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Building on foundations for climate services for sustainable development: A case of coastal smallholder farmers in Kilifi County, Kenya

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ABSTRACT

The study contributes to the development and use of effective climate services for sustainability in agriculture. Specifically, we assessed farming practices of a coastal smallholder farming community in Kilifi County (hereinafter Kilifi), Kenya, to identify barriers to climate services' effective use. The smallholder farmers in Kilifi represent many smallholder farming communities in East Africa whose primary livelihood is rainfed agriculture. First, we carried out an analysis of historical and future rainfall patterns over Kilifi to determine the area's climate patterns. We used a set of five descriptors of rainfall in Kilifi representing seasonal mean daily precipitation and annual precipitation intensity (SDII) and rainy days (R1MM) for the analysis. We assessed March-May (MAM), June-August (JJA), and October-December (OND) seasons, corresponding to the three planting seasons in Kilifi. Here, values for the five descriptors in the historical period (1977–2005) were compared with those in the future period (2071–2099) to determine the potential changes in the rainfall patterns. Results showed high year-to-year rainfall variability, relatively low mean daily rainfall per season, high variability within seasons, and uneven distribution of rainfall within seasons. MAM, OND, and SDII showed an increase in the future period while JJA recorded a considerable reduction in rainfall. No discernible changes were recorded for R1MM. Results from a social survey showed that the smallholder farmers in Kilifi were indeed experiencing climate variability and change. While some effort had been made towards building the farmers' adaptive capacity, the interventions were reported to be too sporadic and inadequately coordinated to achieve meaningful results. Through Focus Group Discussions (FGDs), Key-Informant Interviews (KIIs), and literature review, an innovative climate change adaptation model was developed. Thus, this study provides a preliminary framework for strengthening an enabling environment for climate services for agricultural productivity and sustainable development in a changing climate.

Practical implications

The use of climate services in response to a changing climate is increasingly becoming necessary for socio-economic development and sustainability. However, differences in regional and local impacts, priorities, and capacity necessitate innovative approaches to the design and use of climate services. Kilifi County, Kenya – an example of a predominantly smallholder farming coastal community -has its unique local challenges, including poverty conditions, disease burden, and food insecurity. Any climatic hazards could, potentially, jeopardize the socio-economic wellbeing of the County. In exploring the best means of serving this community with climate services, it was necessary to assess (i) historical and future climate variability for Kilifi, (ii) the farmers' knowledge on climate change and adaptation activities, and (iii) co-design an innovative climate change adaptation approach that is best suited to the community. The proposed innovative adaptation approach provides a better environment in which the use of climate services can thrive.

The need for better-adapted and mainstreamed climate services

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for the sustainability of Kilifi's livelihoods emphasizes understanding the local context and constituting structures and systems from local resources. Some of the underlying factors that were identified include a lack of a well-coordinated approach to climate change adaptation to ensure that interventions are relevant, timely, and implemented in full. Farmers listed some incidences where sporadic projects were initiated at the County but left midway, leaving farmers worse-off than before the interventions. Additionally, farmers identified low literacy levels and relative remoteness of parts of Kilifi as some of the hindrances to sufficient access and use of climate services. The farmers' adaptive capacity was also limited, leading to the overall low crop productivity and dwindling farming yields.

In response to the challenges identified, an innovative climate change adaptation model was co-conceptualized by the stakeholders. The model recognizes that strong progressive leadership is a prerequisite for significant development and use of climate services (Measham et al., 2011; Meijerink and Stiller, 2013). Consequently, at the core of the proposed model is an implementation taskforce that coordinates farmers, researchers, administrators, and the market for effectiveness, relevance, and sustainability. While the proposed model was conceptualized by and for coastal smallholder farmers in Kilifi, the model can be replicated for use in other communities worldwide.

1. Introduction

Climate variability and change in the form of increased occurrence and intensity of wet and dry spells, sea-level rise, and a warming globe, among others (IPCC, 2014) has been observed globally. There is an increasing scientific consensus that change is happening and that the change is attributable to anthropogenic greenhouse gas (GHG) emissions. However, the acknowledged climate crisis impacts, which vary across different ecological zones, are yet to be fully understood (e.g. Tall et al., 2018; Vaughan et al., 2019).

Significant effort has been expended towards understanding climate dynamics and translating the knowledge for use in various sectors of society, referred to as climate services. One such effort is the Global Framework for Climate Services (GFCS), hosted by the World Meteorological Organization (WMO). GFCS defines climate services as those that provide individuals and organizations with information that facilitates climate-smart decision making (Hewitt et al., 2012). The climate services must be produced, translated, and delivered promptly (National Research Council, 2001) to make them useful to intended beneficiaries. Hence, strategic monitoring, evaluation, accountability, and learning are prerequisites for the effective use of climate services as a climate change adaptation option.

There is an increasing discourse on the need for more location and sector-specific climate services (Bessembinder et al., 2019; Vincent et al., 2017). However, lack of adequate policy mainstreaming at national and sub-national levels often leads to sporadic individual and uncoordinated initiatives that yield minimal results (Hassanali, 2017; Naab et al., 2019; Ojwang et al., 2017). This calls for more evaluation efforts to enhance evidence-based climate information services' real value and impact. Specifically, such efforts should combine quantitative and qualitative methods, consider user-group heterogeneity, and focus not only on agricultural production but also on the entire agricultural system (Tall et al., 2018). Following a review and synthesis of the literature, Vaughan & Dessai (2014) identified four critical components of a climate service evaluation approach. These components include the context for problem identification and decision-making; characteristics, customization, and dissemination of climate information; structure and governance of the climate service; and the climate service's socio-economic value.

One of the main challenges hindering the design, delivery, and use of climate services is inadequate awareness (among user groups) of availability, access, and use of information to inform livelihood and agricultural management decisions (Kalafatis et al., 2015; Vogel et al., 2019). The information gap is often caused by inadequate representation and engagement of local farming conditions and knowledge in the development and use of agrometeorological information products (FAO, 2019). While discernible progress has been made towards designing and implementing climate services worldwide, more needs to be done to achieve their full potential (Kull et al., 2016).

Reporting on the status of climate services in 2019, the WMO recommended, among others, the need to address the "last mile" barrier (Dobardzic et al., 2019). Here, a call for multi-stakeholder partnerships and governance was made to spur innovation in climate services for effective information sharing and feedback. Additionally, the report emphasized information co-production processes that ensure that target users are meaningfully engaged in developing information and products. In so doing, better returns on climate action are likely to be achieved, particularly in Africa, where depressed agricultural yields of up to 30% are expected in a changing climate (Global Commission on Adaptation, 2019).

This paper contributes to ongoing efforts in developing and using effective climate services not just for agricultural production but also for the entire agricultural value chain. We do so by studying and working with a smallholder farming community in Kilifi County (hereinafter Kilifi) located on the Kenyan coast. First, we assess Kilifi's historical climate patterns, the smallholder farmers' perception of climate patterns, and their farming adjustments to climate variability and change. Secondly, we work with the smallholder farmers (and other local actors) to identify gaps in the current climate actions and propose a more practical approach to climate change adaptation in Kilifi. The proposed climate change adaptation approach provides a firm foundation on which the development, delivery, and use of climate services can be more successful. The paper is arranged into introduction (1), material and methods (2), results and discussion (3), and conclusion and recommendations (4).

2. Material and methods

2.1. Study area

Like all East African countries, Kenya is economically reliant on agriculture, tourism, and related sectors – all of which are predominantly climate-dependent (Alessandro et al., 2015; Hawinkel et al., 2016). About 90 percent of Kilifi (Fig. 1), a typical coastal smallholder farming community, depends on rain-fed agriculture as a primary source of livelihood (Kilifi County, 2018). The County already experiences low crop productivity, food insecurity, increased frequencies of extreme weather events, and depressed farm yields (Kilifi County, 2018; Obura et al., 2017). With the structure of Kilifi's economy not expected to significantly shift from being climate-dependent, a concerted effort is required from all actors to promote the development and use of climate services to safeguard smallholder farming for sustainable socio-economic development in a changing climate.

Kilifi has a mean annual rainfall ranging from 300 mm at the hinterland to about 1300 mm at the coastal strip. Evaporation in the county ranges from 1800 mm along the coastal strip to 2200 mm in the Nyika plateau in the hinterland. Average temperatures range from 21 °C to 30 °C at the coastal belt and from 30 °C and 34 °C at the hinterland (Kilifi County, 2013).

2.2. Data

2.2.1. Observational data

The daily Climate Hazards Group InfraRed Precipitation with Station data, version 2.0 (CHIRPS; Funk et al., 2015) were used as the reference precipitation data for this study. The CHIRPS dataset ranges from 1981 to near present, integrating satellite imagery (at 0.05° resolution) with

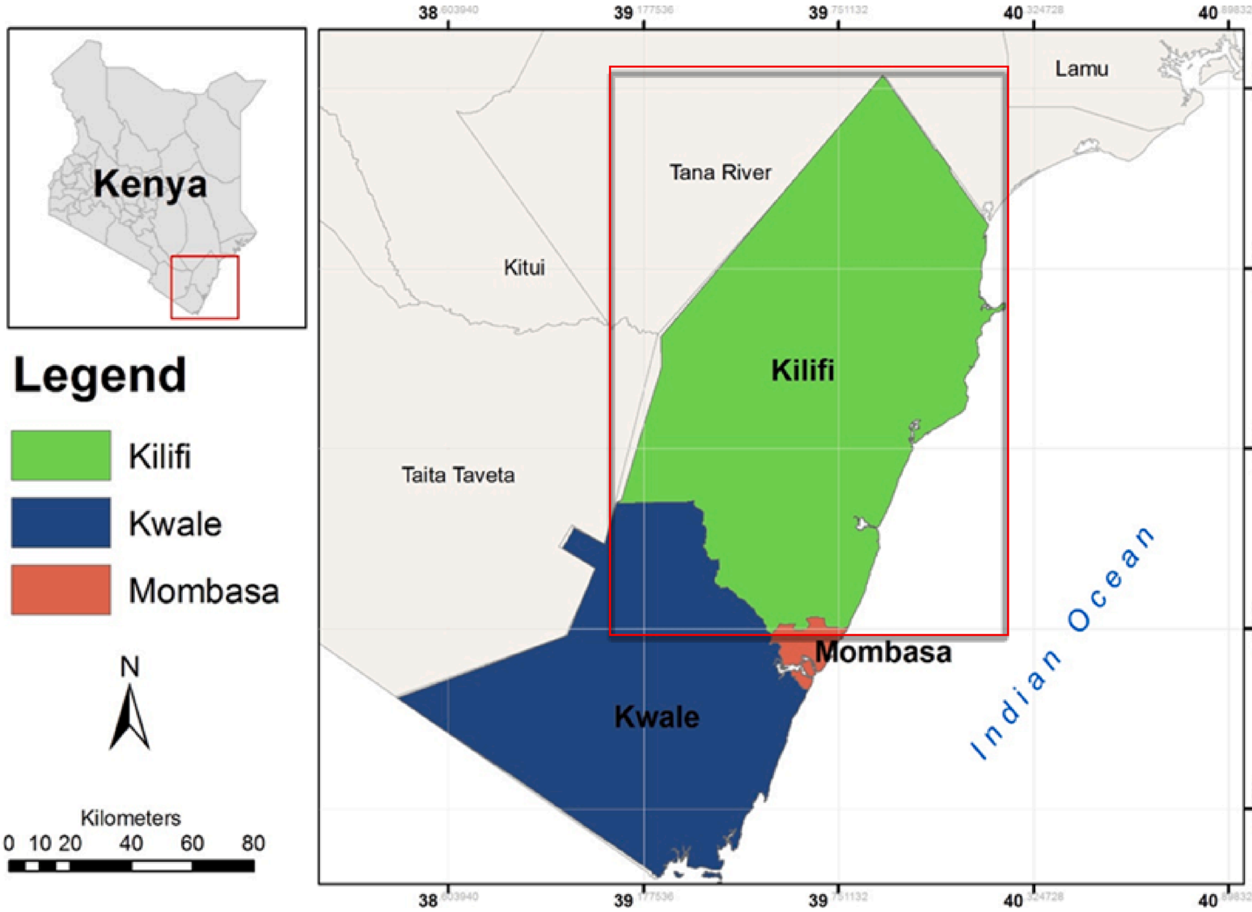

Fig. 1. Map of the study area.

Table 1
A description of the RCA model used in the current study (more details available at https://esg-dn1.nsc.liu.se/search/cordex/).

Institute	RCM ID	Herein-after	Reference paper	Driving GCMs
The Rossby Center, Sveriges Meteorologiska och Hydrologiska Institut (SMHI), Sweden	SMHI-RCA4_v1	RCA	Samuelsson et al., (2011)	CCCma-CanESM2 CNRM-CERFACS-CNRM-CM5 CSIRO-QCCCE-CSIRO-Mk3-6-0 ICHEC-EC-EARTH IPSL-IPSL-CM5A-MR MOHC-HadGEM2-ES MPI-M-MPI-ESM-LR NCC-NorESM1-M NOAA-GFDL-GFDL-ESM2M

in-situ station data producing a gridded rainfall time-series. CHIRPS data have been validated for East Africa and found to be fit for use as a reference dataset (Dinku et al., 2018) and are widely used as a reference data over East Africa (e.g. Cattani et al., 2018; MacLeod, 2018; Ogega et al., 2020).

2.2.2. Regional climate model (RCM) data

Several assessments have been done to establish the performance of regional climate models (RCMs) in simulating East Africa's climate (e.g. Endris et al., 2013; Ogega et al., 2020). The Rossby Centre regional atmospheric model, version 4 (RCA4; hereafter RCA), has been identified as one of the RCMs that give a good simulation of East Africa's rainfall patterns. The RCA is part of the Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative (Giorgi et al., 2009) operated by the World Climate Research Program (WRCP). Therefore, the current study chose the RCA model forced by nine general circulation models (GCMs; Table 1) owing to its performance in reproducing East Africa's climate, a wide range of driving general circulation models (GCMs), and data availability for the historical, and representative concentration pathway (RCP; Moss et al., 2010; Riahi et al., 2011) 4.5 and 8.5 simulations. RCPs represent global warming scenarios because of greenhouse gas emissions into the atmosphere. The RCPs 4.5 and 8.5 represent the 'business-as-usual' and 'worst-case' scenarios, respectively (Riahi et al., 2011).

2.2.3. Qualitative data

Primary qualitative data were generated from a social survey conducted to obtain information on smallholder farmers' perceptions of climate variability and change and existing adaptation measures. The survey used semi-structured questionnaires, focus group discussions, and key-informant interviews to collect the study's qualitative data. Kilifi County's average household size was six persons, while the population was approximately 1.11 million (Kilifi County, 2013) at the time of the current study. A sample size of 1500 people (translating to 250 households) was computed using the pre-determined margin of error (Smith, 2010) sample size estimation method given by

$$ME = z\sqrt{\frac{p(1-p)}{n}} \quad (1)$$

where *ME* represents the desired margin of error, *z* the z-score, *p* is a prior judgment of the correct value of *p*, and *n* is the sample size (being determined).

2.3. Methodology

First, historical seasonal precipitation trends over Kilifi were analysed using CHIRPS data for the period 1981–2018, corresponding to data availability. The study adopted five descriptors (detailed in Table 2) of a rainy season in Kilifi namely the daily mean seasonal precipitation values for March-May (MAM), June-July (JJA), and October-December (OND). Other descriptors used are the rainy days (R1MM) and intensity of rainfall (SDII) in a year. The MAM, JJA, and OND seasons were selected to correspond to the planting seasons in Kilifi (Humphrey, 1939; MoALF, 2016). SDII and R1MM are climate indices (International CLIVAR Project Office, 2001) highly sensitive to global warming and climate change. These descriptors have been widely used in East Africa and beyond (e.g. Gudoshava et al., 2020; Jiang et al., 2015; Ogega et al., 2020; Osima et al., 2018). The analysis was done using standardized anomalies to minimize the influence of data dispersion (as in Dabernig et al., 2017). Here, values within −1 and 1 imply a normal range while those between −2 and −1 and 1 and 2 represent below and above normal, respectively. Values below −2 and above 2 imply the extreme occurrence of the parameter under consideration (in the current study, precipitation).

Secondly, potential future precipitation changes over Kilifi were analysed using boxplots. Here, values for MAM, JJA, OND, SDII, and R1MM for the period 2071–2099 (hereinafter FUTURE) were computed and compared to those in the period 1977–2005 (hereinafter BASELINE). The analysis was done using the RCA model projections under the RCP4.5 and RCP8.5.

A social survey was conducted in Kilifi County from October 2015 to February 2016 to establish the smallholder farmers' perceptions of climate change. The survey also sought to determine the farmers' reactive and proactive responses to the changing climate. Semi-structured questionnaires were administered to 350 households from all the 35 Wards of Kilifi County. Additionally, key-informant persons drawn from the farming community and the county administration, were interviewed in parallel with the household survey. Findings from the climate analysis, social survey, and key-informant interviews were shared with stakeholders in focus group discussions (FGDs) for validation and feedback. The outcomes from the FGDs combined with the literature review were used to develop an innovative climate change adaptation model for the smallholder farmers in Kilifi.

Table 2
Details of rainfall descriptors used in the current study.

Descriptor	Acronym	Description	Unit
Intensity of rainfall	SDII	Adapted from ETCCDI's criterion where simple precipitation intensity index. Let RR_{ij} be the daily precipitation amount on wet day w ($RR \geq 1$ mm) in period *j*. If W represents the number of wet days in j then the simple precipitation intensity index $SDII_j$ = sum (RR_{wj}) / W	mm/ day
Occurrence of rainfall (rainy day)	R1MM	Adapted from ETCCDI's criterion where the number of days with precipitation amount (nn) in each period is counted (Rnnmm). Let RR_{ij} be the daily precipitation amount on day *i* in period *j*. Count the number of days where $RR_{ij} \geq$ nn mm.	days
Mean daily precipitation for MAM season	MAM	For every adjacent sequence $t\_1, \ldots, t\_n$ of timesteps of the same year it is: $o(t, x) = mean\{i(t', x), t_1 < t' \leq t_n\}$; computed for March-May of every year in the series	mm/ day
Mean daily precipitation for OND season	OND	For every adjacent sequence $t\_1, \ldots, t\_n$ of timesteps of the same year it is: $o(t, x) = mean\{i(t', x), t_1 < t' \leq t_n\}$; computed for October-December of every year in the series	mm/ day
Mean daily precipitation for JJA season	JJA	For every adjacent sequence $t\_1, \ldots, t\_n$ of timesteps of the same year it is: $o(t, x) = mean\{i(t', x), t_1 < t' \leq t_n\}$; computed for June-August of every year in the series	mm/ day

3. Results and discussion

3.1. Past and future precipitation patterns over Kilifi

A plot of year-to-year standardized precipitation anomalies for Kilifi (Fig. 2) shows a high interannual variability for all the three seasons considered. However, most of this variability is within the normal range (-1 to 1). Specifically, MAM rainfall variability was mostly within the normal range except for a few cases of above normal (1981, 1986, 2007 and 2017) and below normal (1992, 2001, 2004, 2009, 2011, and 2012). The OND season also showed variability mostly within the normal range except for 1997 and 2006 when the area experienced extreme rainfall (above 2). The JJA season recorded the least rainfall (compared to MAM and OND). No discernible trends were observed for all the three seasons with gradients of −0.01, −0.03, and 0 for MAM, JJA, and OND, respectively. Our results complement other studies done over the study domain (e.g. Muthoni et al., 2019; Ogega et al., 2020; Osima et al., 2018).

Potential future precipitation changes over Kilifi were analysed using nine simulations from the RCA model, using projections under the RCP4.5 and RCP8.5 scenarios. First, the five rainfall descriptors' climatology was done for the period 1977–2005 (Fig. 3). Here, Kilifi seemed to be receiving relatively light rainfall with MAM rainfall recording mean daily precipitation of up to 3 mm. OND, the study area's wettest season, recorded mean daily precipitation of up to 4 mm while JJA was the driest with a maximum mean daily precipitation of 2 mm. Precipitation seemed to decrease from the coastal strip towards the hinterland.

Rainfall over Kilifi seemed to be unevenly spread at the annual scale (R1MM and SDII; Fig. 3). Most parts of Kilifi recorded a simple daily precipitation intensity (SDII) exceeding 6 mm/day. The area recorded up-to 75 rainy days in a year (R1MM). These statistics, coupled with a relatively small mean daily precipitation per season, imply an uneven temporal distribution of rainfall. Such variability is likely to affect the area under crop cultivation, production intensity, and yields (e.g. Iizumi & Ramankutty, 2015; Yoon & Choi, 2020). Our results complement other works done in the study area (e.g. Cattani et al., 2018; Nicholson, 2017; Ogega et al., 2020).

Boxplots (Fig. 4) were made to facilitate the understanding of potential future precipitation changes over Kilifi. Here, minimal changes were recorded. Unlike MAM and OND that recorded a potential for more precipitation by year 2100 (by 0.2 and 0.8 mm/day, respectively), JJA recorded a decrease of up to 0.5 mm/day under RCP8.5. The R1MM index recorded an increase of about 5 days under RCP4.5 but with no

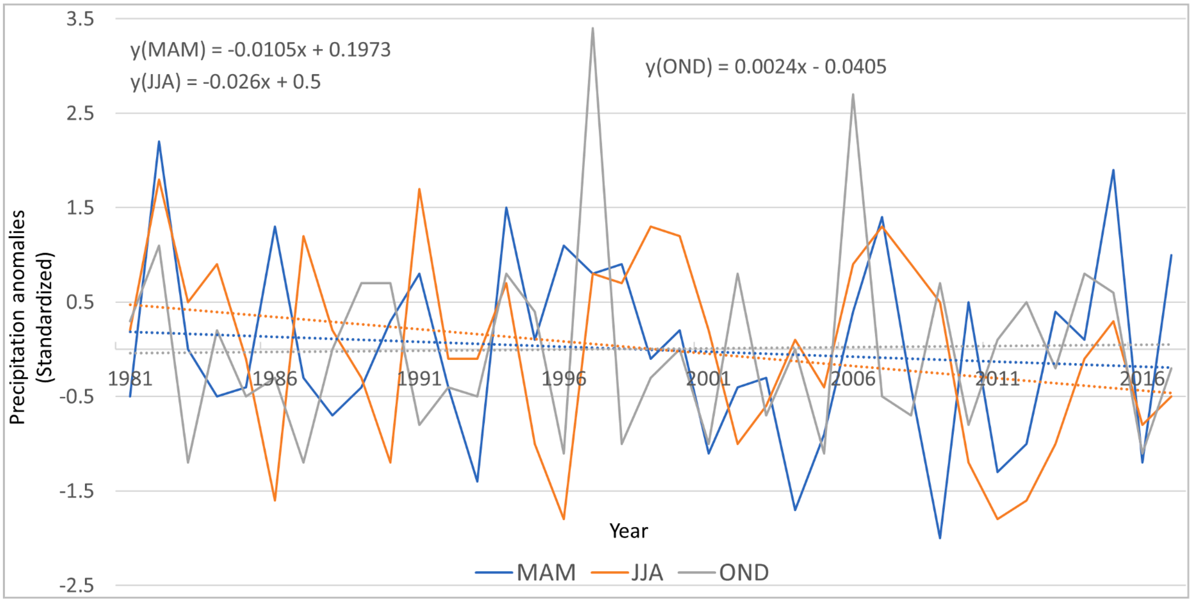

Fig. 2. Year-to-year seasonal precipitation variability over Kilifi for the period 1981–2017, using CHIRPS data.

discernible change under RCP8.5. A potential increase in SDII of about 1 day and 2 days for RCP4.5 and RCP8.5, respectively, was recorded.

Potential for more rainfall in MAM and OND would be a welcome addition to Kilifi's relatively depressed rainfall. However, the enhanced rainfall could be because of potentially more intense precipitation, as shown under SDII. Therefore, more investment should be made towards water harvesting for use during dry periods. Smallholder farmers also need to shift towards climate-smart agriculture to cushion them against the impending climate variability and change. With this information, we conducted a social survey among smallholder farmers in Kilifi to determine their perception of climate variability and change and assess their coping strategies. The results from the social survey were combined with those from the climate analysis to, together with various actors, propose improvements for more effective climate change adaptation in Kilifi as detailed in the following subsections.

3.2. Farmers' perception and response to climate variability and change

All respondents acknowledged having experienced changes in weather and climate over time. In terms of the main changes experienced (Fig. 5, top row), most respondents (95 percent) cited a reduction in rainfall over time. Some respondents also experienced changes in the amount and timing of rainfall. Some respondents (about 5 percent) reported having experienced enhanced rainfall. No discernible changes in the frequency of floods and droughts were reported. The farmers' responses agree with the rainfall analysis results showing a few rainy days with enhanced intensity.

We asked the respondents how climate variability and change had affected their farming activities (Fig. 5, bottom row). Here, most respondents (60 percent) reported crop failure (attributed to changing rainfall patterns) as the main consequence of Kilifi's changing climate. Specifically, inconsistency - in terms of onset and cessation timing, frequency, and intensity - of the rains during crop growing seasons was identified as a perennial impediment to good crop yields. About eight percent of the respondents reported a change in the frequency of floods and droughts. The perceived changes in floods and droughts could be caused by the uneven distribution of rainfall in seasons where a season's total rainfall is received over a few days.

In response to changes in rainfall, farmers had made some adjustments in their farming practices over time (Fig. 6). Most farmers (about 72 percent) had changed crop varieties, while others (54 percent) had intensified the use of fertilizer or manure in their farming. The farmers reported that unlike before, when they could get good yields without using fertilizer/manure, they now had to use fertilizer and/or manure to get yields. Other notable adjustments reported include crop diversification (42 percent) and irrigated agriculture (26 percent).

An analysis of livelihood diversification options (not shown) showed that hardly any farmers were diversifying to other livelihood sources. A few farmers (22 percent) were engaged in some form of business. However, farming remained their primary source of livelihood. With perennial crop failure reported as the main consequence of a changing climate in Kilifi, farmers called for innovative initiatives to enhance their adaptive capacity. Respondents acknowledged interventions from various actors aimed at building the resilience and adaptive capacity of the farmers. However, the farmers reported that the interventions were far between and, often, inadequately coordinated. For instance, farmers reported incidences where subsidized seeds were given, but no market was arranged for the surplus produce. The farmers called for a better mechanism to coordinate access to climate services, enhance the farmers' adaptive capacity, and invest to ensure sustainability. As detailed in the following subsection, discussions were held with relevant stakeholders, after which a comprehensive climate change adaptation approach for Kilifi was proposed.

3.3. An integrated climate change adaptation approach based on climate services

Following results from the climate assessment and social survey, discussions were held with various stakeholders to map gaps in existing initiatives and propose the way forward. Interviews with Kilifi County's Department of Agriculture were done to map out the support provided to smallholder farmers in the County. Here, evidence of a well-structured department from the national government to the County's lowest administrative unit (the Wards) was presented. We also learned about several initiatives that had been developed to support farmers in the County. However, the County reported that it was yet to achieve the desired results despite the investments made thus far.

One of the main challenges hampering effective climate change adaptation in Kenya is inadequate stakeholder involvement and cooperation in the policy formulation and implementation process. Here, farming communities feel, often, excluded (Ampaire et al., 2017). Additionally, the apparent inadequate cooperation and coordination

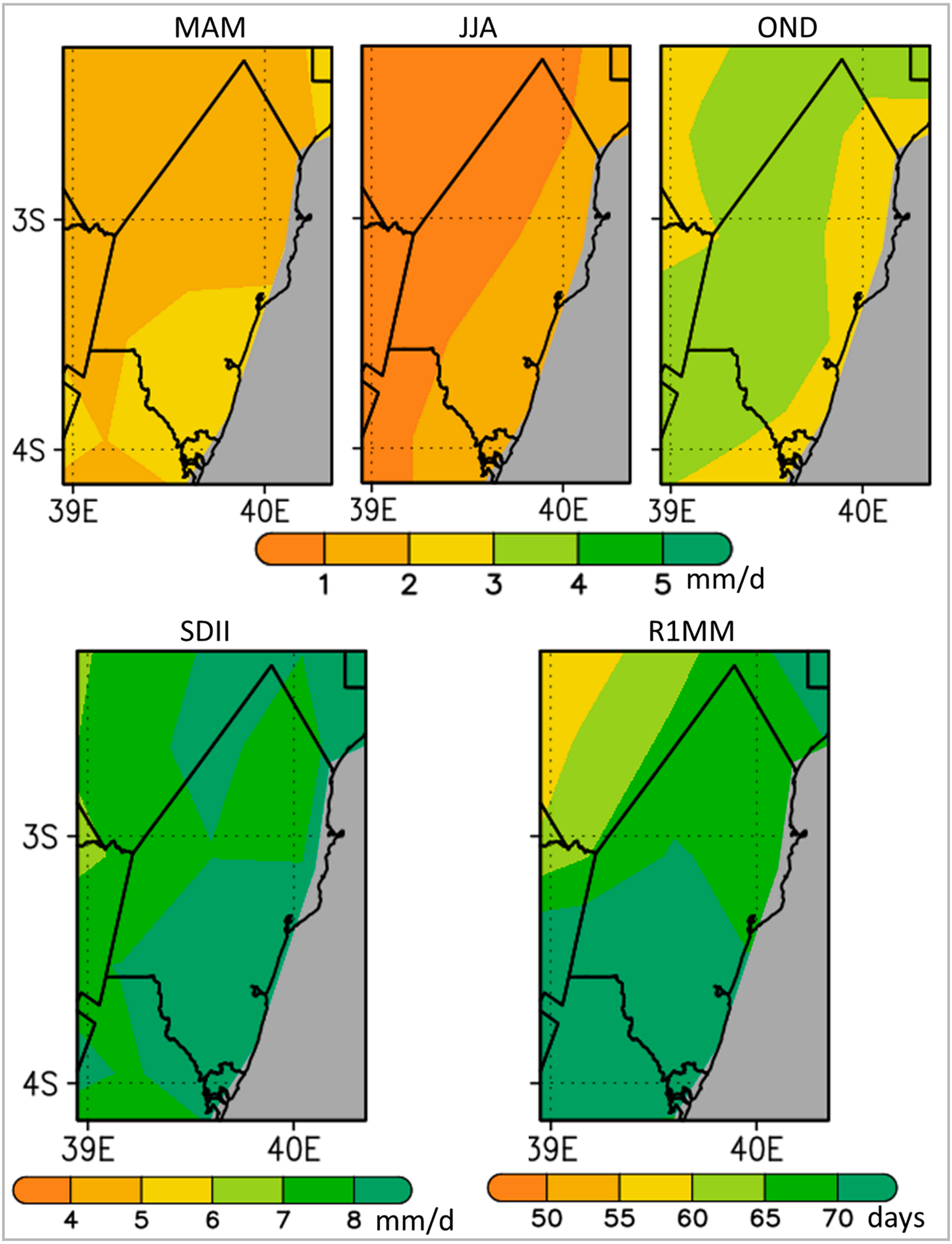

Fig. 3. Mean daily seasonal precipitation (MAM, JJA, and OND), annual simple daily precipitation intensity (SDII), and a count of rainy days per year (R1MM), averaged for the period 1977–2005 over Kilifi, using an ensemble mean of nine simulations from the RCA model. Water bodies are presented in grey.

between central, regional, and local administrative units hamper effective policy implementation (Ongugo et al., 2014). Consequently, the support offered to smallholder farmers fails to achieve the intended results.

We hosted a Focus Group Discussion (FGD) to share and discuss results from the climate analysis and social survey as well as explore potential solutions to strengthen climate change adaptation in Kilifi. Membership of the FGD comprised of representatives of farmers, local

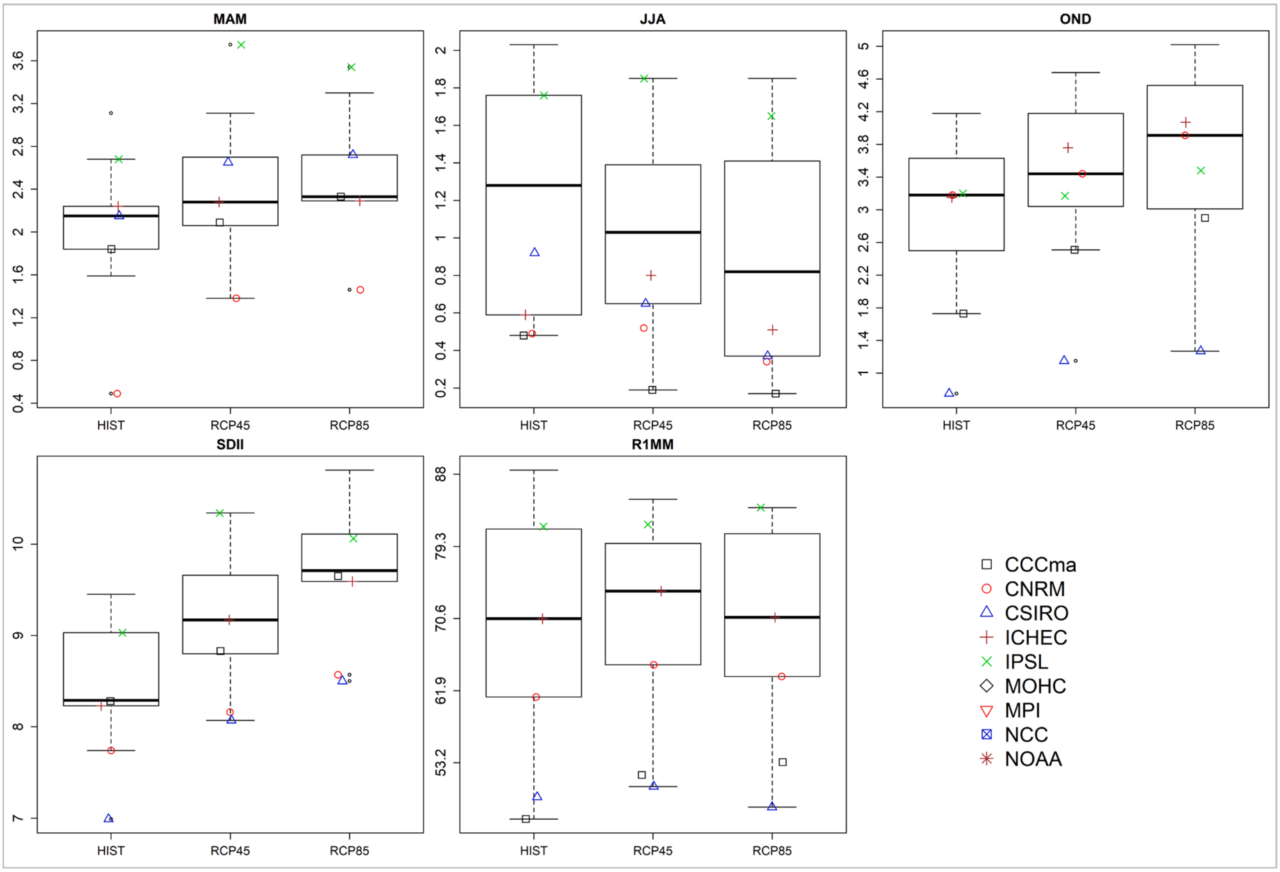

Fig. 4. Mean precipitation values (averaged over Kilifi) for the period 2071–2099 compared to the period 1977–2005 (HIST) using the RCA model projections under RCP45 and RCP85 scenarios. Values for MAM, JJA, OND, and SDII are in mm/day while R1MM is in days.

administration, academia, civil society organizations, and the media. First, the results from the climate analysis and social survey were discussed and validated. Then, issues raised in the social survey were exhaustively discussed, and potential solutions were suggested. Here, it was unanimously agreed that there was a need for a robust and well-coordinated climate change adaptation approach. The adaptation approach would ensure availability and access to relevant climate services, an enabling policy environment, and strategic linkages to the markets to ensure profitability and sustainability in farming.

The FGD recommended the formation and facilitation of an implementation taskforce to coordinate interventions and stakeholder involvement. Representatives of the smallholder farmers, climate researchers, county administration, and the market were identified as crucial implementation taskforce members. Using results from the social survey, FGD, and literature review, this study proposes an innovative climate change adaptation model (Fig. 7). The model uses climate services as a critical input for effective climate change adaptation and sustainability.

Our integrated climate change adaptation approach (Fig. 7) augments earlier works by strategically embedding climate services and strategic management at the core of climate change adaptation. Our proposed model strategically requires climate services to inform interventions made in response to weather and climate variability. Capital, in the form of household and community assets (financial, social, human, political, and environmental), through the Capital Approach Framework (Máñez et al., 2014; Scoones, 1998) provides an enabling environment for interventions to lead to sustainable adaptation. Strategically, our proposed model is driven by a trans-sector implementation taskforce comprised of representatives of farmers, climate researchers, local administration, and the market. The taskforce ensures that farmers get the best climate services, helps implement interventions, and links farmers to pre-arranged markets. Our model addresses gaps in policy formulation and implementation, including adequate stakeholder involvement and cooperation (Ampaire et al., 2017; Ojwang et al., 2017), through the taskforce. It also minimizes barriers to effective climate change adaptation by enhancing availability and access to climate information, coordinating interventions, and mobilizing climate action resources. The model provides a better platform for science-policy-target user discussions to ensure adequate stakeholder involvement and customization of climate services for a more significant impact. Therefore, we believe that our proposed approach to adaptation enhances climate services' effectiveness for sustainability in agriculture and related sectors.

4. Conclusion and recommendations

Smallholder farmers in Kilifi, just like many others in the region, continue to experience the impacts of a changing climate - mainly in the form of erratic rainfall patterns leading to perennial crop failure and affecting their livelihood. Despite the prevailing challenges, there is an apparent lack of a well-planned, coordinated, and implemented adaptation program for the farmers. Future climate projections indicate a possibility of more rainfall variability for Kilifi – presenting a strong case for enhancing the farmers' adaptive capacity. This paper proposes a well-considered model of adaptation that emphasizes the improvement of farmers' adaptive capacity for sustainability. The key highlight of the proposed model is an enabling environment for the use of climate services to thrive. Bringing together carefully selected stakeholders to form a taskforce to drive tailor-made climate services for farmers will significantly enhance smallholder farming's productivity and

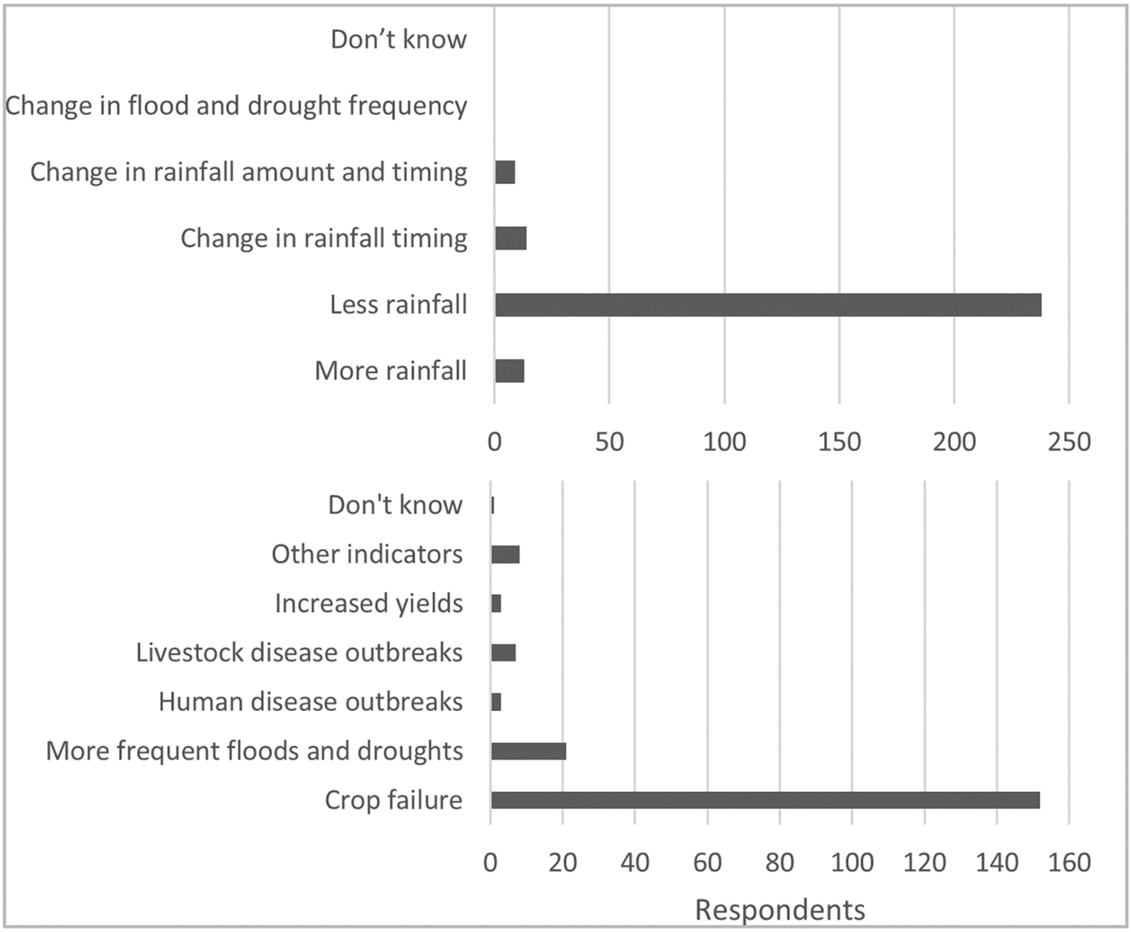

Fig. 5. Farmers’ perceptions (top row) and effects (bottom row) of climate variability and change in Kilifi. Multiple responses were allowed.

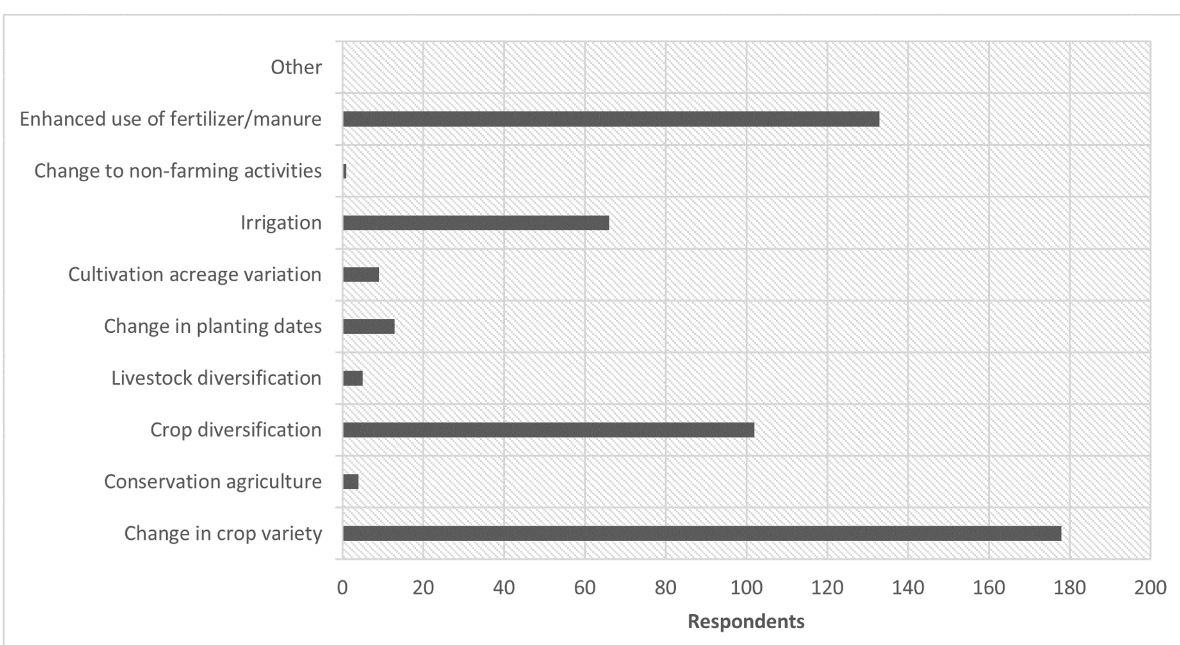

Fig. 6. Primary farming adjustments in response to climate variability and change. Multiple responses were allowed.

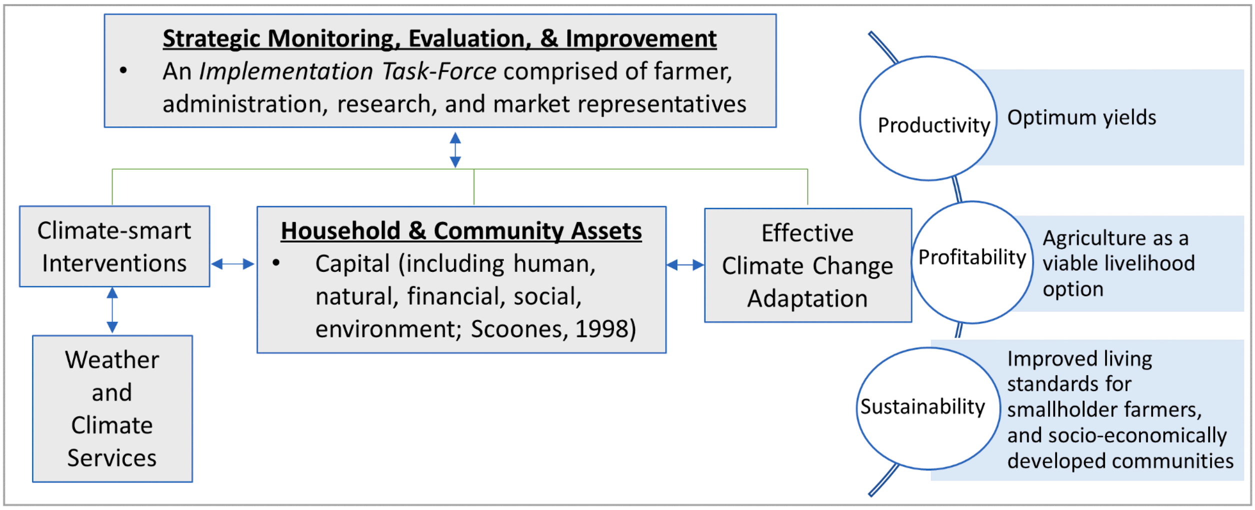

Fig. 7. An integrated climate change adaptation approach (adapted from Máñez et al., 2014; Scoones, 1998).

profitability. With minimal customization, the proposed model can also be replicated for use in other sectors in need of climate action initiatives.

Results from the current study lay the groundwork for further works to continuously improve climate change adaptation frameworks. We call on more investment from stakeholders to make co-exploration and co-production of knowledge more impactful (Turnhout et al., 2020). Continuous and meaningful engagement and involvement of all stakeholders are required to inspire more robust, longer-term, and effective sustainability initiatives in a changing climate (Daniels et al., 2020; Ojwang et al., 2017).

CRediT authorship contribution statement

Obed M. Ogega: Conceptualization, Methodology, Software, Data curation, Formal analysis, Funding acquisition, Writing - original draft , Writing - review & editing, **Benjamin A. Gyampoh:** Conceptualization, Supervision, Writing - review & editing. **Christopher Oludhe:** Conceptualization, Supervision, Writing - review & editing. **James Koske:** Conceptualization, Supervision. **James B. Kung'u:** Conceptualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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