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Smallholder livelihood resilience to climate variability in South-Eastern Kenya, 2012–2015

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Climate change, land degradation, demographic change and persistent poverty pose major challenges to smallholder farmers in the arid and semi-arid lands of sub-Saharan Africa. Though many studies have focused on how resilient these households are to shocks, very few studies deal with how household resilience varies over time. We provide a longitudinal analysis to assess how the resilience of smallholder households in south-eastern Kenya has varied from 2012 to 2015. We use the Livelihood Resilience Indicator Framework to examine the linkages between livelihood outcomes and livelihood resilience (buffer capacity, self-organization and capacity for learning). We collected data from 134 households on three resilience dimensions: buffer capacity, self-organization, and capacity for learning. We performed principal component analysis to identify the key components of these dimensions and examine their relevance for livelihood outcomes. Our findings show that under drought conditions in 2012, conservation agriculture practices significantly contributed to maize yields. In both years 2012 and 2015, there was a positive correlation between resilience dimensions and food security. Key components of this relation were land area, income, conservation agriculture practices, climate forecasts and actions taken for the upcoming growing season.

KEYWORDS

resilience index, smallholder farming, food security, livelihood resilience, climate resilience, drought, conservation agriculture

1. Introduction

Increased frequencies of droughts, floods, tropical storms and heavy rainstorms (Intergovernmental Panel on Climate Change, 2014a; Niang et al., 2014; Ayugi et al., 2020) pose new threats to livelihoods in arid and semi-arid regions (Ulrich et al., 2012; MoALF, 2016). This is particularly the case in Kenya, where the impacts of climate variability and climate change in its arid and semi-arid regions are limiting efforts to achieve food security (Intergovernmental Panel on Climate Change, 2014b). Pastoralism and rain-fed agriculture are the predominant livelihoods in these regions, which are home to about 38% of Kenya's population. This high dependence on climate-sensitive local natural resources and ecosystem services (Government of Kenya, 2012) in combination with low adaptive capacities, inadequate agricultural inputs and technologies, as well as limited extension- and financial services make smallholders in this region particularly vulnerable (Intergovernmental Panel on Climate Change, 2007, 2014a; Government of Kenya, 2018). There is thus a need to enhance their livelihood resilience to climate variability and climate change.

Livelihood resilience refers to the capacity of individuals, social groups, or a social-ecological system (SES) to accommodate stresses, absorb disturbances, self-organize, and learn in order to maintain and improve essential basic structures and ways of functioning under adverse conditions (Carpenter et al., 2001; Berkes et al., 2002; Adger, 2003, 2006; Folke, 2006; Ifejika Speranza, 2013; Denton et al., 2014). Therefore, one can use resilience to describe the ability of a livelihood system to cope with change and recover from adverse consequences (Obrist et al., 2010). Resilience in relation to livelihoods depends on the capacity and agency of actors and households, as well as on social and natural conditions (Adger, 2003). A resilient livelihood is defined by its capability to maintain its key functions (food, income, insurance, poverty reduction, etc.) and to absorb the impacts of disturbances without causing major declines in production and wellbeing (Cumming, 2011; Ifejika Speranza, 2013). A livelihood displaying low sensitivity to shocks and high resilience is therefore considered robust, while a livelihood characterized by low resilience and high sensitivity is considered vulnerable (Allison and Ellis, 2001).

Linking livelihoods to resilience thinking can enhance the understanding of livelihood dynamics in the face of shock-driven changes and help to characterize the ability of livelihoods to recover after disruptions (Marschke and Berkes, 2006; Scoones, 2009; Sallu et al., 2010; Ifejika Speranza et al., 2014). Livelihood resilience has become an integral part of development research (Ifejika Speranza et al., 2014), as livelihoods (capabilities, assets and activities required for a means of living) are increasingly exposed to global environmental change and its interactions with economic, political and social systems (Chambers and Conway, 1992; Bahadur et al., 2015). It thus provides an important lens to examine complex rural development questions (Scoones, 2009).

Livelihood resilience thus focuses on factors and processes that keep livelihoods functioning despite change. Addressing the question of resilience of what, to what and for whom (Quandt, 2018), thus shifts attention from risk management to people's capabilities, assets and activities, and interactions with their social-ecological contexts (Berkes et al., 2002). This approach helps to understand the capabilities that enable smallholders to cope with and adjust to adverse conditions, create options and responses that increase competence to mitigate or overcome adversity (Obrist et al., 2010).

Therefore, a resilience assessment involves characterizing and assessing the exposure to shocks and stresses (Bahadur et al., 2010; Sallu et al., 2010). However, the unpredictability of these shocks and stresses makes it difficult to observe and measure resilience empirically (Carpenter et al., 2001; Obrist et al., 2010; Quandt, 2018). For this reason, several proxy-based approaches to measuring livelihood resilience and its different aspects have been proposed and sometimes applied (cf. Alinovi et al., 2010; Ifejika Speranza et al., 2013, 2014; Boillat et al., 2019; Matter et al., 2021). Developing such indicators pose several challenges. For example, selected indicators should capture the multidimensionality of resilience in the specific context of focus. Existing approaches to select indicators include reviewing literature (e.g., Sina et al., 2019) validated by group discussions and interviews (e.g., Gong et al., 2020; Campbell, 2021), principal component analysis (PCA) (e.g., Liu et al., 2020; Matter et al., 2021), or cluster analysis (e.g., Anbar et al., 2020).

A further challenge is to assess how livelihood resilience varies through time. Most studies on livelihood resilience have focused on a single situation in time or on a single event. Few studies have assessed different resilience dimensions across time in order to monitor livelihood dynamics, gain insights on whether smallholder livelihoods continue functioning despite droughts, and learn about the effectiveness of measures to improve livelihood resilience. In this study, we use a longitudinal approach to analyse livelihood resilience of smallholder farmers in south-eastern Kenya. Analyzing livelihood resilience over time can provide insights into changes in its key components and their relation to livelihood outcomes such as crop yields and food security. By conducting a longitudinal analysis and focusing on livelihood dynamics, temporal changes can be identified, enabling a better understanding of coping-, adaptation-, diversification- and transformation strategies (Scoones, 2009). In the following, we describe the study area, the resilience framework applied, data collected and analysis methods. We then present and discuss the results and conclude.

2. Livelihood resilience framework

To conceptualize livelihood resilience, we apply the indicator framework of Ifejika Speranza et al. (2014). The indicator framework is based on three dimensions of livelihood resilience: buffer capacity, self-organization, and capacity for learning. Buffer capacity refers to the capacity to cushion change and use emerging opportunities to achieve better livelihood outcomes (e.g., reduced poverty) (Ifejika Speranza et al., 2013). Self-organization describes the ability of farmers to connect in flexible networks as well as the ability to be involved in the social, economic and institutional environment at other scales than the local one (Milestad and Darnhofer, 2003). The capacity for learning refers to adaptive management and implies that a resilient SES is a learning system, memorizing previous experiences and incorporating them into current actions (COMPAS, 2007). These dimensions can be further decomposed into various contextually and temporally specific proxy indicators (Figure 1), as it is the case with other similar frameworks (Carpenter et al., 2001; Milestad and Darnhofer, 2003; Ifejika Speranza et al., 2013, 2014). The framework implicitly captures agency through smallholder ability to self-organize and to learn. The framework equally weighs all three resilience dimensions. It also captures diversity in all variables based on the premise that a diverse livelihood is likely to be more resilient than a livelihood that depends on fewer capabilities (Figure 2). The variables underpinning the three dimensions have been described in detail in Ifejika Speranza et al. (2014) and empirically tested in Matter et al. (2021).

3. Materials and methods

3.1. The study area

Situated in south-eastern Kenya (1° 35'–2° 59' S and 37° 10'–38° 30' E), Makueni County has an arid to semi-arid climate (Gichuki, 2000; MoALF, 2016) (Figure 2). Rainfall is bimodal, with the main rainy and growing season from October to December and a mean rainfall of 348 mm between 1981 and 2010

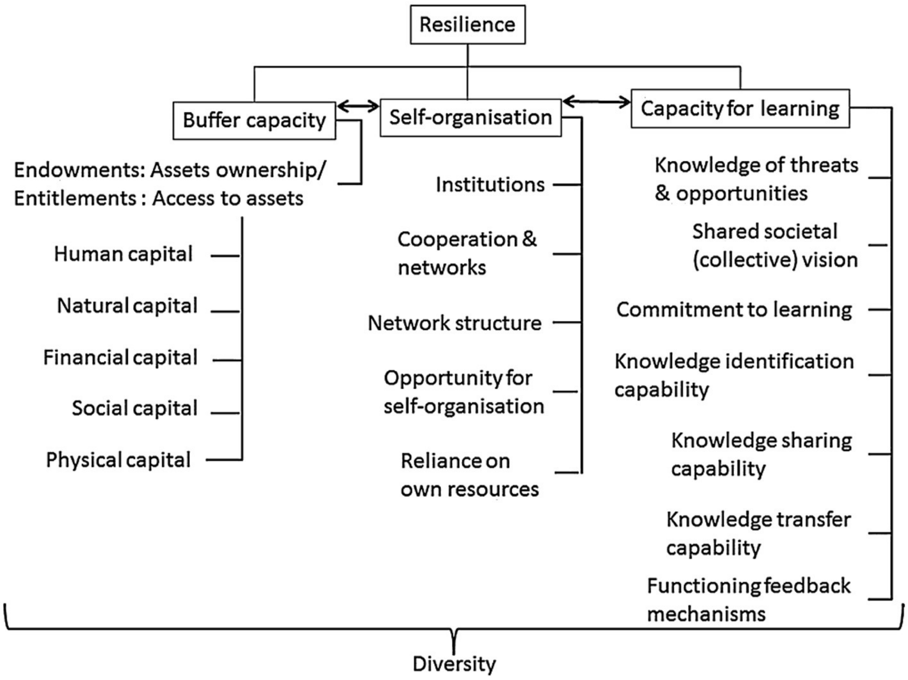

FIGURE 1
The applied livelihood resilience framework (Ifejika Speranza et al., 2014, p. 112). The data collection instrument (semi-structured household questionnaire) in 2013 and 2016 were based on the livelihood resilience framework of Ifejika Speranza et al. (2014). The questionnaire was structured according to the three resilience dimensions, namely Buffer Capacity (BC), Self-Organization (SO), and Capacity for Learning (CfL).

(Gichuki, 2000). The secondary rainy season lasts from March to May (mean rainfall 1981–2010: 253 mm) (Ifejika Speranza et al., 2008; United States Geological Survey Climate Hazards Center, 2021). The mean annual rainfall from 1981-2010 was 697 mm (United States Geological Survey Climate Hazards Center, 2021). However, rainfall in the region has a high interannual and seasonal variability, posing major constraints on the agricultural sector (Government of Kenya, 2013). This particularity affects maize, the main staple crop (Nowak et al., 2020) whose yields have shown a declining trend since 1979. This trend is expected to continue due to climate change (Mumo et al., 2018; Food Agriculture Organization, 2022). Furthermore, Makueni County has a poverty rate of 34.8% with a significant population with insufficient access to food to meet daily dietary requirements (Government of Kenya, 2018). During the assessed period, growing seasons were characterized by a series of successive droughts with below-average rainfall, which ended only in 2015, when above-average rainfall was recorded.

3.2. Sampling procedure and data collection

Our study is based on two household surveys conducted in 2013 and 2016 in the context of previous research projects (Ifejika Speranza et al., 2014; Boillat et al., 2019). A stratified random sampling was applied to survey 134 smallholder households in 38 villages, distributed according to their adoption of conservation agriculture practices as well as according to administrative units and being located in the semi-arid region of Makueni County. The surveyed households are part of a long-term collaboration involving the Kenya-based Center for Training and Integrated Research in Arid and Semi-arid Lands Development (CETRAD), who provides them with capacity building and rural extension activities, and the University of Bern. Data was collected through questionnaires to the 134 households in 2013 (focusing on the farming period 2012) and again in 2016 (focusing on the period 2015) using an adapted version of the 2013 questionnaire, but still largely capturing the same variables so the data sets are comparable. While the survey from 2016 included data on maize yields and food shortages as livelihood outcomes, the survey from 2013 only included data on maize yields. The questionnaires captured variables related with the three dimensions of the livelihood resilience framework (Figure 1), namely BC (e.g., household demographics and livelihood assets, agricultural techniques applied), SO (e.g., membership in farmer groups and role in farmer and other social groups), CfL (e.g., actively sourcing information on weather forecasts, participation in learning events and sharing knowledge), the diversity in the three dimensions as well as livelihood outcomes (e.g., crop yields, pest and disease incidences and food insecurity).

3.3. Data analysis

Principal Components Analysis (PCA) allows to identify the most meaningful indicators for enhancing resilience of the surveyed smallholders (Field, 2013; Matter et al., 2021).

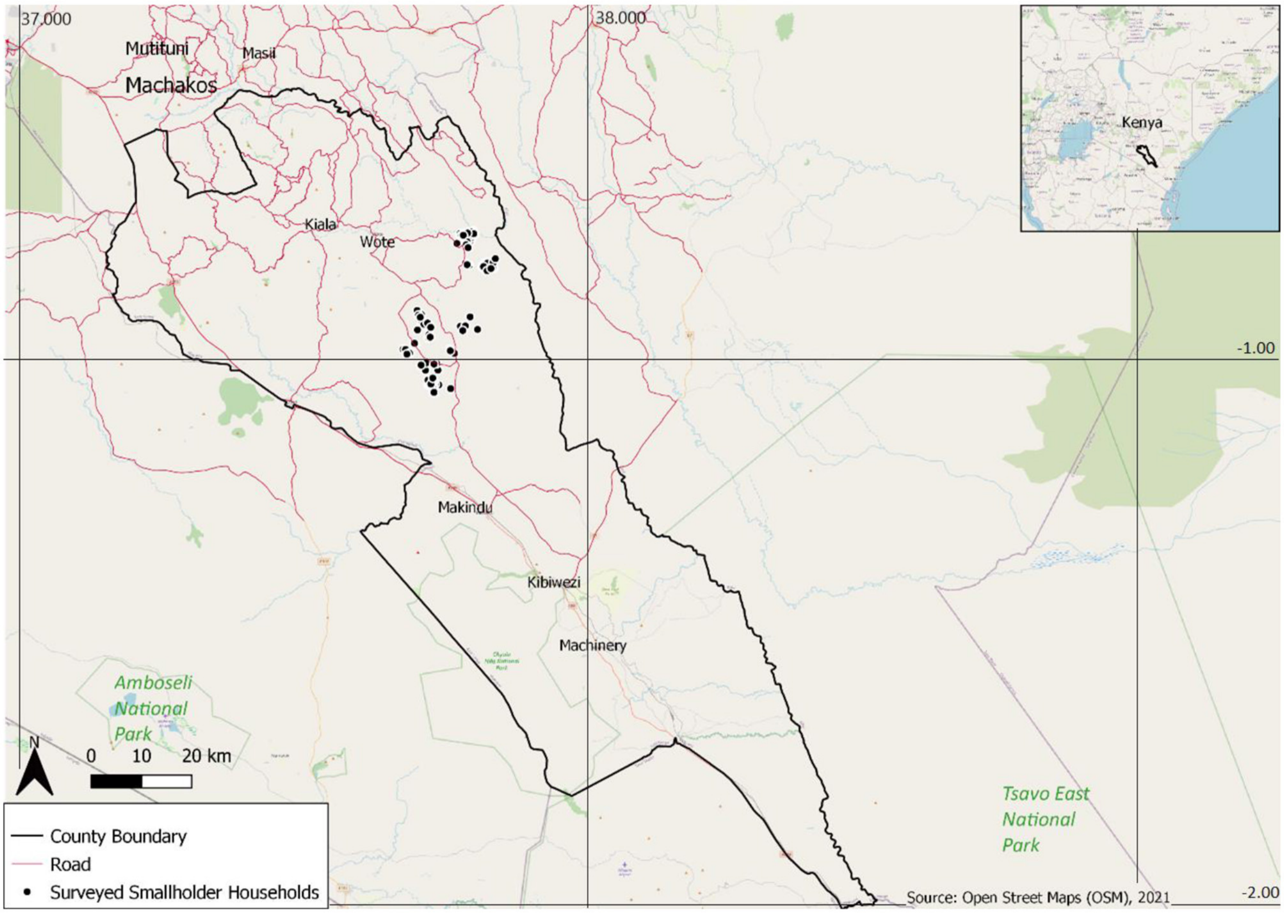

FIGURE 2
Surveyed smallholder households in Makueni County, Kenya [OSM (Open Street Maps Foundation)., 2021].

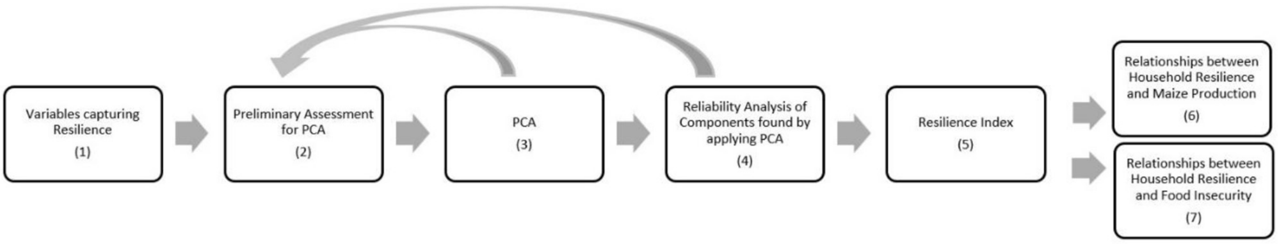

FIGURE 3
Analysis steps applied for assessing livelihood resilience.

We applied the following steps to analyse the data (Figure 3), performing all calculations with the IBM SPSS® version 28 software. To ensure the robustness of the results, we applied an iterative approach, comprising a preliminary assessment (Step 2), a PCA assessment (Step 3) and a reliability analysis (Step 4) according to Matter et al. (2021). We repeated these quality control steps until remaining variables passed the preliminary assessment (Step 2), the PCA assessment (Step 3) as well as the reliability analysis (Step 4) Due to missing data for some variables, we ended up with a final sample size of 111 households.

Step 1: Data preparation and selection of variables (Figure 3, Box 1). Based on the framework (Figure 1) of Ifejika Speranza et al. (2014), we selected 62 variables capturing the three dimensions of resilience from the two surveys (see Supplementary material). Table 1 presents a summary of the variables according to the three dimensions. Data with high values corresponding to low resilience (e.g., high distance to markets) were reverse scored.

TABLE 1 Main statistics of variables capturing resilience dimensions.

Resilience dimension	Variable	*N*	Mean 2013	Std. Deviation 2013	Mean 2016	Std. deviation 2016
Buffer capacity	Education level household head	132	3.43	2.25	3.43	2.25
	Education level spouse of household head	131	3.30	2.17	3.30	2.17
	Number of years working in agriculture	131	29.31	14.38	32.31	14.38
	Number of languages spoken	131	2.03	0.75	1.79	0.82
	Household dependency ratio	131	3.30	2.21	0.75	1.35
	Percentage of household members working off-farm	133	69.63	18.09	27.83	25.72
	Number of economic activities	134	1.85	0.69	1.72	0.69
	Tropical livestock units (TLU)	133	4.32	2.92	5.23	3.91
	Herfindahl index	121	0.70	0.21	0.70	0.22
	Number of income sources	134	2.03	1.08	1.96	1.20
	Total income (Kenya Shilling per year)	134	150,482	204,895	93,671.27	146,513.97
	Main house construction quality	133	6.84	1.32	7.20	1.25
	Toilet type	134	1.07	0.40	1.04	0.23
	Land legal status score	134	3.43	1.01	3.66	0.77
	Land area used for cash/food crops (acres)	134	4.84	3.75	4.12	4.32
	Land area used for other purposes (acres)	134	5.20	10.98	7.00	7.46
	Number of crop types	133	3.92	0.88	4.62	0.96
	Number of livestock types	134	4.63	1.63	4.60	1.58
Self-organization	Number of beneficial group memberships	134	2.70	1.31	2.11	1.16
	Number of types of support received	134	3.18	1.76	0.56	0.76
	Years since formation of oldest group	120	10.73	8.76	12.25	10.51
	Number of members, largest group	123	74.46	114.09	42.79	55.74
	Number of attended meetings	124	51.01	37.71	50.01	36.74
	Number of group activities	134	3.12	1.32	3.72	2.31
	Longest group membership duration	123	9.73	8.27	10.99	9.04
	Number of group memberships	134	2.70	1.31	2.20	1.21
	Group meeting attendance rate	122	0.92	0.19	0.95	0.13
	Household cannot do farming without support	134	0.15	0.36	0.10	0.30
	Household is supporting others	133	0.32	0.47	0.22	0.41
	Number of services available in <120 min.	126	4.52	1.05	4.61	0.85
	Travel time to crop extension facility (minutes)	131	85.85	62.50	54.68	46.13
	Travel time to livestock extension facility (minutes)	128	78.73	56.30	53.15	47.78
	Travel time to input market (minutes)	133	76.05	48.43	54.31	41.49
	Travel time to food and produce market (minutes)	134	66.46	44.10	44.52	37.44
	Travel time to livestock market (minutes)	134	91.38	58.07	100.18	72.74
Capacity for learning	Number of crops affected by disease	134	3.44	0.94	2.01	1.27
	Number of crop diseases	133	3.12	1.19	1.10	1.17
	Number of other crop production problems	133	2.04	0.87	0.62	0.69
	Storage facility type	133	1.17	0.89	1.51	0.52
	Number of storage problems	133	1.27	0.57	0.43	0.61

(Continued)

TABLE 1 (Continued)

Resilience dimension	Variable	N	Mean 2013	Std. Deviation 2013	Mean 2016	Std. deviation 2016
	Number of measures to address storage problems	132	1.35	0.75	0.46	0.68
	Prediction made for next season	134	0.76	0.43	0.99	0.12
	Number of actions taken after prediction	134	0.86	0.64	1.22	0.89
	Number of conservation agricultural practices	134	2.34	1.67	1.87	1.47
	Number of structural (agricultural) measures	134	1.58	0.54	1.15	0.76
	Number of other agronomic measures	134	1.25	0.61	2.18	0.65
	Number of management measures	134	2.47	1.15	1.62	0.93
	Number of synthetic input measures	134	0.23	0.49	0.24	0.60
	Number of radio weather forecast consultations a year	134	271.51	217.01	176.50	168.75
	Number of prediction/forecast sources consulted for upcoming season	133	0.65	0.49	1.19	0.59
	Number of problems (faced) with support received	134	1.88	1.74	0.56	0.76
	Number of new methods/information shared with others	134	0.46	1.24	1.87	0.38
	Number of sources (people) of techniques learned in the last 12 months	134	0.54	0.71	0.22	0.63
	Number of techniques learned from friends, farmers, relatives, neighbors in last 12 months	134	0.18	0.44	0.05	0.22
	Number of new techniques implemented for water conservation	134	0.22	0.58	0.06	0.24
	Number of new techniques implemented for soil conservation	134	0.13	0.38	0.04	0.19
	Number of new techniques implemented for productivity reasons	134	0.37	0.81	0.16	0.53
	Number of new techniques implemented for other reasons	134	0.04	0.19	0.03	0.21
	Number of livestock types affected by disease	134	3.59	0.87	1.13	1.13
	Number of livestock diseases	129	6.30	1.99	1.27	1.47
	Number of unknown livestock diseases	129	0.45	0.86	0.22	0.53
	Number of other livestock problems	134	1.56	0.83	0.32	0.53

For a detailed description of the variables and their coding see Supplementary material.

To allow the development of longitudinal indicators to assess livelihood resilience, we employed a single database PCA approach (Libório et al., 2020). We thus compiled the data from both points in time into one single database to allow for a longitudinal analysis of the indicators. We then standardized the aggregated data (Z-scores) to perform the PCA (Field, 2013; Libório et al., 2020).

Step 2: Preliminary assessment of data for fit for a principal component analysis (Figure 3, Box 2): During the process the variables were removed if one of the following conditions applied.

- High amount of missing data
- Inadequate sample size and item to sample size ratio
- Multicollinearity issue (determinant above 0.1E-5; correlation coefficients <0.8), removal of variables if correlation coefficients >0.8
- Bartlett's test of sphericity not significant
- Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and individual variable KMO anti-image correlation (anti-image correlation matrix) <0.5

In total, we excluded 15 of the 62 variables during the process, due to high correlation coefficients or low individual Kaiser-Meyer-Olkin criterion (overall KMO = 0.746). For detailed reasons of removal of individual variables, see Supplementary material.

Step 3: Principal Component Analysis (PCA) (Figure 3, Box 3): We applied a PCA to characterize the respondents' resilience at the two different points in time, characterized by above-(2015) and below-average precipitation (2012). During the process the variables were removed if one of the following conditions applied.

- Extracted communalities after extraction <0.5

- Total variance explained after varimax rotation <60% (assurance of validity of PCA)
- Loadings to components <0.5

In total we excluded 10 variables due to low loading onto components or low communalities after extraction during the process of applying PCA. For detailed reasons of removal of individual variables, see Supplementary material. We applied orthogonal (varimax) rotation under the assumption that the underlying components were independent. Varimax rotation disperses the loadings within the components, leading to more distinct component clusters (Field, 2013).

Step 4: Reliability analysis of identified PCA components (Figure 3, Box 4).

During the process the variables were removed if one of the following conditions applied.

- Components Cronbach's alpha >0.65, removal of variables if Cronbach's alpha <0.65
- Corrected item-total correlations >0.3, removal of variables if corrected item-total correlations <0.3
- Cronbach's alpha of item deleted < Cronbach's alpha (increase of 0.1 is tolerated)

Three variables were removed due to low Cronbach's alpha of the components or an increase of Cronbach alpha of the components after excluding variables from components. For detailed reasons of removal of individual variables, see Supplementary material.

Step 5: Building a livelihood resilience index (Figure 3, Box 5):

Subsequent to the PCA, we calculated the scores of the individual households for each component according to the Anderson-Rubin method. The Anderson-Rubin method constitutes a variation of the Bartlett's procedure, in which the least squares formula is adjusted to produce component scores that are not only uncorrelated with other factors, but also uncorrelated with one another (DiStefano et al., 2009; Field, 2013). The resilience scores were obtained through summing the component scores per household and were subsequently divided into four categories of equal range (very low, low, moderate, and high), allowing to categorize households according to their obtained scores.

We then applied the non-parametric Wilcoxon test to check whether the resilience score and its underpinning component scores significantly differed between 2012 and 2015. We used this test because the prerequisites for a parametric procedure (e.g., t-test) were not met, as the results of the PCA were not normally distributed. The effect sizes (r-values) of the results of the Wilcoxon test were calculated according to Equation 1.

$$r = \left| \frac{Z}{\sqrt{n}} \right|$$

The effect sizes were then assessed using the classification of Cohen (1992) displayed in Table 2.

Step 6: Examining relationships between livelihood resilience and livelihood outcomes (Figure 3, Box 8 and 9): Finally, we examined the interrelations between resilience, its dimensions and livelihood outcomes (maize yields from October-November-December—OND 2012 and OND 2015, and food security) by applying Spearmen's rho. Data on food shortages (number of days a household was without food), were only available for the year 2015 and were therefore not analyzed for the year 2012.

TABLE 2 Effect sizes of the Wilcoxon test according to Cohen (1992).

r-value	Effect size
0.1	Weak
0.25	Medium
0.4	Strong

4. Results

4.1. Components of livelihood resilience

The 34 variables (Table 3) remaining after performing PCA formed ten components, which were indicatively labeled as "Farming problems" (1), "Infrastructure" (2), "Experimentation with new techniques" (3), "Land area and income" (4), "Forecasts and actions" (5), "Conservation agriculture practices" (6), "Education" (7), "Livestock" (8), "Social capital and diversification" (9) and "Storage facility" (10). Farming problems capture crop and livestock diseases, other problems related to crop production as well as the amount of help received to cope with farming problems. Infrastructure captures the travel times to extension services and markets. Experimentation with new techniques captures the number of new agricultural techniques applied in the last year, as well as the number of information sources for new agricultural techniques. Land area and income relates to the area of land that the household can access, and the amount of income the household generated in the last year. Forecasts and actions relate to the amount of weather forecasts and subsequent actions taken by a household. Conservation agriculture practices capture the number of agricultural practices applied for soil conservation reasons, including synthetic inputs and management measures such as planting drought adapted crops, fallowing, water harvesting and early planting. Education relates to the degree of education of the household head and his spouse, and the number of years the household head has worked in agriculture. Livestock relates to the number of tropical livestock units and livestock types. Social capital and diversification relate to the number of group memberships, group activities and income diversification. Storage facility describes whether a household has stored none, part, or all its yield in a granary. Except for the variable number of income sources, which was found to highly load on land area and income and on social capital and diversification, all other variables loaded exclusively on a single component.

4.2. Livelihood resilience index

The resilience scores ranked the 111 households based on the sum of their component scores (Figures 4, 5). The index ranged

TABLE 3 Rotated component matrix–resilience.

Variables (Zscores)	Component loading										Component	Cronbach's alpha	Cronbach's alpha if item deleted	Wilcoxon signed rank test		
	1	2	3	4	5	6	7	8	9	10				Z 2015–2012	Asymp. Sig. (2-tailed)	Effect Sizes
Number of crop diseases (reversed****)	**0.821**					−0.130		0.168		−0.153	(1) Farming Problems	0.886	0.862	−9.133[a]	0.000	0.8669***
Number of livestock diseases (reversed****)	**0.808**	0.103			0.205			−0.147		0.125			0.859			
Number of other crop production problems (reversed****)	**0.754**		−0.121		0.125					0.142			0.870			
Number of crops affected by disease (reversed)	**0.737**	0.115					−0.102		0.131	−0.234			0.874			
Number of supports received (reversed****)	**0.729**	0.131	−0.212			−0.131			−0.120				0.866			
Number of storage problems (reversed)	**0.703**				0.112								0.880			
Number of other livestock problems (reversed****)	**0.684**		−0.145				−0.100			0.417			0.872			
Travel time (min.) to crop extension services (reversed****)	0.114	**0.885**									(2) Infrastructure	0.873	0.833	−2.386[a]	0.017	0.2265*
Travel time (min.) to livestock extension service (reversed****)		**0.854**											0.830			
Number of services available in under 120 min.		**0.790**		0.101				−0.127		0.126			0.872			
Travel time (min.) to input market (reversed)	0.176	**0.765**	−0.129			−0.101		0.171		−0.213			0.838			
Travel time (min.) to food market (reversed)	0.168	**0.675**				−0.200			0.232	−0.293			0.855			
Number of sources (people) of techniques learned in the last 12 months	−0.112	−0.128	**0.855**								(3) Experimentation with new techniques	0.742	0.570	−0.594[b]	0.552	
Number of new techniques implemented for productivity			**0.720**	−0.236	−0.134	0.104							0.697			
Number of new techniques implemented for soil conservation	−0.180		**0.687**	0.158	0.109	0.107		−0.141	−0.110	0.146			0.728			

(Continued)

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TABLE 3 (Continued)

Variables (Zscores)	Component loading										Component	Cronbach's alpha	Cronbach's alpha if item deleted	Wilcoxon signed rank test		
	1	2	3	4	5	6	7	8	9	10				Z 2015–2012	Asymp. Sig. (2-tailed)	Effect Sizes
Number of new techniques implemented for water conservation	−0.183		**0.668**	0.132		−0.111			0.126	−0.209			0.721			
Land area used for cash and food crops				**0.775**		0.146		0.315			(4) Land area and income	0.700[a]	0.611	−0.324[b]	0.746	
Land area used for other purposes				**0.686**	0.150			0.346					0.609			
Total income (inflation adjusted to 2015)	−0.210			**0.580**		−0.117	0.393		0.212	−0.217			0.622			
Forecast made for next season					**0.862**						(5) Forecasts and actions	0.731	0.530	−3.298[a]	0.001	0.3130**
Number of actions taken after forecast	0.102				**0.729**	0.256			0.169	−0.132			0.729			
Number of forecast sources consulted for upcoming season	0.274			0.153	**0.718**	−0.127		−0.112		0.234			0.662			
Number of synthetic input measures						**0.819**		0.167	0.107		(6) Conservation agriculture practices	0.673	0.677	−0.609[b]	0.542	
Number of conservation agricultural techniques	−0.120		0.170			**0.796**		−0.101	0.140				0.391			
Number of management measures	−0.428	−0.185		0.207	0.196	**0.546**			0.118	−0.113			0.637			
Education level spouse of household head				0.112			**0.805**				(7) Education level	0.655	0.459	−1.733[a]	0.083	
Education level household head				0.159			**0.769**		0.133				0.546			
Number of years working in Agriculture (reversed****)				−0.302	−0.113	0.174	**0.687**	−0.143					0.660			
Number of livestock types			−0.107	0.104				**0.838**			(8) Livestock assets	0.810	n/a	−0.871[a]	0.384	
Tropical livestock units (TLU)				0.361				**0.814**		0.101			n/a			
Number of types of group activities	0.179				0.161	0.177			**0.836**		(9) Social capital and diversification	0.680 [b]	0.45	−0.553[b]	0.580	
Number of group memberships	−0.250		0.131		0.107	0.158	0.129		**0.746**	0.153			0.529			
Number of income sources				**0.535**				−0.164	**0.541**	0.137			0.699[a] 0.743[b]			

(Continued)

TABLE 3 (Continued)

Variables (Zscores)	Component loading										Component	Cronbach's alpha	Cronbach's alpha if item deleted	Wilcoxon signed rank test		
	1	2	3	4	5	6	7	8	9	10				Z 2015–2012	Asymp. Sig. (2-tailed)	Effect Sizes
Storage facility type	0.161	−0.108						0.181	0.154	**0.738**	(10) Storage facility	n/a	n/a	−2.663[a]	0.008	0.2499*
Resilience score														−7.147[a]	0.000	0.6784***
Resilience quartile-ranges based scale														−6.308[a]	0.000	

Extraction Method: Principal Component Analysis. Rotation Method: Varimax Kaiser Normalization. Rotation converged in 9 iterations.
[a]Based on negative ranks.
[b]Based on positive ranks.
Effect Sizes of the Wilcoxon test according to Cohen (1992).
*Weak effect (r-value ≥ 0.1).
**Medium effect (r-value ≥ 0.25).
***Strong effect (r-value ≥ 0.4).
****Reversed means that the values of a variable were reversed so all variable values point in the same direction. For example, higher "number of crop diseases" indicates low resilience. This was reversed to higher scores for low number of crop diseases to reflect "higher resilience".
Bold values < 0.5.

from −8.19 to 7.63 in 2012, and from −4.33 to 14.47 in 2015 (Table 4). The mean resilience score of −1.275 in 2012 increased to 1.275 in 2015 (Figure 5). While the resilience scores for 2012 did not significantly deviate from normality according to the Kolmogorov-Smirnov test at $p < 0.01$ ($D_{(111)} = 0.053$, $p = 0.200$), the scores for 2015 differed significantly from normality ($D_{(111)} = 0.111$, $p = 0.002$). In 2012, one respondent and in 2015, four respondents at the high end of the scale were considered outliers (Table 4).

In 2012 as well as in 2015, the majority of respondents were in the category of low resilience. In 2015, 50 households increased their resilience, 58 remained in the same category as in 2012 and 3 were classified in a lower category (Figure 4).

4.3. Relationships between household resilience and livelihood outcomes 2012–2015

Using Spearman's rho, we found significant correlations between the livelihood resilience index of 2012 and maize yields, and between that of 2015 and maize yields ($N = 80$) as well as between the 2015 livelihood resilience index and food insecurity ($N = 111$) (Supplementary material). Due to a lack of data on food insecurity for the year 2012, we could not assess this relationship for this year.

Significant correlations between the resilience components, and the resilience score and maize yield were only found for the survey from 2012. Specifically, a significant positive correlation was found with conservation agricultural practices (Figure 6). This means that the usage of synthetic inputs, conservation agriculture and management measures (fallowing, early planting, drought tolerant crops and water harvesting) is associated with increased maize yields under below average rainfall conditions.

Regarding food insecurity in the year 2015, we found significant negative correlations with several components: farming problems, land area and income, forecasts and actions, conservation

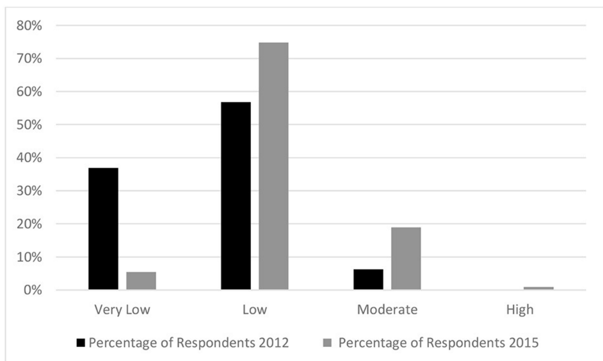

FIGURE 4
Frequency of resilience score ranges.

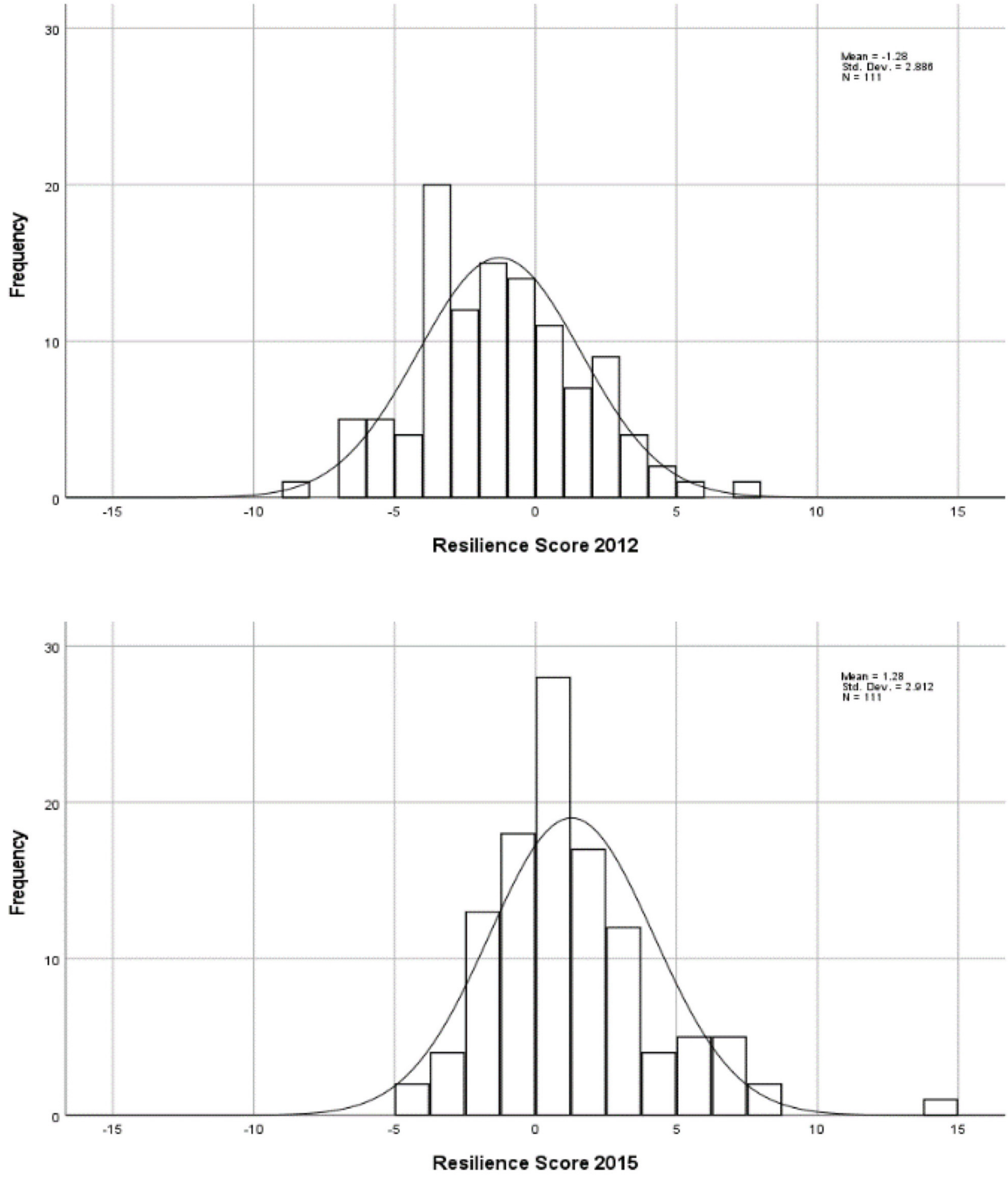

FIGURE 5
Distributions of resilience scores in 2012 and 2015. We also observed changes between specific resilience components from 2012 to 2015. The results of the Wilcoxon test showed that the components farming problems, infrastructure, forecasts and actions, and storage facility as well as the resilience score had significantly changed within the period from 2012 to 2015.

agricultural practices, social capital and diversification, storage facility as well as with the resilience score (Figure 6). This means that households who underperformed on these indicators had a higher chance of being food insecure. Surprisingly, we also found a significant positive correlation between food insecurity and infrastructure, meaning that households with better access

TABLE 4 Resilience scores ranges.

Resilience category	Range	Percentage of respondents 2012 (%)	Percentage of respondents 2015 (%)
Very low	−8.19 to −2.525	36.9	5.4
Low	−2.525 to 3.140	56.8	74.8
Moderate	3.140 to 8.805	6.3	18.9
High	8.805 to 14.470	0	0.9

to extension services and markets were worse off regarding food security.

4.4. Interrelations between components of resilience 2012–2015

We found several correlations between the different components of resilience for years 2012 and 2015 (Tables 5, 6, Supplementary material). Infrastructure positively correlated with farming problems in 2012, as well as with conservation agricultural practices, forecasts and actions in 2015. A negative relationship existed between farming problems and experimentation with new techniques in 2015, meaning that those smallholders experiencing farming problems are likely not to experiment with new farming practices.

In 2012, a positive correlation existed between forecasts and actions, and farming problems. In 2015, farming problems negatively correlated with storage facility. Further, the quality of the storage facility was found to positively correlate with land area and income.

While in 2012 households with higher scores of social capital and diversification were experiencing more farming problems, in 2015, the situation was the opposite. Livestock also positively correlated with experimentation with new techniques in 2015.

5. Discussion

5.1. Components of livelihood resilience

Our findings show that livelihood resilience varies across time and space. The period 2012–2015 (4 years) was characterized by an overall improvement of resilience in Makueni County.

However, the fact that only four out of ten components of resilience had significantly increased from 2012 to 2015 (4 years), raises questions about whether this trend is sufficient to enable smallholders to cope with future shocks. Factors underpinning resilience also vary over time—a variable that is important for resilience in 2012 becomes less important for livelihood resilience in 2015 (e.g., forecasts and actions related to farming problems). While common variables underpinning livelihood resilience across geographic context such as wealth and financial capital exist (Béné et al., 2016), Awazi and Quandt (2021) show that context matters in capturing livelihood resilience, as variables important for resilience in one context might be less important for resilience in another context. Thus, a robust and multi-dimensional/multi-factorial index is necessary.

5.2. Interrelations between components of resilience

Besides the overall resilience increase, our findings also show that the relationships between the different components of resilience, and their relations to livelihood outcomes have changed during the assessed time period. The period from 2012 to 2015 was characterized by a succession of droughts, which ended only in 2015, when above-average rainfall was recorded. We can therefore assume that the OND season in 2015 was the only main growing season during the research period that provided sufficient rainfall for a successful agricultural production.

In 2015, food security positively correlated with resilience, as well as with several of its components. However, the fact that all farmers, although harvesting above-average yields during normal-above average rainfall conditions in 2015, ran out of food at some point during the year, shows that even better-off households are not self-sufficient. Regarding Buffer Capacity, households with more land and income were more food secure. This finding aligns with the results of Matter et al. (2021) and those of Ifejika Speranza et al. (2008), who reported that access to croplands larger than 2 ha reduced the vulnerability to food insecurity during dry seasons as well as during seasons with average precipitation. In 2015, households with farming problems were also food insecure and had fewer storage facilities. The positive correlation between the quality of the storage facility and land area and income, suggest that households with storage facilities can make more money by selling their produce at higher prices or avoid food purchase at higher prices. This also depends on whether they have other sources of income than farming.

Regarding the Self-Organization dimension of resilience, the negative correlation between infrastructure and food security implies that remote households with constrained access to services and markets are more food secure. As shown by Matter et al. (2021), this contrasts the Livelihood Resilience Framework as well as the findings of other studies that show that adequate access to markets and services fosters resilience (e.g., Colting-Pulumbarit et al., 2018). Matter et al. (2021) argue that remote households are likely to be more self-sufficient and have more land and are therefore less exposed to price fluctuations. Likewise Ifejika Speranza et al. (2008) state that massive selling of produce due to cash needs leads to food deficits and seed shortages. Food insecurity may also be related to farmers' lack of engagement with extension services (Ifejika Speranza et al., 2008). This could be explained with privatization processes and reduced support under neoliberal policies and rising costs for farmers (Heidhues et al., 2004; Nyangito et al., 2004; Muyanga and Jayne, 2008; Matter et al., 2021). Hence, socio-economic characteristics of farming households clearly affect their possibilities to access extension services (Makate et al., 2019). Households with higher scores of social capital and diversification in 2015 were found to be more food secure. This result is in line with the findings of Andersson and Gabrielsson (2012), who found that collective action strengthens food production and security. While

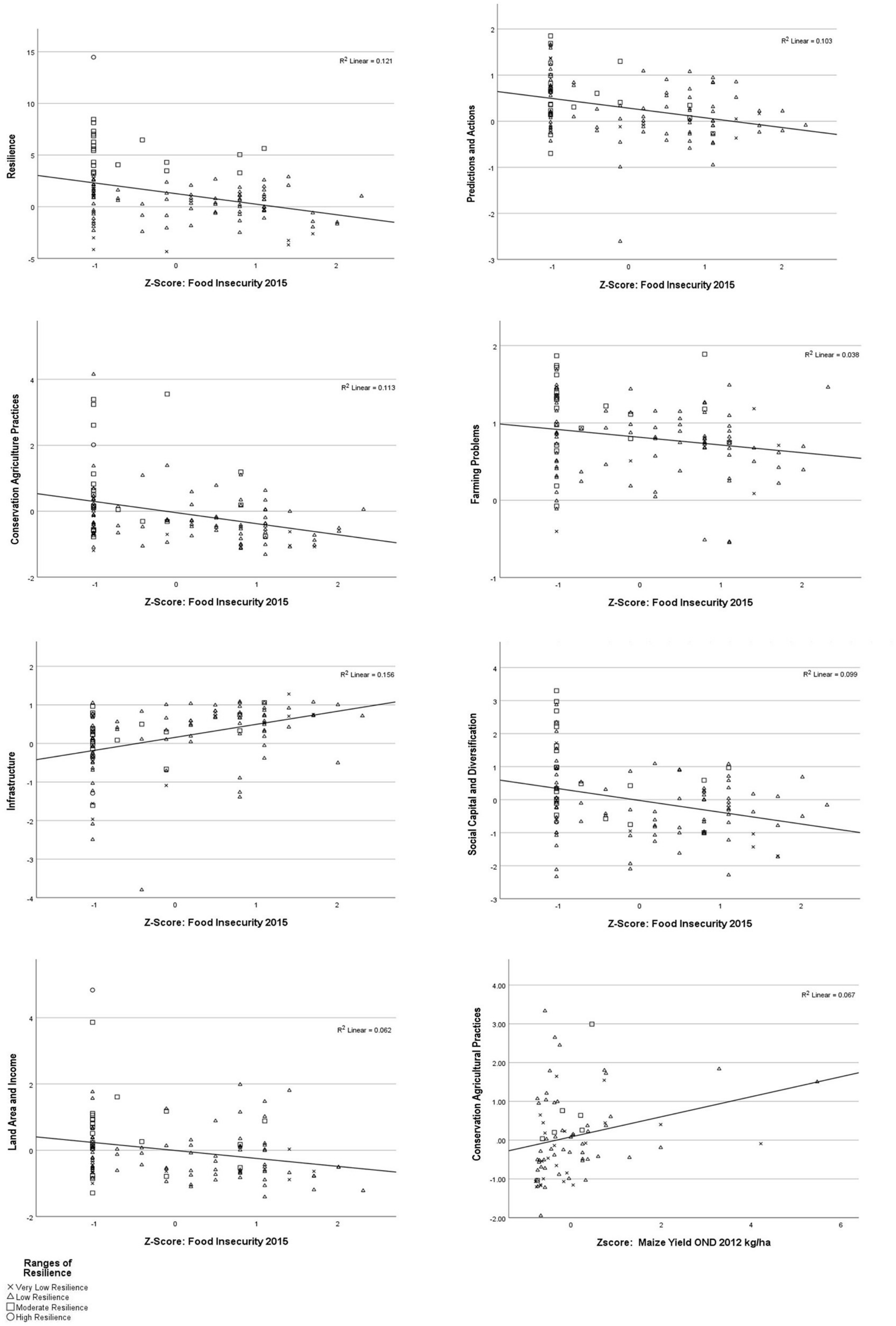

FIGURE 6
Scatterplots resilience components and food insecurity/maize yields.

in 2012, households with higher social capital and diversification were found to experience more farming problems (probably related with drought conditions in 2012), in 2015, the situation was the opposite. Different interpretations apply—those households

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TABLE 5 Correlation matrix components of resilience 2012 (significant correlations).

	Correlations 2012 ($N = 111$) ρ								
	Farming Problems (reversed)	Infrastructure	Experimentation with new techniques	Forecasts and actions	Conservation agriculture practices	Education	Livestock	Social capital and diversification	Storage Facility
Infrastructure ρ	**−0.325****								
Forecasts and actions ρ	**−0.559****								
Social capital and diversification ρ	**−0.260****				**-0.220***				
Resilience Score (sum) ρ	**−0.327****	**0.376****	**0.312****	**0.215***	**0.226***	**0.347****	**0.330****	**0.318****	**0.420****
Maize yields (N = 80) ρ					**0.380****				

Bold values < 0.5.
*p < 0.05; **p < 0.01.

TABLE 6 Correlation matrix components of resilience 2015 (significant correlations).

	Correlations ($N = 111$) 2015									
	Farming Problems (reversed)	Infra-structure	Experimentation with new techniques	Land area and income	Fore-casts and actions	Conserva-tion agriculture practices	Educa-tion	Live-stock	Social capital and diversify-cation	Resili-ence Score (sum)
Experimentation with new techniques ρ	**0.439****									
Forecasts and actions ρ		**−0.235***								
Conservation agricultural practices ρ		**−0.195***			**0.211***					
Education ρ			**−0.219***							
Livestock ρ			**0.222***							
Social capital and diversification ρ	**0.265****									
Storage facility ρ	**−0.302****			**0.244****						
Resilience score (sum) ρ	**0.312****		**0.260****	**0.381****		**0.407****	**0.239***	**0.204***	**0.462****	
Food shortages ρ	**−0.232***	**0.485****	0.116	**−0.270****	**−0.342****	**−0.377****			**−0.285****	**−0.351****

Bold values < 0.5.
*p < 0.05; **p < 0.01.

that face challenges join groups to take advantage of collective capacity or use membership as a means to access support and services accessible to groups and not to individuals (Ulrich et al., 2012; Mukhovi et al., 2020). Studies have also shown that more diversified households have less time to focus on farming and their farming activities and hence negatively affecting their agricultural production (e.g., Pfeiffer and Taylor, 2009; Amare and Shiferaw, 2017). At the same time, they can earn better incomes outside agriculture (Bezu et al., 2012).

Regarding Capacity for Learning under drought conditions, in 2012, maize yield was related to conservation agriculture practices. This finding underlines the importance of conservation agriculture practices and management measures like water harvesting, early planting, growing drought tolerant crops, and using fertilizers and plant protection inputs. It is in line with the results of Matter et al. (2021) for the yield in 2015 and with Boillat et al. (2019), whose findings for the OND rain seasons in 2014 and 2015 suggest that a combination of crop rotation, herbicide and fertilizer application increased the chances of harvesting higher yields. Furthermore, food security was found to be positively related to conservation agriculture practices in 2015, reinforcing the findings of Boillat et al. (2019) that conservation agriculture practices are also beneficial during favorable rainfall conditions.

Forecasts and actions were found to be negatively related to food insecurity in 2015. As the year 2015 was characterized by a strong El Niño event (Siderius et al., 2018), the positive correlation between forecasts and actions and conservation agriculture practices in 2015 suggests that farming households respond to forecasts by applying a wider variety of practices.

5.3. Limitations of this study

This study applied the livelihood resilience framework to assess smallholder livelihood resilience over a period of 4 years (2012–2015). This period might be too short to capture dynamics in livelihood resilience; hence, observations over a longer period might yield more insights. Given more financial resources, the sample size of 111 households could be increased to capture more smallholder households in the study area. The Kaiser–Meyer–Olkin (KMO) Measure showed that 74.6% of variance could be attributed to factors underlying livelihood resilience. Hence, there seems to be other variables not captured in the framework that are important for livelihood resilience.

6. Conclusions

This study aimed to assess the dynamics in smallholder farmers' livelihood resilience in Makueni County by examining the interrelations between indicators of livelihood resilience and livelihood outcomes in 2012 and 2015. It identified 10 components that characterize livelihood resilience, namely farming problems, infrastructure, experimentation with new techniques, land area and income, forecasts and actions, conservation agriculture practices, educational level, livestock assets, social capital and diversification and storage facility. The results showed that depending on households' scores in the different resilience components, the probability of negative or positive livelihood outcomes altered significantly. Moreover, the study revealed that food insecurity still prevails among the surveyed smallholder population in Makueni County, even under favorable rainfall conditions.

Applying the Livelihood Resilience Indicator Framework in a longitudinal study showed that the impacts of the different resilience dimensions on livelihood outcomes have changed within the period of only 4 years. The dynamic interrelations found between the three dimensions and their components highlight the complexity of interactions underpinning livelihood resilience and its dimensions and the crucial need to address it through continuous monitoring. The various indicator variables found relevant for determining smallholders' resilience in 2012 and 2015, pose a potential starting point for further research on livelihood resilience and monitoring over a longer period.

Data availability statement

The raw data supporting the conclusions of this article can be made available by the authors upon request. Requests to access these datasets should be directed to chinwe.ifejika.speranza@giub.unibe.ch.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The authorities and participants were informed about the research and fieldwork. Both the authorities' and participants' consent were orally obtained before the data collection.

Author contributions

CI: supervision and project coordination. CI and SB: conceptualization and methodology. RA: data organization, data analysis, and writing of first draft. RA, SB, and CI: interpretation of results and review and editing. All authors have read and approved the submitted version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1070083/full#supplementary-material

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