Otherwise (Categorical)
Sex	Sex of the household head	1 = Male, 0 = Otherwise (Categorical)
Age	Age in years	Continuous
Household size	Number of family members	Continuous
Education level	Level of education	1 = Primary 2 = Secondary 3 = College 4 = University
Marital status	Marital status	1 = Married, 0 = Otherwise (Categorical)
Household income	Income of the household	Continuous
Financial services	Access to financial services	1 = Access to financial services, 0 = Otherwise (Categorical)
Agriculture societies	Membership in agriculture societies	1 = Member in agriculture society, 0 = Otherwise (Categorical)
Extension service	Access to extension	1 = Yes, 0 = Otherwise (Categorical)
Years of schooling	Number of years in school	Continuous
Employment	Household employment status	1 = Employed, 0 = Otherwise (Categorical)
Fertilizer	Amount of fertilizer in kg	Continuous
Sanitation	Household sanitation status	1 = Poor sanitation, 0 = Otherwise (Categorical)
Residence	Area of resident	1 = Rural, 0 = Otherwise (Categorical)
Average temperature anomalies	Difference between recorded temperature and average value time	Continuous
Government support	Government support on climate adaptation	1 = Yes, 0 = Otherwise (Categorical)

Table 2 Test to verify assumptions and interpretations.

Tests	Statistics (F statistic)	*P* Value	Interpretation
Relevance Test for the Instrument	37.58	0.0000	The instrument is relevant to climate change.
Exogeneity Test for the Instrument	-	0.4281	The instrument is exogenous to food security.
Weak Instrument Test	99.48	above critical value (max critical value = 32.56)	The instrument is strong.
First Stage Regression	$R^2 = 0.6632$	0.0005	The instrument is positively correlated with climate change.
F-Statistic for Instrument Validity	35.78	0.0006	The instrument is valid and relevant.
Heteroskedasticity and Autocorrelation Tests	47.23	0.5630	No evidence of these issues.
Endogeneity Test	3571.43	0.0040	There is endogeneity present.
Overidentification Test (Sargan Test)	25.17	0.3613	The model is well-specified.
Interpretation and Policy Implications	◆ Significant effect of climate change on diarrhoea prevalence ◆ Significant effect of climate change on food security		◆ Policies addressing climate change may have positive effects on the prevalence of diarrhoea in households. ◆ Policies combating climate change may have positive effects on food security in communities.

Here y_{1i}^{*} is the outcome variable for the i^{th} observation (the answer to the diarrhoea prevalence among households). Therefore, this study has used average temperature anomaly as an instrument. The choice is based on the fact that there exists a theoretical plausibility that deviations from average temperatures have the potential to exert an influence on climate patterns, which in turn may have an impact on the prevalence of diarrhoea, therefore it has indirect effects through climate change and fulfil the exogeneity conditions (Kitole et al. 2023a; Thomas 2020; Kitole and Sesabo 2024) as justifies in Table 2.

Table 3 Descriptive statistics.

Characteristics	Categories	Frequency	Percentage
Residence	Rural residents	15,840	56.41%
	Urban residents	12,240	43.59%
Sex	Male	13,380	47.65%
	Female	14,700	52.35%
Level of education	Primary education	12,355	44.00%
	Secondary education	10,951	39.00%
	College education	3931	14.00%
	University	842	3.00%
Marital status	Married	12,254	43.64%
	Not Married	15,826	56.36%
Extension services	Have access to extension service	1685	6.00%
	Don't have access to extension services	26,395	94.00%
Membership to agriculture societies	Members	7876	28.05%
	Not members	20,204	71.95%
Government support	Yes	9963	35.48%
	No	18,117	64.52%
Financial services	Have access financial services	6571	23.40%
	Don't have access to financial services	21,509	76.60%

On the other hand, as shown at Fig. 1, climate change can influence food production and hence the status of food security, same in Fig. 2, Tanzania is one of the country whose average temperature have raised by more than one degree Celsius (1 °C) for the past 50 years. Therefore, in this study the effects of climate change on food security have been analyzed by the use of the Control Function Approach which is powerful in suppressing endogeneity and heterogeneity through using the predicted residuals. In CFA, heterogeneity is mitigated by incorporating predicted reseals from auxiliary regression.

Therefore, since average temperature anomalies are the appropriate instrument, it has to be calculated and included in the regression. Mathematically, it is obtained through the following steps;

Let $T_{i,j}$ denotes the recorded temperature for month j in a year i given that $j = 1, 2, \dots, 12$. Moreover, assume $\bar{T}_j$ is the long-term average temperature for a month j. Thus, the average temperature anomaly $A_{i,j}$ in every month j in a year i is obtained by:

$$A_{i,j} = T_{i,j} - \bar{T}_j. \quad (8)$$

Also

$$\bar{T}_j = \frac{\sum Historical\ temperature}{Number\ of\ historical\ data\ points}. \quad (9)$$

Therefore,

$$A_{i,j} = T_{i,j} - \frac{\sum Historical\ temperature}{Number\ of\ historical\ data\ points}. \quad (10)$$

Hence, Eq. 10 elucidates the disparity between the recorded temperature and the temperature average over an extended period, thereby yielding the temperature anomaly for the specified time intervals encompassing the three iterations of the agriculture census survey conducted in 2002/03, 2007/08, and 2019/20.

Results

Results in Table 3 present the descriptive statistics for the households' socioeconomic characteristics. The results show that 56.41 percent of households under the study are living in rural areas while 43.59 percent are in urban areas. These results are slightly different from those of Kitole and Sesabo (2024) who found that nearly three-quarters of the residents in Tanzania are living in rural areas. The differences are attributed by the fact that this study involve information of four different rounds (2002/03 to 2019/20), and it has only covers small group of the smallholder farmers. In cementing this, Tanzania's latest census report of 2022 show that only 35% of Tanzanians are living in urban areas while 65% are still living in rural areas (NBS 2022b). On the other hand, results have further shown that males are more compared to females by 52.35 percent and 47.65 percent respectively. These findings are relatively similar to those of the latest 2022 Tanzania National Census which indicates that the number of females is higher than that of males as their proportions stand at 51.3 percent and 48.7 percent respectively (NBS 2022b).

Moreover, the results of this study in Table 3 have shown that 6.00 percent of farmers in Tanzania have access to extension services while the majority 94.00 percent do not have access to extension services. These results are slightly different from those of the Ministry of Agriculture (MoA) budget report for 2022/23 which shows that only 7 percent of farmers in Tanzania have access to extension services, and the remaining 93 percent don't have access to extension services (MoA 2022a, b).

Furthermore, the study has found that the majority of farmers (71.95 percent) in Tanzania are not members of any agriculture societies hence operating and conducting their agriculture activities independently at the household level. This implies that most farmers produce just for household consumption and not for commercial basis which may require them to be in agriculture groups such as cooperative societies (Kitole and Sesabo 2022).

Nonetheless, farmers have shown dissatisfaction with the government support in the agriculture sector as results in Table 3 show that only 19.51 percent of farmers agreed on the availability of government support for their farming activities while 80.49 percent reject the idea that there is government support. These results are concurrent to the findings of the NCSA survey which made the government of Tanzania increase the agriculture sector budget from Tanzania shillings 251 billion in the financial year 2021/22 to 791 billion in 2022/23 (MoA 2022a, b).

Findings in Fig. 3 show that only 38.18 percent of 18,219 farmers with primary education anticipate that climate change has effects on health while the majority 61.82 percent with similar characteristics do not believe climate change has effects on health. On the other hand, the number of farmers who believe climate change has effects on health has been increasing as their education level increases. This is evidenced by the percentage increase and decrease from left to right in Fig. 3, thus those with secondary education, college and university showed that climate change has effects on their health by 56.14 percent, 69.21 percent, and 76.23 percent respectively. Several studies (Zampieri et al. 2017; Matiu et al. 2017) have shown that more educated farmers are more effective in understanding the effects of climate change than uneducated ones.

Results in Table 4 illustrates the trends of climate status, food security, and diarrhoea presence among various socio-economic groups over the years 2002/03, 2007/08, and 2019/20. Notable patterns emerge when examining different classifications. For the Christian group, the increase in climate change prevalence from 11.54% in 2002/03 to 37.55% in 2019/20 coincided with a notable decline in food security, dropping from 45.62% to 72.86%. This suggests that as climate change intensified, food security deteriorated (Musengimana et al. 2016). Similarly, diarrhoea prevalence increased from 23.41% to 34.95%, indicating a simultaneous rise in climate-related health challenges. For the Muslim group, the decrease in food security from 27.98% to

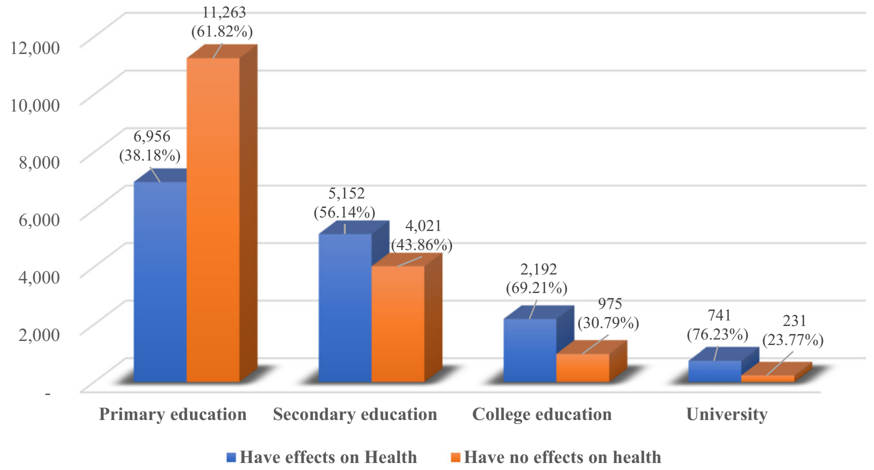

Fig. 3 Level of education and predicted effects of climate change on health.

Table 4 The trends of climate status, food security status, and Diarrhoea status among socio-economic groups.

Classification	2002/03			2007/08			2019/20		
	Climate change	Food security	Diarrhoea presence	Climate change	Food security	Diarrhoea presence	Climate change	Food security	Diarrhoea presence
Religious									
Christianity	11.542	45.623	23.414	26.375	1.793	30.733	37.547	22.439	34.947
Muslim	9.321	27.983	25.175	19.804	11.041	29.443	38.876	10.765	31.502
Traditional belief	27.894	4.871	53.538	25.153	30.202	18.521	52.988	30.883	49.124
Level of education									
No schooling	65.831	−29.641	47.723	46.553	−31.553	23.505	44.798	−41.485	58.01
Primary education	35.803	−5.374	22.253	10.464	−18.572	40.434	32.398	−23.763	46.665
Secondary education	26.552	22.870	9.469	50.932	12.040	5.875	19.014	−4.405	36.851
College education	11.723	35.811	−1.083	34.608	−26.61	12.631	45.493	34.163	24.525
University education	4.630	29.853	2.521	15.275	34.176	13.454	39.195	46.128	25.954
Residence									
Rural residents	27.602	−23.841	34.738	38.403	−33.093	41.556	49.051	−39.761	52.627
Urban residents	18.731	42.605	12.925	20.642	22.073	20.153	27.673	14.874	31.231
Sector of main employment									
Agriculture	38.421	−32.719	37.763	56.263	−45.213	42.585	63.136	−51.485	53.873
Private sector	13.465	42.605	15.538	16.584	15.274	21.287	24.888	29.960	27.532
Public sector	19.084	22.077	19.606	10.378	36.575	26.234	18.871	19.874	33.658
Sex									
Male	27.453	36.163	13.462	29.826	20.617	11.62	40.368	17.367	25.842
Female	67.931	−6.331	30.640	45.895	−14.463	21.783	72.856	−22.061	46.094
Economic status									
Poor	24.059	−48.972	35.093	45.207	−59.276	47.297	73.695	−71.325	65.870
Non poor	22.582	22.563	−11.408	32.51	12.078	24.253	48.445	14.474	29.354

11.04% suggests increased vulnerability, and the rise in diarrhoea prevalence to 31.50% implies a health-related impact. Traditional belief followers experienced a decrease in food security from 4.87% to 30.20%, coupled with an increase in diarrhoea prevalence to 49.12%, signifying a vulnerable socio-economic group facing compounded challenges (Moors et al. 2013).

Rural residents experienced a decrease in food security from −23.84% in 2002/03 to −39.761% in 2019/20, coupled with an increase in climate change and diarrhoea prevalence from 27.60% to 41.56% and 34.74% to 52.63%, respectively. This indicates that as climate change increases, food security dropped, and the number of households facing food insecurity increased, similar to the rise in diarrhoea cases (McLeod et al. 2020). Urban residents showed mixed trends despite positive trends in climate change. Although food security was decreasing from 42.61% in 2002/03 to 22.07% in 2019/20, the percentage in diarrhoea prevalence also showed a slight increase from 12.93% to 20.15%.

Among poor individuals, the significant decline in food security from −48.97% in 2002/03 to −59.28% in 2019/20 highlights the disproportionate impact of economic vulnerability on food security. Simultaneous rises in climate change (24.059 in 2002/03, 45.207 in 2007/08, and 73.695 in 2019/20) and diarrhoea

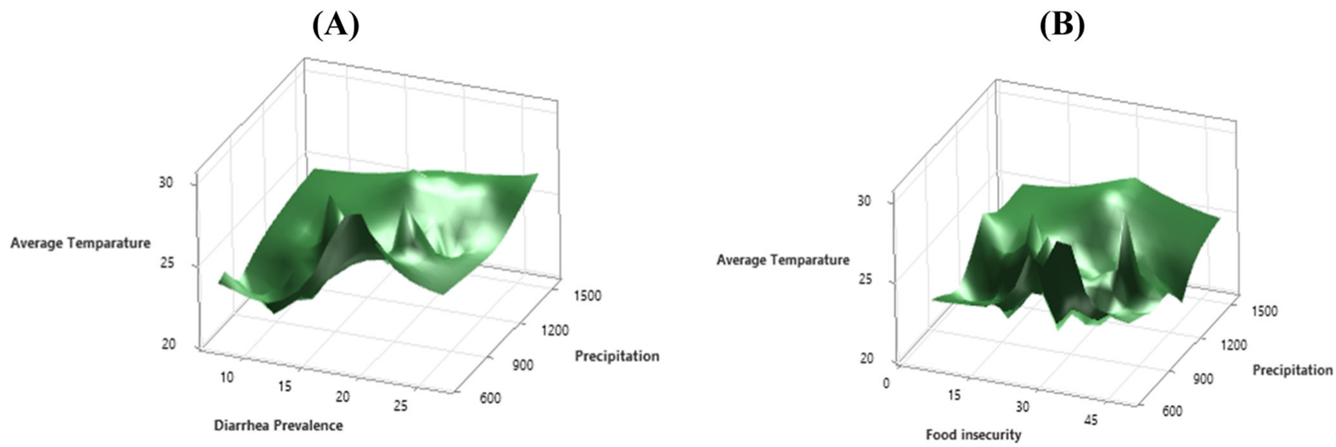

Fig. 4 Average temperature vs. Diarrhoea prevalence vs. Precipitation and Food insecurity.

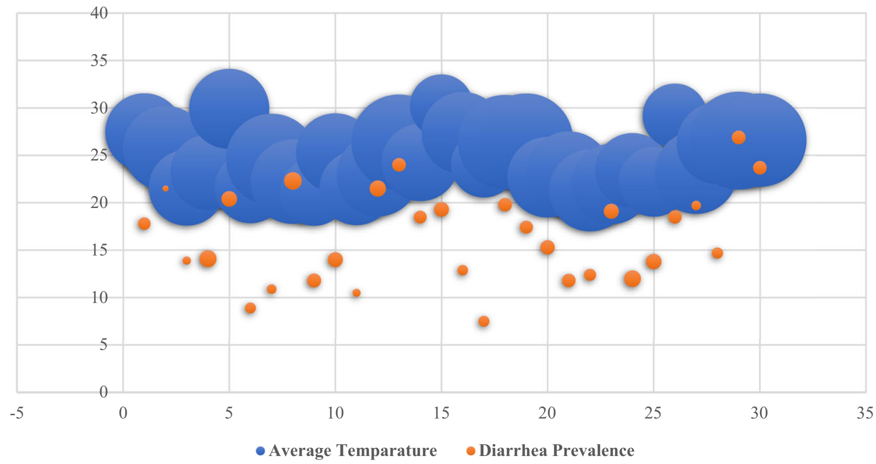

Fig. 5 Average temperature and diarrhoea prevalence in Tanzania.

prevalence (35.093 in 2002/03, 47.297 in 2007/08, and 65.870 in 2019/20) signify compounded challenges faced by poor individuals. Non-poor individuals experience diverse impacts on food security, with varied patterns in climate change and diarrhoea prevalence highlighting the complexity of socio-economic disparities within this category. Furthermore, those whose main sector of employment is agriculture are highly affected as climate change trends increases with ethe increase in diarrhoea prevalences and decline in food security (Melese et al. 2019; Matiu et al. 2017).

Findings in Figs. 4A and 5 indicate that an increase in the precipitations has a direct relationship with the increase in diarrhoea prevalence in Tanzania. These findings are similar to studies of Jofre et al. (2009) and McLeod et al. (2020) who argued that higher precipitation levels increase the chances of the outbreak of waterborne diseases including diarrhoea. On the other hand, findings in Fig. 4B show that an increase in the average temperature increases chances for the food insecurity. These findings are similar to several studies (Smith and Gregory 2013; Ray et al. 2019) which suggest that an increase in average temperature increases stress to crops, accelerates droughts, pests and disease outbreaks and therefore, increases chances for the low food production.

In addition, Fig. 6 demonstrates that as precipitation increased, food insecurity among farmers in Tanzania increases. This indicates that an accretive increase in precipitation increases the likelihood of floods, waterlogging, crop diseases, particularly fungal and bacterial, and loss of soil fertility, all of which have direct effects on food crop production and therefore increase the likelihood of food insecurity. These findings are comparable to those of Kinda and Badolo (2019), Sloat et al. (2018) and Newsham and Thomas (2011), who argued that, despite the fact that water is essential for agriculture and food security, poorly timed or excessive precipitation can reduce food production and exacerbate food insecurity among households that rely heavily on agriculture.

Effects of climate change on diarrhoea prevalence among households in Tanzania. The instrumental variable Probit regression model was used to analyse the effects of climate change on the incidence of diarrhoea in Tanzanian farming communities; the results are presented in Table 5. Thus, findings indicate that older people are significantly more susceptible to diarrhoea by 0.09565 ($p < 0.01$). These results suggest that older individuals are at a greater risk of contracting diarrhoea than younger individuals (Schiller 2022). This is supported by the fact that as people age, their immune systems weaken, making them more susceptible to diseases such as diarrhoea. In addition, these results contradict previous research (Melese et al. 2019; Gupta et al. 2015; Shine et al. 2020) claiming that children and adolescents are more susceptible to diarrhoea than adults. Additionally, according to Fenta and Nigussie (2021), diarrhoea is the second leading cause of death among children worldwide. Despite this debate, UNICEF (2020) asserted that diarrhoea has no age and that it is crucial for older people to manage underlying health conditions and remain hydrated.

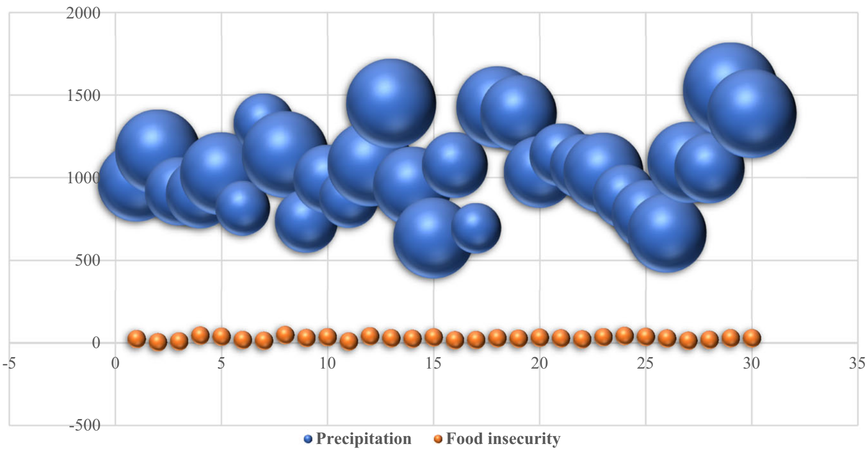

Fig. 6 Precipitation and food insecurity in Tanzania.

Table 5 Effects of climate change on prevalence of diarrhoea among households in Tanzania.

Outcome Variable (Prevalence of diarrhoea)	Estimation methods	
	Simple Probit	IV Probit
Age	0.02365**	0.09565***
	(0.00672)	(0.00149)
Age squared	0.01451***	0.05772**
	(0.00119)	(0.00617)
Sex (Male)	−0.18342**	−0.20521**
	(0.02560)	(0.06391)
Log of household income	−0.21126**	−0. 24064***
	(0.09810)	(0.052693)
Years of schooling	−0.14365*	−0.17721**
	(0.04610)	(0.01006)
Married	0.00813*	0.07591**
	(0.00052)	(0.02791)
Extension service	−0.11641	−0.22654
	(0.25118)	(0.31563)
Member to agriculture societies	−0.11005**	−0.18752**
	(0.00271)	(0.00342)
Government support	−0.17532**	−0.29210**
	(0.01462)	(0.00190)
Financial services	−0.15896**	−0.18098**
	(0.03271)	(0.02115)
Climate change	0.19942***	0.214602***
	(0.00141)	(0.000801)
Sanitation	−0.32106**	−0.37217***
	(0.06832)	(0.00783)
Residence (Rural)	0.21814***	0.26001***
	(0.02010)	(0.00562)
Sample size	28,080	28,080
R squared	0.3187	0.3432
Instrumented	Climate change	
Instrument	Average temperature anomalies	

Standard errors in parentheses.
***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Additionally, farmers' income (−0.24064, $p < 0.01$), years of education (−0.17721, $p < 0.05$), financial service accessibility (−0.18098, $p < 0.05$), institution factors such as government support (−0.29210, $p < 0.05$), and good sanitation (−0.37217, $p < 0.05$) were found to significantly reduce the prevalence of diarrhoea. These findings are consistent with previous research by Kibria et al. (2022) who argued that improved income and education levels contribute to better health outcomes, including lower rates of diarrheal diseases. Additionally, Kinda and Badolo (2019) found that access to financial services and government support for sanitation infrastructure play crucial roles in reducing diarrheal disease prevalence in rural communities. Conversely, marital status was found to have a positive effect on the prevalence of diarrhea, with married partners exhibiting a 0.07591 ($p < 0.05$) greater likelihood of contracting diarrhea compared to unmarried partners (Larbi et al. 2021; Levy et al. 2016). Supporting these findings, studies by Mellor et al. (2016) and Melese et al. (2019) have shown that married individuals may be more susceptible to diarrheal illnesses due to factors such as increased household exposure and shared living spaces, which can facilitate the transmission of pathogens.

Table 6 Marginal effects of factors explaining the effects of climate change on food security in Tanzania.

Outcome Variable (Food security status)	Estimation methods		
	Probit	2SRI	Control function approach
Age	−0.01410* (0.00521)	−0.07833** (0.00895)	−0.10082*** (0.00932)
Fertilizer	0.21692** (0.04671)	0.24933** (0.03119)	0.27218*** (0.00568)
Sex (Male)	−0.00213 (0.09521)	−0.09060 (0.12782)	−0.10321* (0.04264)
Log of household income	0.17221* (0.06310)	0.198842** (0.04002)	0.210043*** (0.03103)
Years of schooling	0.04195** (0.00313)	0.09011** (0.00210)	0.13105*** (0.00715)
Married	0.0672995* (0.001586)	0.0935041** (0.0137595)	0.1103841*** (0.02589123)
Employed	0.20881* (0.096711)	0.23110** (0.053721)	0.26004*** (0.01621)
Extension service	0.26662* (0.11592)	0.28015** (0.09561)	0.31691*** (0.03518)
Member to agriculture societies	0.16052* (0.06401)	0.20197** (0.05382)	0.24621*** (0.03201)
Government support	0.36281*** (0.07831)	0.39562*** (0.02642)	0.417841*** (0.00784)
Financial services	0.10031** (0.02367)	0.143950** (0.01031)	0.18003*** (0.00910)
Residence (Rural)	−0.11960** (0.08728)	−0.16337** (0.034502)	−0.191022*** (0.004210)
Climate change	−0.26411*** (0.01301)	−0.28146*** (0.00116)	−0.331142*** (0.01632)
Climate change residual		−0.24531** (0.08110)	−0.31001** (0.08932)
Climate change*residual			−0.21250*** (0.0281021)
Sample size	28,080	28,080	28,080
R squared	0.3145	0.3266	0.3271
Instrumented	Climate change		
Instrument	Average temperature anomalies		

Standard errors in parentheses
***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Moreover, the study reveals a significant association, with rural residents exhibiting a 0.26001 higher likelihood of experiencing diarrhoea compared to their urban counterparts ($p < 0.01$). This finding underscores the vulnerability of rural populations to diarrhoeal diseases, possibly attributed to varied factors such as limited access to clean water, inadequate sanitation facilities, and lower healthcare infrastructure. The literature supports this observation, as rural areas often face challenges in basic amenities, predisposing residents to higher health risks (Fagbamigbe et al. 2021; Ferede 2020; Larbi et al. 2021). The heightened susceptibility among rural dwellers emphasizes the urgent need for targeted interventions in improving water and sanitation.

In addition, results indicate that climate change significantly increases the prevalence of diarrhoea by 0.214602 ($p < 0.01$). These findings suggest that climate events such as prolonged periods of rain caused by an increase in precipitation can facilitate the occurrence of stagnant water pools, which serve as breeding grounds for a variety of insects that carry diseases and pathogens that can contribute to the prevalence of diarrhoea. In Tanzania, the number of diarrhoea cases has increased from 157,000 in 2011 to 300,000 in 2022, with the majority of those infected being children (Citizen 2021). During this time, Tanzania has experienced an extreme climate event, including prolonged rainfall, particularly in flood-prone areas such as Mbeya, Dar es Salaam, and Pwani (Kajubi 2022).

Similar to the findings of this study, Wang et al. (2022), Mellor et al. (2016), and Sam et al. (2019) all suggested that prolonged rainfall as a result of climate change has the potential to cause significant disruptions to water and sanitation infrastructure, resulting in an inadequate supply of clean water and sanitation facilities. Inadequate adherence to hygiene protocols has the potential to exacerbate the spread of diarrheal diseases (Costello et al. 2013).

Effects of climate change on food security in Tanzania. According to Table 6, farmers' likelihood of food security decreases by 0.10082 ($p < 0.01$) as they age. These results suggest that farmers' ability to produce declines with age, thereby increasing the likelihood of food insecurity. Contrary to Rinsky-Halivni et al. (2022) and Guo et al. (2015), age is not a decisive factor for production and food security; however, the more farming experience farmers have, the more they become competent in the production of the specific crop and be able to withstand extreme weather events caused by climate change. Other research (Hasbun 2018; Heather and James 2020) suggests that age is positively correlated with food security, meaning that as age increases, both food production capacity and food security improve.

Moreover, the findings of this study indicate that as the effects of climate change intensify, food insecurity among households increases by 0.331142 ($p < 0.01$). In accordance with these findings, Gregory et al. (2005) stated, "Climate change affects food systems in a variety of ways, including direct effects on crop production (e.g., changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of the growing season), as well as changes in markets, food prices, and supply chain infrastructure."

Additionally, Mwakaje (2013), Theodory and Malipula (2016) as well as Kitole and Sesabo (2022) argued that climate change has greater effects in the shortage of food and the welfare of people especially those living by pastoral activities through the disappearance of pasture, increase of water scarcity, outbreak of animal diseases and death of animals. Thus, climate change has left the majority of pastoral societies vulnerable to extreme poverty conditions. According to Makoye (2022) through his interview with pastoralists in the Manyara region (Northern Tanzania), they reported that:

> *"…. a total of 62,585 animals, including 35,746 cattle, 15,136 sheep, 10,033 goats, and 1670 mules, starved to death in December 2021 alone due to drought. This is a terrible situation. As you move around, a heavy stench from the rotting carcasses is permanently hovering in the air. At the moment even life is difficult because you can even sell a cow at the lowest price of Tanzania shillings 230,000 ($100), we are totally stuck in the hades of climate change"*

To corroborate these findings, the effects of climate change have been felt throughout the East African region, where similar events of animal deaths were reported in Kenya, where more than 2.5 million livestock were reported dead as a result of droughts and insufficient rainfall (Wasike 2022). In addition, over 16,7 million people in Kenya and Somalia face acute food insecurity, which is greater than the combined populations of Austria and Switzerland (Nash 2022). In addition, since 2020, more than four rainy seasons have failed, making this the most frightening climate event of the past four decades.

Conclusion

This study concludes that climate change is a nightmare that will not end, and that it is here to stay. As a result, it requires global and collective initiatives to aid countries that are severely affected by it, as its causes are global while its effects vary greatly from country to country. Failure to reduce the effects of climate change through global cooperation will exacerbate global poverty and hunger, thereby impeding the achievement of global development agendas, such as the Sustainable Development Goals (SDGs) for 2030. And because climate change has a greater impact on food security than on public health, global communities should not relax their efforts to mitigate the latter.

There is an urgent need for governments in developing countries to unite, and for developed nations, which are the major contributors to climate change, to keep their funding commitments to initiatives that aim to reduce the effects of climate change, such as tree-planting programmes, development of water reservoirs for irrigation, development and protection of river basins and catchment areas, and raising community awareness on climate change and its effects on the environment.

Given the low income of the majority of developing nations, including Tanzania, it is difficult to achieve any of the global agendas for environmental protection and climate change resilience, as the majority of available country income is insufficient to fund even the most fundamental sectors, such as health, education, and agriculture. Therefore, climate change is a burden that will likely destroy the economies of the majority of developing nations faster than any other future catastrophe. Countries in the developing world are urged to utilise and expand their local knowledge of climate change adaptation in order to combat the climate change's effects on food security and health. To achieve these objectives, nations should invest in programmes that address both climate change and public health. As everyone strives to improve their health, incorporating climate change into health programmes can be an innovative way to increase people's awareness and efforts regarding climate change.

Furthermore, the contribution of this study lies in its comprehensive investigation of the effects of climate change on diarrhoea prevalence among households in Tanzania, utilizing an instrumental variable Probit regression model. It offers valuable insights into the complex interplay between climate change and diarrhoea incidence, particularly highlighting the susceptibility of older individuals to the disease. Additionally, the study underscores the significance of addressing climate change as a key factor in mitigating diarrhoea prevalence, emphasizing the urgency of targeted interventions for vulnerable demographics. Moreover, the study sheds light on the effects of climate change on food security in Tanzania, revealing the increasing vulnerability of rural populations to food insecurity. By providing evidence-based insights into the relationship between climate change and food security, the paper contributes valuable knowledge that can inform policy interventions aimed at enhancing resilience and sustainability in the face of climate-related challenges.

Data availability

The raw data used in this study are available at Tanzania's National Data Archive at https://www.nbs.go.tz/tnada. The final dataset are available upon reasonable request from the corresponding author.

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Notes

1 Tanzania's National Bureau of Statistics.
2 Tanzania's Ministry of Agriculture.
3 Individuals have both physical and economic access to the food they need.

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Author contributions

FAK conceived of the presented idea. JM, FAK and JKS performed extensive literature reviews. FAK, JKS and FYT prepared the methodology. FAK and JM performed the analyses and interpretations. FAK and JKS prepared the discussion and conclusion of the study. All authors reviewed and approved the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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