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Leveraging Geospatial Data to Enhance Crop Production in Kenya

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Abstract

With the growing availability and accessibility of geospatial data, its application across various sectors has also expanded. The agricultural sector has not been left behind, experiencing improvements in areas such as crop monitoring, climate and weather forecasting for better planning, farm management practices, yield and production estimation, and even post-harvest planning. However, a significant challenge remains in delivering relevant information to farmers. While the production of geospatial data and information has advanced, the ability to understand, interpret, and effectively use this data requires specific knowledge and skills, which are often lacking. Extension officers, who serve as the key link to farmers, play a critical role in ensuring that not only is the information shared, but that farmers also understand and utilize it properly. Two prior studies on the availability and use of geospatial data for crop production informed the design of this research. The main objective of this study was to evaluate the positive outcomes of using geospatial data and related information in crop production by small-scale farmers. Conducted in the Vihiga and Kilifi Counties of Kenya, the study utilized participatory methods involving both farmers and extension officers to define the metrics for successful crop production outcomes. These metrics were used to design a baseline and final survey to assess changes in production attributed to the shared geospatial data and information. The results were encouraging, showing significant positive outcomes from the study.

Keywords

Geospatial Data, Small-Scale Farmers, Crop Production, Participatory Approach

1. Introduction

Geospatial data availability has increased recently, with many commercial providers offering free access to their data [1]. In Kenya, while the use of geospatial data has risen in national institutions, a report on GIS needs revealed limited usage at the county level [2]. Meanwhile, climate change impacts, including unpredictable rainfall patterns, have negatively affected both small- and large-scale farmers, leading to decreased yields due to poor timing of farming activities such as land preparation and planting [3]. Without effective mitigation measures for climate variability, small-scale farmers are likely to face further negative outcomes [4].

The benefits of using Earth Observation (EO) data for crop monitoring have been demonstrated in several studies. Orusa, Viani, Cammareri and Borgogno Mondino [5] highlighted the use of a Google Earth Engine algorithm to map crop phenological metrics, helping farmers make informed decisions about crop health. Burke and Lobell [6] used high-resolution satellite data for a yield variation assessment in Western Kenya, showing promising results. A review by Chivasa, Mutanga and Biradar [7] also suggested that remote sensing for maize yield estimation, though underutilized, could be cost-effective. However, the use of geospatial data in agriculture has limitations, such as issues with data standards and insufficient government support [8]. Additionally, high costs associated with farm-level data, which require high spatial and temporal resolution, may hinder accessibility [9]. A 2012-2013 analysis by Teucher, Hornetz, JaTzold and Mairura [10] identified the need for specific data sources and system components to support smallholder farmers in Kenya, emphasizing the need for precise recommendations on suitable crops and management options.

The effective use of geospatial data and technologies by farmers depends on how the information is shared with them. Challenges in sharing methods—such as poor interpretation, language barriers, mismatched farming contexts, and high implementation costs—can hinder utilization, even if the information itself is valuable. Studies by Mitheu, Petty, Tarnavsky, Stephens, Ciampi, Jonahbutsatsa and Cornforth [11] and Wahome, Kiema, Mulaku and Mukoko [12] emphasize that timely and understandable dissemination is crucial for farmers to benefit from such data.

This study aimed at evaluating whether using geospatial data improves outcomes for farmers across different stages of the crop production cycle (preparation, planting, growth and harvesting) in Kenyan counties. Two surveys were conducted—the first in 2022 (short rains season) to establish a baseline farm productivity, and the second a year later to measure any changes linked to geospatial information provided to farmers during that period.

2. Materials and Methods

This study involved three phases as shown in **Figure 1** below.

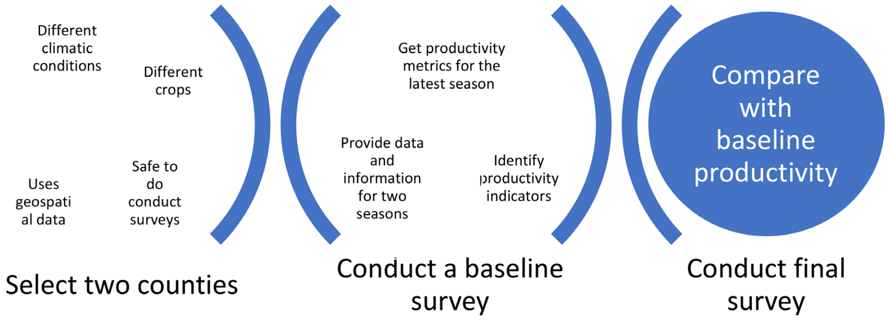

Figure 1. Flow diagram of study activities.

2.1. Study Counties

The study selected Vihiga and Kilifi counties based on prior research assessing geospatial data usage among small-scale farmers in four counties (Nyeri, Vihiga, Kilifi, Wajir) [12] [13]. Wajir was excluded due to security risks, sparse agriculture, and inconsistent farming practices. Nyeri had some active crop production but limited geospatial data adoption by local agriculture officers, who lacked advanced skills in data interpretation. In contrast, Vihiga and Kilifi counties offered diverse farming practices and greater experience in using geospatial data, making them more suitable for the study.

The study selected two sub-counties from each of the two counties. In Vihiga County, Vihiga served as the experimental sub-county and Emuhaya as the control. In Kilifi County, Kaloleni was the experimental sub-county, while Magarini was the control as shown in **Figure 2**.

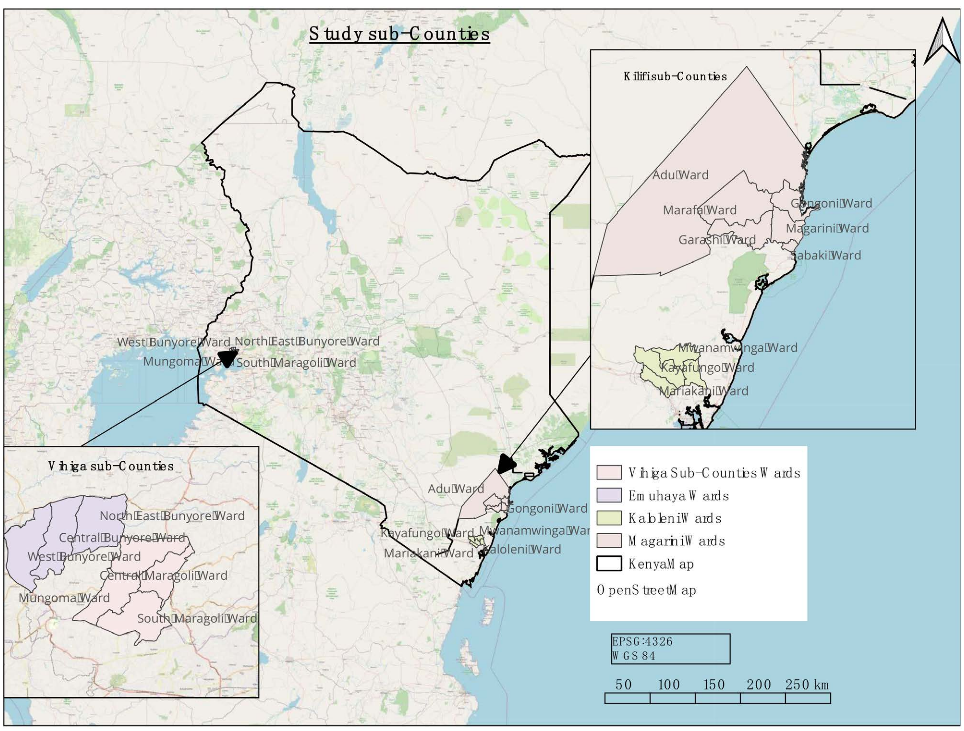

Figure 2. Map of selected sub-counties.

2.2. Identification of Indicators for Crop Productivity

A participatory process was conducted with the farmers, moderated by the sub-County agricultural officer to identify crop production indicators for use in the experimental survey in March 2023. Plate 1 shows a photo of farmers in one of the discussion groups in Vihiga County. The identified indicators were subsequently used in the development of a questionnaire which was used for the baseline survey.

Plate 1. Photo showing a farmer group discussion session in Vihiga sub-County.

2.3. Relevant Information and Related Geospatial Data

Farmers discussed key issues such as the importance, timeliness, and accuracy of information, as well as preferred delivery methods. They reviewed findings from a previous survey [12], evaluating its strengths and weaknesses. Farmers proposed solutions to improve information sharing, which were incorporated into the dissemination methods. Due to cost constraints, options like radio and TV were excluded, with county extension services and champion farmers being the preferred methods.

Farmers prioritized rainfall forecasts (seasonal onset, duration, intensity, and cessation), soil information, and commodity prices. This information was obtained from credible sources and shared through sub-county agricultural officers, ward agricultural officers, and champion farmers. Rainfall forecasts, both seasonal and weekly, were sourced from the Kenya Meteorological Department (KMD).

2.4. Sampling Method and Data Collection

The study used the 2019 Kenya National Housing and Population Census [14] to determine the number of farmers to be interviewed. A stratified random sampling method was applied, resulting in a sample size of 383 per county, rounded to 400. Each sub-county had 200 participants. Farmers were selected randomly, ensuring interviews were not conducted with neighbouring farmers.

Baseline data was collected in March-April 2023, referencing the short rains of October-November-December (OND) 2022, while a second survey took place in June 2024, referencing the short rains of OND 2023 season. A digital questionnaire, developed in Kobo Toolbox, was administered via the Kobo Collect App. Research assistants were trained, and the questionnaire was tested in each sub-county.

Crop production data from the Ministry of Agriculture and Livestock Development (MOALD) was used for comparison with survey results. Remote sensing data from Landsat 8 and Landsat 9, accessed via Google Earth Engine, was analyzed to monitor crop health using Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). Due to cloud cover, Landsat 8 was used when Landsat 9 images were unusable. Three scripts were developed to process Landsat images and calculate the vegetation indices—NDVI and EVI.

3. Results

3.1. Crop Production Indicators

Farmers measured productivity mainly by harvest quantity and quality. Other key indicators included reduced losses from pests, disease, or post-harvest damage, and income from the harvest. These metrics align with those used by organizations like FAO, USAID, and Feed the Future, which assess productivity through average yield per unit of land, crop quantity per household, and production value [15]-[17].

3.2. Geospatial Data and Information for Crop Production

In group discussions, farmers shared their preferred types of information and the frequency of updates. They also identified specific networks for information sharing, including champion farmers, local radio stations, and local administrators. The data and information identified were then shared with farmers during the two seasons in 2023.

- **Seasonal weather forecasts**: this was provided at county level by KMD and were shared with the county agricultural officers. These officers added agricultural implications and then distributed the forecasts as advisories to farmers. **Figure 3** shows a forecast map of the short rains season (OND) 2022 for Kilifi County.
- **Weekly weather forecasts**, provided by County Meteorological Officers, were shared with County Extension Officers and then disseminated to farmers through Sub-County Agricultural Officers (SCAOs), Ward Agricultural Officers (WAOs), and farmer champions. **Figure 4** and **Figure 5** show weekly weather forecast maps for Kilifi and Vihiga Counties, respectively.

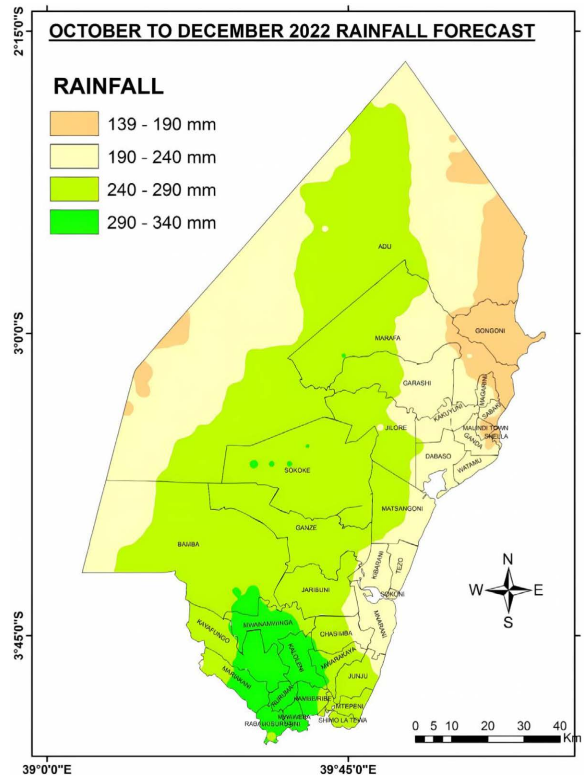

Figure 3. October-December (OND) 2022 seasonal weather forecast for Kilifi County. (Source: KMD).

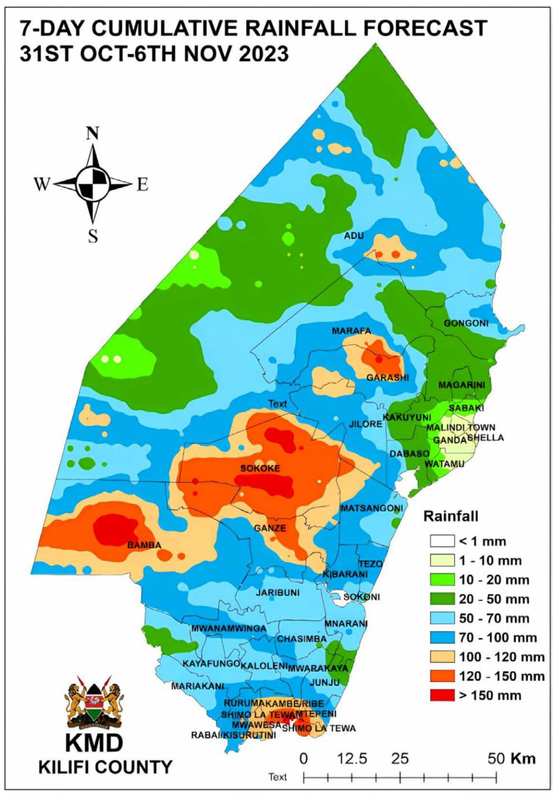

Figure 4. 7-day cumulative rainfall forecast for Kilifi County (Source: KMD).

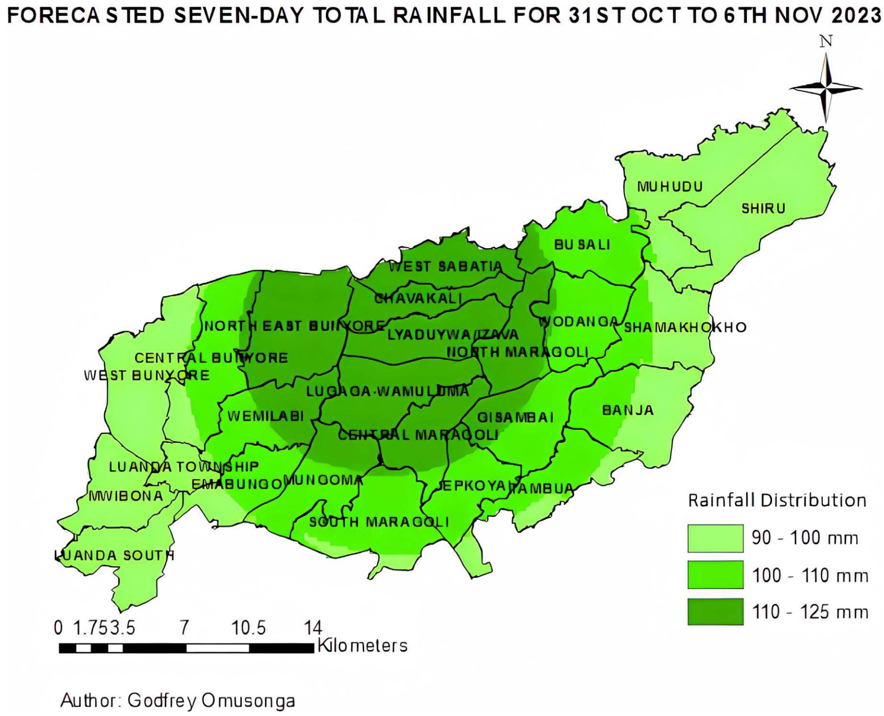

Figure 5. 7-day cumulative rainfall forecast for Vihiga County (Source: KMD).

- **Soil characteristics**: the soil data for the sub-counties was obtained from the Kenya Ministry of Agriculture and Livestock Development's (MOALD) Kilimo-Stats website. The data included characteristics such as texture, consistency, soil class, drainage properties, color, and implications for farming practices. Soil data maps and attribute tables for Vihiga and Kaloleni sub-counties are shown in Figure 6 and Figure 7, and Table 1 and Table 2 respectively.

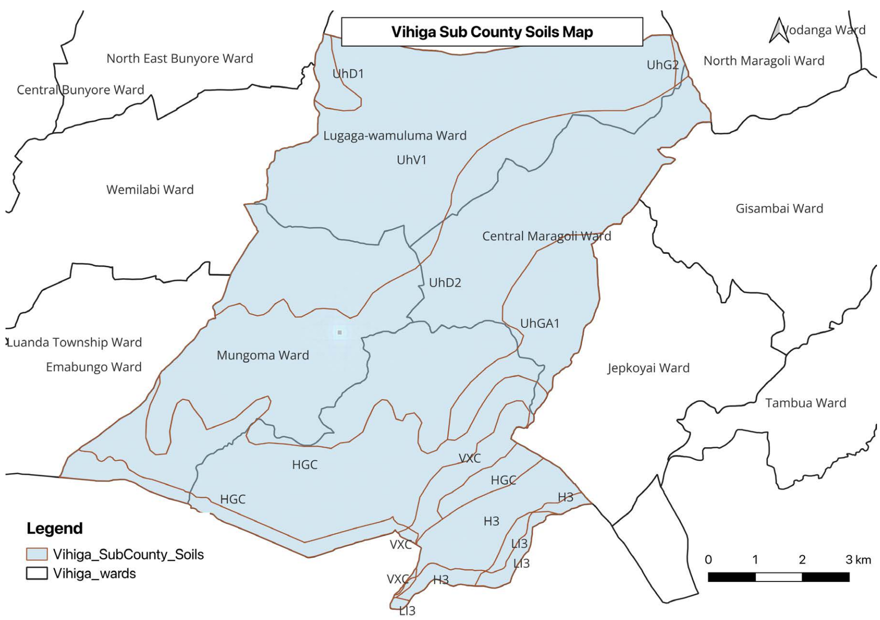

Figure 6. Map of Vihiga sub-county soils (Source: MoALD).

Table 1. Soils description for Vihiga sub-county (Source: MoALD).

Soil	Soil class	Drainage	Depth	Colour	Description
H3	Lithosols and Phaeozems	well drained	shallow to moderately deep	very dark brown	organic manuring, mulching and protection against soil erosion especially necessary, due to young and/or shallow and slopy soils, but partly or completely unsuitable soil for agriculture
HGC	Regosols with Rankers, Cambisols and Lithosols	excessively drained	shallow	varying colour	combination of organic manuring, mulching and protection against soil erosion especially necessary, due to young and/or shallow and slopy soils and organic manuring, mulching and protection against denudation, due to young and/or footslope soils
LI3	Ferralsols	well drained	very deep	dark reddish brown to dark red	heavy organic manuring, due to senile deep soils
UhD1	Acrisols	well drained	very deep	dark reddish brown to yellowish red	mulching with deep rooting bushes especially profitable because bedrock has many nutrients
UhD2	Ferralsols	well drained	extremely deep	dusky red to dark red	heavy organic manuring, due to senile deep soils
UhG2	Acrisols	well drained	deep to very deep	yellowish red to dark reddish brown	heavy organic manuring and additional fertilizer necessary, due to senile deep soils and/or poor parent material like acid bedrocks or sands
UhGA 1	Cambisols with Lithosols and Rankers	excessively drained to well drained	very shallow to deep	brown	heavy organic manuring and protection against denudation and erosion and additional fertilizer necessary, due to senile and/or shallow soils and/or poor parent material like acid bedrocks or sands
UhV1	Nitisols	well drained	extremely deep	dark red	mulching with deep rooting bushes especially profitable because bedrock has many nutrients
VXC	Cambisols, Acrisols and Ferralsols and Gleysols with Vertisols and Histosols	imperfectly drained to well drained	shallow to deep	varying colours	combination of flood control & drainage, channeling and ridging, due to seasonal inundations and waterlogging and heavy organic manuring and protection against denudation and erosion, due to senile and/or shallow soils

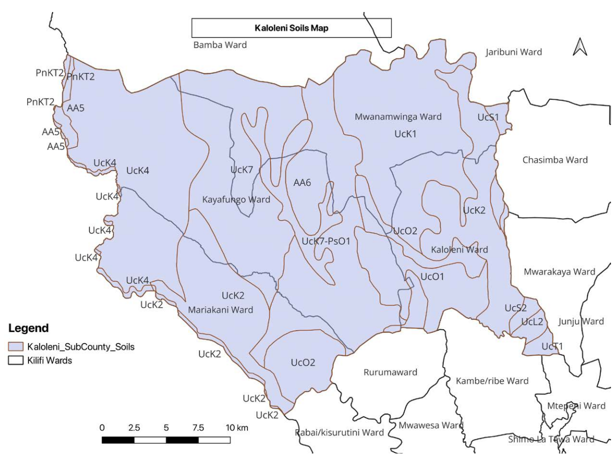

Figure 7. Map of Kaloleni sub-county soils (Source: MoALD).

Table 2. Soils description for Kaloleni sub-county (Source: MoALD).

Soil	Soil class	Drainage	Depth	Colour	Description
AA5	Vertisols	imperfectly drained to poorly drained	very deep	dark reddish brown to dark greyish brown	flood control & drainage, channeling and ridging, due to seasonal inundations and waterlogging
AA6	Luvisols	imperfectly drained	very deep	dark brown	flood control & drainage, channeling and ridging, due to seasonal inundations and waterlogging
PnKT2	Cambisols and Lithosols	well drained	shallow	dark reddish brown to very dark brown	combination of mulching with deep rooting bushes especially profitable because bedrock has many nutrients and organic manuring, mulching and protection against denudation, due to young and/or footslope soils
UcK1	Arenosols	excessively drained	very deep	light brown to yellow	heavy organic manuring, due to senile deep soils
UcK2	Luvisols and Acrisols	well drained	deep to very deep	red to yellowish brown	combination of mulching with deep rooting bushes especially profitable because bedrock has many nutrients and heavy organic manuring, due to senile deep soils
UcK4	Cambisols and Luvisols	well drained	shallow	dark brown to dark yellowish brown	combination of mulching with deep rooting bushes especially profitable because bedrock has many nutrients and heavy organic manuring, due to senile deep soils
UcK7	Luvisols and Planosols	well drained	deep	dark brown to yellowish brown	flood control & drainage, channeling and ridging, due to seasonal inundations and waterlogging, but partly or completely unsuitable soil for agriculture
UcK7-PsO1	Luvisols with Planosols and Solonetz	well drained to poorly drained	deep	dark brown to greyish brown	unsuitable soil for agriculture
UcL2	Nitisols and Acrisols	well drained	very deep	red to dark reddish brown	combination of mulching with deep rooting bushes especially profitable because bedrock has many nutrients and heavy organic manuring, due to senile deep soils
UcO1	Luvisols with Acrisols and Arenosols	well drained to moderately well drained	deep to very deep	yellowish red to light yellowish brown	combination of organic manuring, mulching and protection against denudation, due to young and/or footslope soils and heavy organic manuring, due to senile deep soils
UcO2	Luvisols and Solonetz	moderately well drained to imperfectly drained	moderately deep to very deep	light yellowish brown to olive grey	unsuitable soil for agriculture
UcS1	Arenosols	excessively drained	deep to very deep	reddish yellow to pale brown	combination of organic manuring, mulching and protection against denudation, due to young and/or foot slope soils and heavy organic manuring, due to senile deep soils
UcS2	Luvisols and Acrisols	well drained	very deep	red to yellowish red	combination of organic manuring, mulching and protection against denudation, due to young and/or footslope soils and heavy organic manuring and protection against denudation and erosion, due to senile and/or shallow soils

Continued

UcT1	Vertisols and Luvisols	well drained to moderately well drained	moderately deep to deep	yellowish red to light olive brown	flood control & drainage, channeling and ridging, due to seasonal inundations and waterlogging, but partly or completely unsuitable soil for agriculture

- **Agro-Ecological Zones**—these are maps showing the agro-ecological zones, containing information on the type of climate and the major crops suitable for growing in the zones (see Figure 8 and Figure 9, and Table 3 and Table 4). The list of crops is not exhaustive and has not been updated since the development of the original maps in 1984.

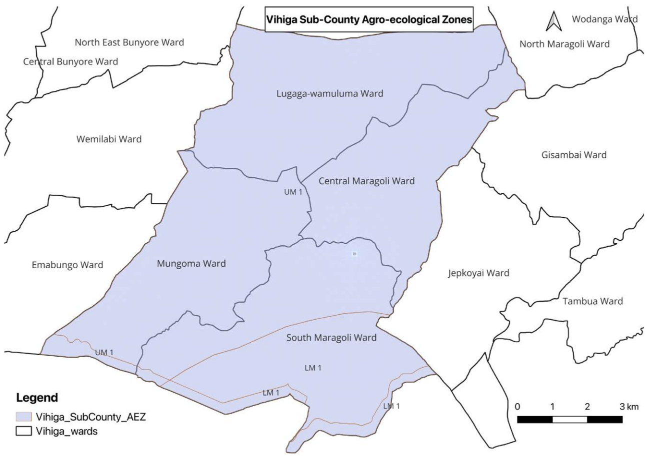

Figure 8. Agro-ecological zones map of Vihiga sub-county (extracted from the Kenya agro-ecological zones map by MoALD).

Table 3. Agro-ecological zones in Vihiga sub-county.

AEZ Code	AEZ Name	Major Crop
LM 1	Lower Midland	Sugar Cane Zone
UM 1	Upper Midland	Coffee-Tea Zone

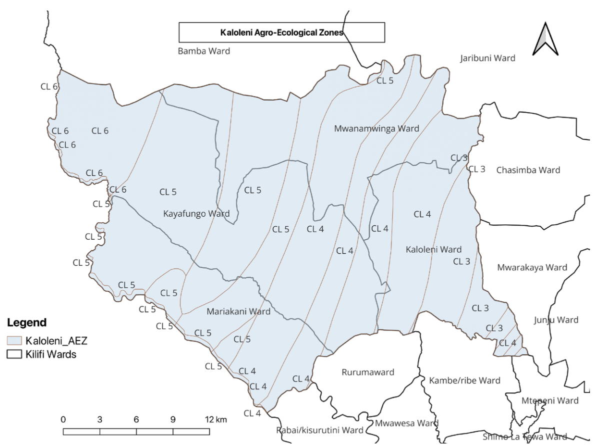

Figure 9. Agro-ecological zones map of Kaloleni sub-county (extracted from the Kenya agro-ecological zones map by MoALD).

Table 4. Agro-ecological zones in Kaloleni sub-county.

AEZ Code	AEZ Name	Major Crop
CL 3	Coastal Lowland	Coconut-Cassava Zone
CL 4	Coastal Lowland	Cashew nut-Cassava Zone
CL 5	Coastal Lowland	Livestock-Millet Zone
CL 6	Coastal Lowland	Ranching Zone

- **Crop health maps** were sourced from GEOGLAM Crop monitors and the Ministry of Agriculture.
- **Crop suitability maps** from Kenya Agricultural and Livestock Research Organization (KALRO) for the top three commonly grown crops in the Counties were shared, in addition to the County Directors of Agriculture advisories. The crop suitability information had information on most of the common crops in the two sub-Counties of Kaloleni and Vihiga, *i.e.* Maize, cowpeas, green grams and beans.

3.3. Farmer Survey Results

a) Farmer characteristics

i. **Age groups**

In Emuhaya, the largest group of farmers (37%) were in the 26 - 35 age range, while in Vihiga, the highest proportion (38%) were in the 36 - 45 age group. In Kilifi, Kaloleni had 34% of farmers in the 36 - 45 age range, and Magarini had 28% in the 26 - 35 age group.

ii. Sex

The highest proportion of farmers in all the 4 sub-counties were male; Kaloleni had 62% male farmers, Magarini 53%, Emuhaya 59% and Vihiga. 57%.

iii. Level of education

Vihiga sub-County had the highest proportion of farmers with secondary education (48%), while the other three sub-counties had the highest proportion with primary education: Emuhaya (54%), Kaloleni (44%), and Magarini (47%).

iv. Size of farms

In all the four sub-Counties, the farm size of most farmers was less than 5 acres (Magarini 97%, Kaloleni 89%, Emuhaya 100% and Vihiga 77%).

b) Advisory information

In Vihiga sub-County, 75% of farmers received advisory information during the 2023 OND season, up from 60% in 2022. In Kaloleni sub-County, 42% received advisories in 2023, down from 68% in 2022. In the control sub-counties, 42% of farmers in Emuhaya received advisories in 2023, compared to 48% in 2022, while in Magarini, 31% received advisories in 2023, down from 41% in 2022. Both Magarini and Kaloleni experienced notable decreases.

Most farmers who received advisory information felt it was adequate, timely, and accurate, except in Kaloleni, where only 7% found it accurate. The results are shown in **Figure 10**.

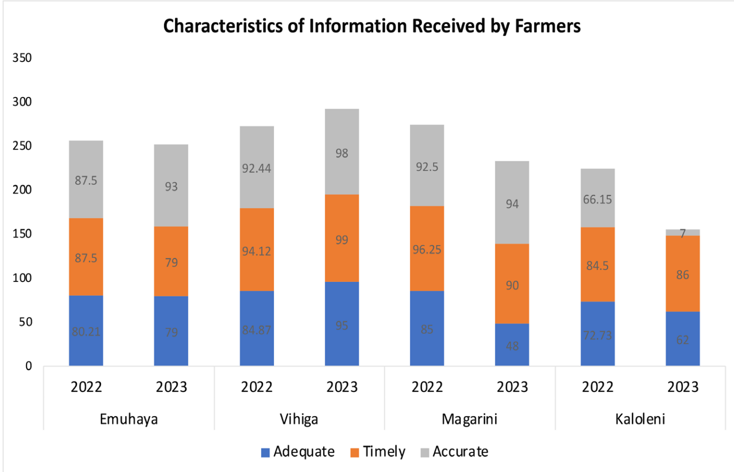

Figure 10. Adequacy, timeliness and accuracy of provided information.

i. The type of information received by farmers

In the OND 2022 season, the top three types of information received by farmers were rainfall, crop suitability, and pest control as shown in **Figure 11**. Vihiga sub-County had a higher proportion of farmers receiving soil information compared to the other sub-counties. While soil information was shared with the SCAO in Kaloleni, it was not effectively disseminated to farmers due to challenges in movement and coordination by WAOs.

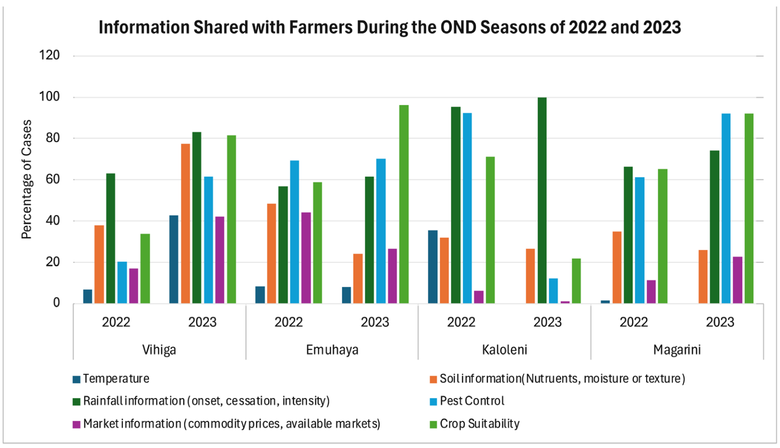

Figure 11. Type of information received by farmers in OND 2022 and 2023 seasons.

ii. Sources of information

In the OND 2022 season, the most common information sources for farmers were fellow farmers, Radio/TV, and friends in Kaloleni. In Vihiga, farmers primarily relied on Radio/TV, fellow farmers, and County extension officers. Magarini's top sources were fellow farmers, County extension officers, and Radio/TV, while Emuhaya's were fellow farmers, County extension officers, and friends. KMD was not a popular source in any sub-county, and Kaloleni had a notably low proportion of farmers receiving information from extension officers compared to the other sub-counties (Figure 12).

In the OND 2023 season, there was an increase in farmers receiving information from friends in Vihiga and Emuhaya sub-counties, and a sharp rise in those getting information from extension officers in Magarini. In Vihiga, the proportion of farmers receiving information from KMD increased from under 10% to nearly 50%, while those receiving information from extension officers rose from 35% to 50%. In Kaloleni, fellow farmers and Radio/TV remained the most popular sources, with over 90% of farmers using them. Emuhaya saw more than 50% of farmers getting information from friends, fellow farmers, Radio/TV, and extension officers. A notable shift in Vihiga was the rise in digital media use, increasing from 6% to 64%.

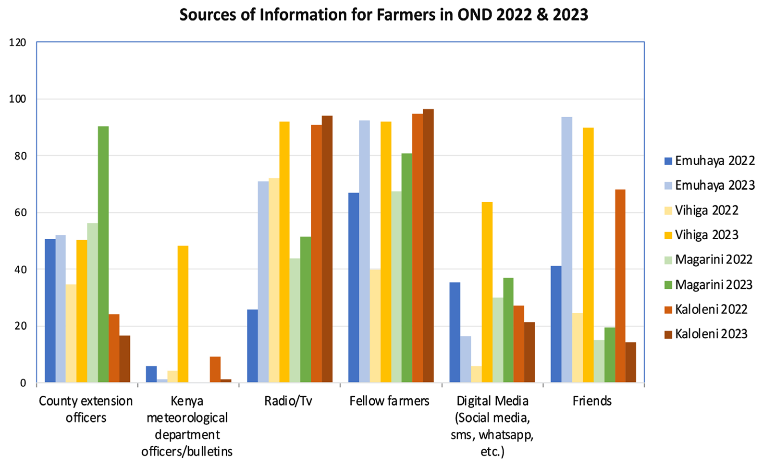

Figure 12. Farmers' source of information—OND 2022 and OND 2023.

iii. Format used to share the information

In the OND 2023 season, the most popular format for sharing information with farmers was direct, verbal communication, used by over 90% of farmers in all four sub-counties (Figure 13). Printed materials and soft copy materials, like brochures and bulletins, were used by fewer farmers (10% or less), with Vihiga having the highest usage at 35%. Radio/TV was widely used across all sub-counties, and digital media ranked third in usage.

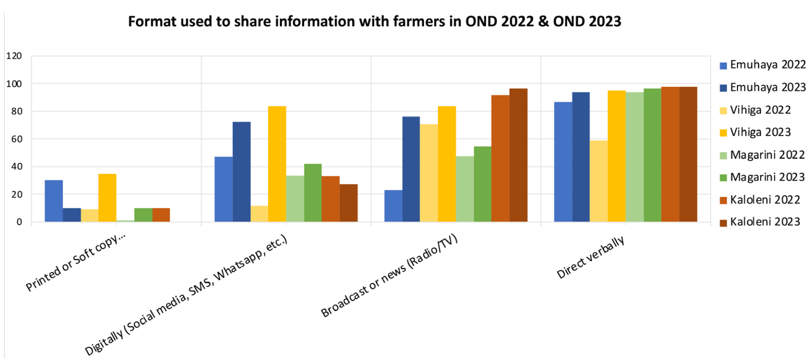

Figure 13. Format of sharing information in OND 2022 & OND 2023.

iv. Challenges using information provided

The 2023 survey showed that a high proportion of farmers across all four sub-counties reported no challenges in using the provided information (Figure 14). Few farmers mentioned language as a barrier, suggesting that efforts to share information effectively, such as verbal and direct communication, along with trusted sources like fellow farmers, friends, and Radio/TV, were successful.

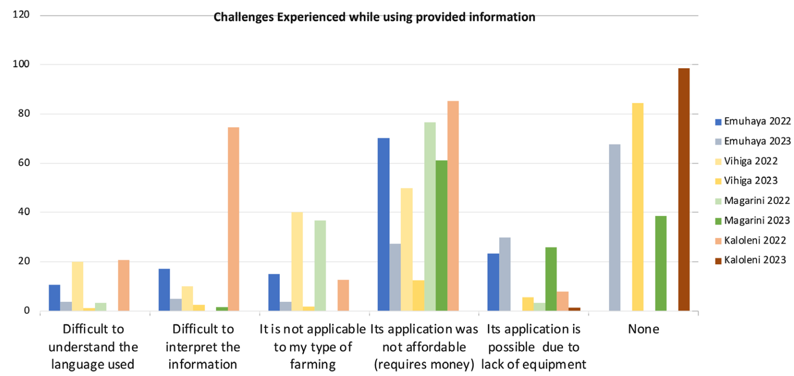

Figure 14. Challenges experienced by farmers while using provided information.

c) Crops grown in the two study seasons and the outcomes of the harvests

Maize was grown by over 95% of farmers in all four sub-counties. In Vihiga, beans (94%) and bananas (31%) were also commonly grown. In Kaloleni, cowpeas were grown by all farmers, and cassava by 83%. Most farmers in all sub-counties grow crops for subsistence, with Vihiga at 82%, Emuhaya at 66%, Kaloleni at 94%, and Magarini at 66%.

From 2022 to 2023, Vihiga saw a significant increase in the proportion of farmers reporting a good harvest (Figure 15). In Emuhaya, there was a decrease in those reporting a poor harvest and an increase in those reporting good and average harvests. In Kaloleni, the proportion of farmers reporting a good harvest decreased, while those reporting average and poor harvests increased. In Magarini, the number of farmers reporting a good harvest increased, while those reporting average and poor harvests decreased.

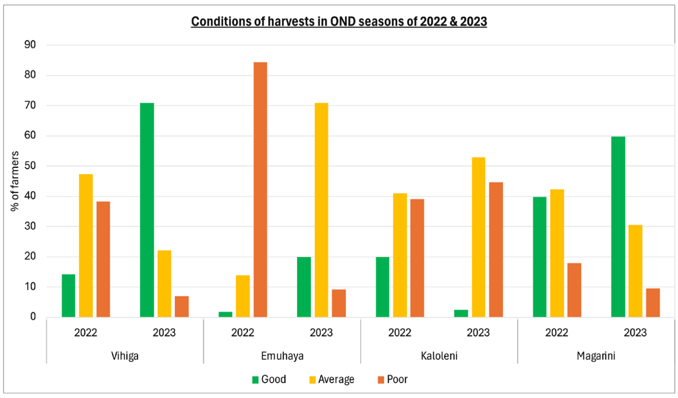

Figure 15. Outcome of OND 2022 and OND 2023 harvests.

Farmers in all four sub-counties primarily assessed their harvests based on the quantity and quality of the crops (Table 5). However, in Emuhaya, there were significant post-harvest losses in 2022, with 84% of farmers reporting a poor harvest for that season.

Table 5. Characteristics of outcome of OND 2022 and OND 2023 harvests.

Cases of Good Harvest								
	Percentage of cases							
Sub-County	**Vihiga**		**Emuhaya**		**Kaloleni**		**Magarini**	
Attribute of good harvest	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
Increased yields (quantity)	81.8	97.8	100	22.9	81.4	88.9	92.6	99.2
Better quality crop	63.6	55.0	66.8	95.8	39.5	55.6	81.5	54.7
Reduced losses (due to disease, pests or post-harvest losses)	45.6	20.8	0	99.2	23.3	22.2	14.3	30.5
Increased income	18.2	16.6	0	12.7	48.8	0	12.2	14.0
Cases of Average Harvest								
	Percentage of cases							
Sub-County	**Vihiga**		**Emuhaya**		**Kaloleni**		**Magarini**	
Attribute of average harvest	2022	2023	2022	2023	2022	2023	2022	2023
No significant change in yields (quantity)	68.5	92.1	95.5	3.4	82.2	99.5	88.6	82.3
No significant change in quality of yields.	41.1	61.1	18.2	98.8	40	0	58.7	81.5
No significant change in losses (due to disease, pests or post-harvest losses)	17.8	21.4	22.7	97.1	4.4	2.1	10.0	31.5
No significant change in income	24.7	7.1	0	5.8	6.7	0	8.0	0.8
Cases of Poor harvest								
	Percentage of cases							
Sub-County	**Vihiga**		**Emuhaya**		**Kaloleni**		**Magarini**	
Attribute of Poor harvest	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
Decreased yields (quantity)	34.0	97.5	81.3	24.1	90.7	100	100	74.4
Poor quality crop	62.7	70	89.6	88.9	30.2	3.8	37.7	53.9
Increased losses (due to disease, pests or post-harvest losses)	27.1	10	24.6	85.2	7.0	6.9	9.4	51.3
Decreased income	50.9	2.5	0	27.8	0	0	9.4	10.3

In Vihiga sub-County, the increase in good harvests was largely attributed to favorable weather, the advice and information provided, and the cultivation of suitable crops—information that was actively shared with farmers. While all sub-counties experienced enhanced rainfall, some poor harvests were linked to flooding, which damaged leguminous crops like cowpeas and green grams. The factors farmers attributed to their harvests are shown in Table 6.

Table 6. Farmers' opinions on the drivers of the outcome of OND 2022 and OND 2023 harvests.

	Percentage of cases							
Sub-County	**Vihiga**		**Emuhaya**		**Kaloleni**		**Magarini**	
Drivers of Good Harvest	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
Favourable weather	81.8	83.8	0	98.3	44.2	100	73.2	98.8
Advise and information on farm management	50	54.3	100	57.6	67.4	11.1	26.7	28.3

Continued

Growing suitable crops	72.73	47.4	66.7	97.5	51.2	44.4	86.6	47.5
Lower cost of inputs	4.6	24.6	0	31.4	7.0	0	21.4	7.0
Good market prices	13.6	18.1	0	23.7	51.2	0	20.9	9.4
	Percentage of cases							
Sub-County	**Vihiga**		**Emuhaya**		**Kaloleni**		**Magarini**	
Drivers of Average Harvest	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
No changes in weather	65.3	27.4	81.8	1.7	37.8	100	21.1	5.4
No change in advice and information on farm management	34.7	33.1	0	85.8	48.9	0	23.1	23.2
Growing same crops	55.6	88.7	18.2	98.3	44.4	0	76.4	100
No change in cost of inputs	29.2	31.5	4.6	58.7	11.1	1.1	36.7	18.6
No significant change in market prices	2.8	10.5	0	21.2	6.7	0	12.6	0
	Percentage of cases							
Sub-County	**Vihiga**		**Emuhaya**		**Kaloleni**		**Magarini**	
Drivers of Poor Harvest	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
Unfavourable weather	94.9	51.4	99.3	90.7	93.0	98.1	50.6	68.6
Lack of advice and information on farm management	61.0	32.4	80.6	55.6	27.9	5.0	29.1	42.9
Growing unsuitable crops	50.9	59.5	6.7	87.0	4.7	0	43.0	48.6
Higher cost of inputs	79.7	46.0	35.1	24.1	4.7	7.6	53.2	31.4
Poor market prices	3.4	5.4	1.5	1.9	0	0	53.2	0

In 2023, Vihiga and Emuhaya had a high proportion of farmers who harvested their crops (over 90%) for each of the three commonly grown crops. However, Kaloleni and Magarini had lower proportions of successful harvests. For maize, which was grown in all sub-counties, Vihiga had 67% of farmers reporting a good harvest, while 24% had an average harvest. In Emuhaya, 19% had a good harvest, with 73% having an average harvest. Kaloleni, impacted by extreme rainfall, had only 4% with a good harvest, 50% with an average harvest, and 46% with a poor harvest. Magarini had 54% with a good harvest and 32% with an average harvest. Similar trends were observed for other crops in the sub-counties, as shown in Table 7 and Table 8.

Table 7. Outcome of OND 2023 harvest for common crops in Vihiga and Emuhaya sub-counties.

Crop/outcome of harvest	Vihiga			Emuhaya			
	Good	Average	Poor	Crop/outcome of harvest	Good	Average	Poor
Maize	67.4	24.3	8.3	Maize	18.9	73.8	7.3
Beans	71.8	21.0	7.2	Beans	25.3	66.1	8.6
Bananas[1]	76.7	18.3	5.0	Vegetables	16.5	69.2	14.3

[1]The growing season for bananas is not the same as that of the other crops and may therefore not have been affected by the short duration of the experiment.

Table 8. Outcome of OND 2023 harvest for common crops in Kaloleni and Magarini sub-counties.

Crop/outcome of harvest	Kaloleni			Magarini			
	Good	Average	Poor	Crop/outcome of harvest	Good	Average	Poor
Maize	4.1	49.6	46.3	Maize	53.9	32.0	14.1
Cowpeas	1.7	54.6	43.7	Green grams	64.8	29.6	5.6
Cassava	1.0	55.2	43.8	Cowpeas	44.6	44.6	10.8

Analysis of farmers who received advisory information during the OND 2023 season and reported a good harvest showed that those who received advisories generally had better harvests. The results, as shown in Figure 16, indicated higher proportions of farmers with good harvests in Vihiga and Kaloleni compared to Emuhaya and Magarini.

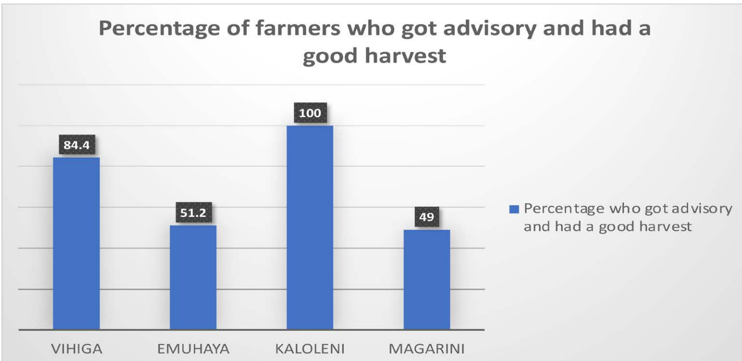

Figure 16. Farmers who got information in OND 2023 and also got a good harvest.

3.4. Experimental Period Monitoring and Outcomes

a) Weather conditions

The seasonal forecasts for both Kilifi and Vihiga for the short rains season showed enhanced and well-distributed rainfall across the four sub-counties. In Vihiga, the forecast predicted above-normal rainfall, exceeding the 30-year average by over 20 mm in most areas. Similarly, Kilifi was expected to experience above-normal rainfall. Kaloleni sub-County, within a high rainfall area, was forecasted to receive the highest amount of rainfall in Kilifi County during the season. Monthly and weekly forecasts from KMD were also shared.

Weekly weather advisories for Vihiga and Kilifi sub-counties, produced by KMD, were shared with the SCAOs, who then communicated the information to farmers, emphasizing its impact on farming activities. In Vihiga, for example, advisories included guidance on farm management practices based on the expected rainfall, such as measures to prevent soil erosion and clear drainage channels to prevent flooding in cropped areas.

b) Crop Conditions and Yield estimates from Remote Sensing Data

Crop condition maps produced by MoALD and GEOGLAM Crop Monitors were used to monitor crop performance over the duration of the season. Satellite data and other ancillary data used to produce the maps include: Crop calendars for the short and long rain seasons, cropland maps, crop specific masks, NDVI, NDVI anomaly, precipitation and precipitation anomalies, temperature, soil moisture and evapotranspiration. These were supplemented with farm observation data from within the crop growing areas collected by the SCAOs and WAOs. These maps are also used at Global level to produce the GEOGLAM Crop Monitors which provide open, timely, and science-driven information on crop conditions in support of market transparency and early warning of production shortfalls [18] [19]. Crop condition maps for some of the months of the study season, were retrieved and they indicated Watch[2] and Favourable conditions for maize throughout the season in the two study sub-Counties (see e.g., Figure 17 and Figure 18). The indicators showed positive outcomes at the end of the season towards the harvest with 75% favourable conditions for maize in the country.

The areas marked in yellow and labelled Watch include those that were affected by floods where 36 counties affected by floods which destroyed over 17,600 areas of farmland in the country [20].

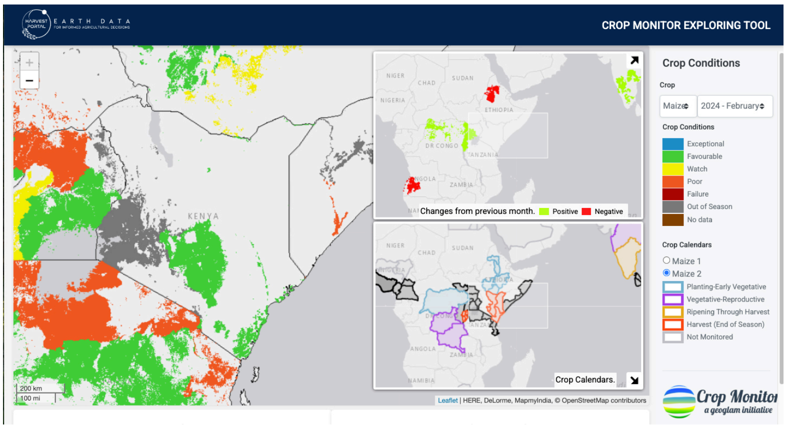

Figure 17. Crop conditions map for February 2024, crop calendar shows harvesting in Eastern and Coastal Kenya (Source: https://cropmonitortools.org).

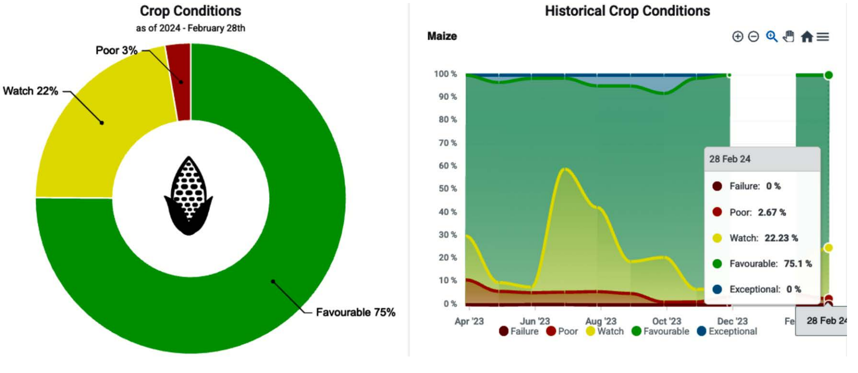

Figure 18. Crop conditions summary in February 2024. Right image shows historical conditions (Source: https://cropmonitortools.org).

[2]Watch—harvest could turn out to be favourable or poor.

Enhanced Vegetation Index (EVI) and NDVI trends were calculated using Landsat8 and Landsat9 images for the four sub-counties, with Google Earth Engine (GEE) used to extract data for analysis between January 2022 and December 2023. NDVI and EVI were calculated using specific bands from the satellite images. The formulae used for NDVI and EVI are shown in Equations (1) and (2) respectively with the monthly average NDVI and monthly average EVI trends shown in Figure 19 and Figure 20 respectively, the results revealed a marked increase in both indices during the OND 2023 season compared to OND 2022, indicating improved vegetation health.

$$\boldsymbol{NDVI} = \frac{\boldsymbol{NIR} - \boldsymbol{RED}}{\boldsymbol{NIR} + \boldsymbol{RED}}$$

Equation (1): NDVI formula (Source: USGS—https://www.usgs.gov/)

Where

NIR = Near InfraRed band (SR_B5) value

Red = Red band (SR_B4) value

$$\boldsymbol{EVI} = 2.5 * \frac{(\boldsymbol{NIR} - \boldsymbol{RED})}{(\boldsymbol{NIR} + 6) * (\boldsymbol{RED} - 7.5) * (\boldsymbol{Blue} + 1)}$$

Equation (2): EVI formula (Source: USGS—https://www.usgs.gov/)

Where

NIR = Near InfraRed band (SR_B5) value

Red = red band (SR_B4) value

Blue = blue band (SR_B2) value

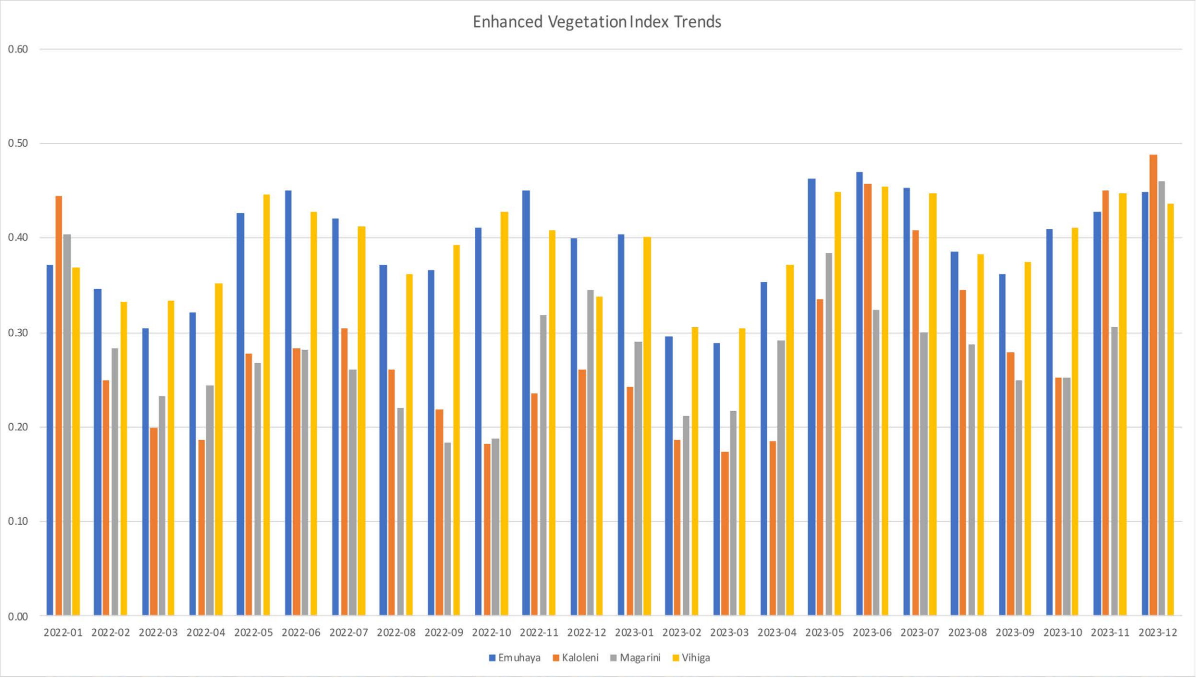

Figure 19. EVI trends for the study sub-counties for the duration of the study.

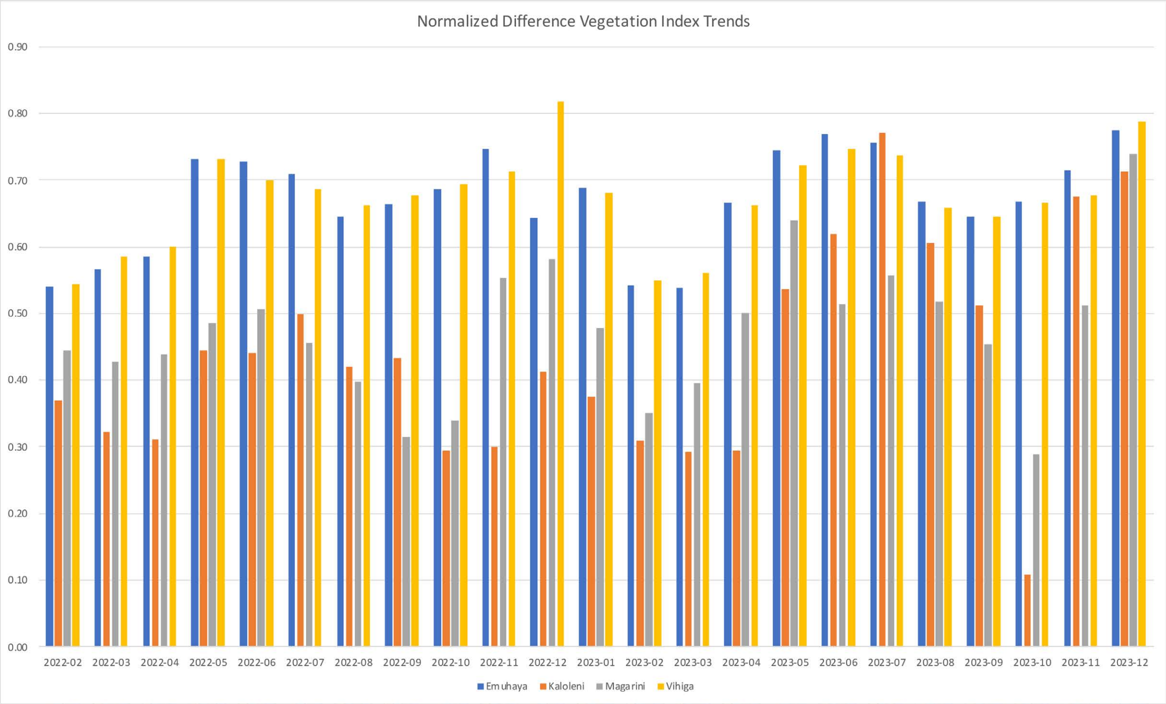

Figure 20. NDVI trends for the study sub-counties for the duration of the study.

c) Yield Data from MoALD

The Ministry of Agriculture collects crop production data monthly through County agricultural officers, which is forwarded to the National Government's Statistics Unit to produce crop monitoring reports. At the end of the season, the production data is also used to estimate the yield for the season for various crops. In some of the Counties, such as those that produce staple crops in large scale, ground validation of the yield is conducted through physical crop cuts and weighing.

Table 9 shows that in the OND seasons of 2022 and 2023, maize yields significantly increased in both Kilifi and Vihiga Counties. Kilifi saw a more than 100% increase in cowpea yields, while Vihiga experienced a notable decrease in bean yields. The reduced bean yield in Vihiga was attributed to heavy rainfall, which caused flooding and prolonged high soil moisture, damaging the crop.

Table 9. Crop yields for 2022 and 2023 (Source: MoALD).

Crop	Yield in Tons/Ha (2022)	Yield in Tons/Ha (2023)
	Kilifi	
Cowpeas	0.2	0.6
Maize	0.7	0.9
	Vihiga	
Beans	0.5	0.3
Maize	1.0	1.2

4. Discussion

In Vihiga, the use of all six evaluated information sources increased, driven by frequent interactions with the SCAO and champion farmers, which improved information dissemination. In contrast, Kaloleni faced challenges in maintaining close interactions with the SCAO, limiting information sharing and farmers' understanding. In Kaloleni, fewer farmers received advisories for the 2023 OND season due to challenges in extension services. The SCAO noted that ward officers lacked adequate resources, making it difficult to cover the large area and reach farmers effectively.

Radio and TV were popular among farmers but too costly for this study. While stations offered complimentary advisories, they were insufficient to keep farmers informed throughout the season. Success stories like *Shamba Shape Up* TV series [21] highlight the potential of TV, suggesting the need for cost-effective ways to integrate it into future interventions.

Another concern was that crop suitability maps on the KALRO platform contained discrepancies compared to seasonal advisories, with some popular crop varieties missing altogether. This issue affected both Vihiga and Kaloleni, and its source could not be identified. Further engagement between agricultural officers, KALRO, and other stakeholders is needed to resolve it. In the meantime, SCAOs relied on information agreed upon with KMD officers for agro-meteorological advisories.

During the experiment, interventions like the National Agricultural Rural Inclusivity Program (NARIP) that promoted commercial farming and input use were ongoing. However, their impact on the study's results was considered minimal since they did not focus on information sharing during the season.

The harvest results indicated the experiment's success, with many farmers attributing good yields to enhanced advisories. Productivity data was based on farmers' reports, and while validation was not feasible, comparisons with MoALD data and remote sensing analysis confirmed increased production.

Despite extensive planning, the study faced challenges. Close interaction with SCAOs was essential, sometimes requiring impromptu training on geospatial data. However, cost constraints limited the use of effective sharing methods like local radio stations. Instead, the study relied on extension officers, farmer groups, champion farmers, and, where possible, social media, which may have reduced its reach. The availability of SCAOs also impacted outcomes, Vihiga's SCAO was highly engaged, while Kaloleni's busy schedule made coordination more difficult.

5. Conclusion

The study highlights the complexities of effectively sharing geospatial data with farmers. Despite efforts to make the information accessible and understandable, coordinated collaboration among stakeholders is essential for its effective use. Unplanned disruptions can affect activities, making coordination crucial to prevent duplication and conflicting information. Resource limitations also posed challenges, emphasizing the need for innovative, cost-effective, and sustainable service delivery.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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