INITIATIVE ON
Diversification in East and Southern Africa

Technical report

Characterization of maize-based mixed crop-livestock system: key components, their interaction and profiling of priority interventions in the Central Rift Valley of Ethiopia

Gerba Leta

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1. Executive summary

Characterization of the mixed crop-livestock system was done in the Central Rift Valley (CRV) and Hawassa Lake Basins by focusing on selected six districts (woredas) in these basins. The aim was to identify maize-based mixed farming systems, key components, and their interactions, and to identify core innovations with the potential for system transformation. The mixed crop-livestock system is a farming method in which farmers simultaneously grow crops and raise livestock. Key informant interviews, expert group discussions, and community-focused group discussions were carried out in study woredas and kebeles1. These were further complemented by secondary data, consultation with zonal and regional experts, field observation, analysis of the biophysical features, farming system, climate-smart agricultural practices, and application of remote sensing data for geospatial analysis. The CRV and Hawassa Lake Basins are characterized by highly variable climatic conditions which challenge farming under rainfed conditions. Rapidly growing population and increasing need for necessities of life trigger the conversion of forest and vegetation into farmland. The cultivated land increased by 58,349.68 hectares from 2002 to 2023 at the expense of grassland, shrubs, and bushlands. In addition, the application of improper agricultural practices aggravates land degradation and reduces biomass production and the sustainability of system functioning. Also, the nexus of anthropogenic and natural factors induces widespread poverty and food insecurity. This series of events reduces farmers' adaptation to change. Currently, the conventional cropping season and cropping patterns are inconsistent because of recurrent drought. In general, the mixed crop-livestock system is highly threatened by climate change, pest and disease outbreaks, water erosion, and land degradation. Shortage of agricultural inputs and its mounting prices are other challenges to resource-poor farmers. The compounded effect of the aforementioned issues aggravated inhabitants' vulnerability to food insecurity. Against the growing odds, irrigation emerged as an alternative farming practice. However, irrigation as an alternative livelihood option is being challenged by limited access to water sources, facilities, and capital for investment on an individual and group basis. Adoption and implementation of innovative technologies and climate-smart agriculture (CSA) practices nurture farmers' resilience-building capacity against climate change. Improving farmers' access to agricultural inputs, and creating awareness of the emerging change and challenges and means of adaptation are vital. Promoting natural resource management activities, introducing resilient germplasm, and improving livestock breeds and their management practices reduce the harmful consequences of the impacts of human action and climate change. Hence, assisting

[1] Woreda is the administrative equivalent of a district, whereas Kebele is the smallest administrative unit in Ethiopia.

rainfed agriculture with irrigation and implementation of CSA practices and innovative technology notably the combined application of minimum tillage practice, crop rotation, intercropping and crop diversification, production and use of vermicompost, use of solar pump for irrigation development, nurturing area exclosure and agroforestry. The integration and configuration of the technologies across the landscape ensure the sustainability of the mixed crop-livestock system that links benefits, resources, and energy at scales.

2. Introduction

Globally, agricultural systems face the challenges of producing more and better food and feed biomass under the emerging drivers of change including climate change and climate variability (Nikzaad and Nusrathali, 2023; Herrero *et al*., 2010). The mixed crop-livestock system is a holistic and creative approach to solving smallholders' problems in contemporary agriculture (Muhie, 2022). Smallholder farmers in mixed crop-livestock systems produce about half of the world's food (Herrero *et al*., 2010). This implies the contribution of mixed farming system to the livelihoods of subsistence smallholders in developing countries. Therefore, mixed crop-livestock systems could be key to future food security. In Sub-Saharan Africa, smallholders depend largely on the use of land resources in which mixed crop-livestock systems serve as the main sources of livelihood (Amejo et al., 2019). The mixed system improve soil nutrients, reduces risks and smallholder dependency on external inputs (Rahman et al., 2019; Duressa et al., 2014; Wanyama et al., 2012).

If agriculture is to meet feeding the growing human and livestock population, the necessity of adopting more efficient ways of production is commendable (Stark *et al.*, 2017). Efficiency promotes more resilience and less vulnerability of agriculture to unpredictable hazards. Therefore, subsistence smallholder agriculture should be supported by resources efficient mixed crop-livestock farming systems (Herrero *et al*., 2010). As part of the mixed farming systems, livestock is mostly kept on natural grass, browse, and nonfood biomass such as maize, beans and other crop residues. Conversely, livestock provides draft power, transport, and organic fertilizers, and supplies farmers with a source of regular income from the sale of milk, eggs and other products (Management Entity, 2021; Herrero *et al*., 2010).

In Ethiopia, population growth and competition for natural resources, fragmentation of farmlands and the use of improper agricultural practices, soil erosion and land degradation, and climate change are among several factors confronting the livelihoods of smallholders (Fritzsche *et al*. 2007; Bekele *et al*. 2019). Against the growing challenges, mixed farming systems such as maize-based crop-livestock systems enable smallholders to integrate different enterprises on the farm.

Maize-based mixed farming is the main farming system that is being practiced by smallholders in the CRV and Hawassa Lake Basins. In Ethiopia, maize is the second-highest crop in area coverage but is the first in total production and yield per unit area (Issa, 2009). The grain supplies enormous energy and protein to humans, and its residue/stover serves as feed to livestock (Lule *et al*., 2012). In the system, the integration determines flows of materials, energy, food and cash that influences how the entire production systems needs to be managed (Amejo *et al*., 2018). The management system influences resources uses efficiency and economic returns at different levels. Therefore, the system has huge potential for resource recycling in which case crop residues are fed to livestock and in return livestock manures are used as valuable sources of soil nutrients.

Regardless of the potential and actual benefits the maize crop provides, food and nutrition insecurity are the main issues smallholder farmers are facing in the CRV and Hawassa Lake Basins. In this area, food insecurity is often chronic and attributed largely to several biophysical and socio-economic problems, climate change, pest and disease outbreaks, and soil degradation (Mekuria et al. 2020; Cochrane, 2018; Sida, 2011). Rainfed agriculture is the main system vulnerable to erratic and erosive rainfall and its effect has become severe with climate change. The problems are common in the six study woredas with similar farming system.

Therefore, to address the emerging drivers of changes and food insecurity issues with a growing population and declining productivity, adopting and intensifying more resource efficient and resilient mixed farming systems that are friendly to the environment is of paramount importance. This study is initiated to, i) characterize distinct maize-based mixed farming systems; ii) identify the key components and major interactions between the components, and iii) identify and profiling of core innovations with the potential for system transformation in the dynamic and interacting crop-livestock system.

3. Conceptual framework

In smallholder agriculture, a mixed system such as a maize-based crop-livestock system enables the integration of different enterprises on the farm. In this study, we adopted Herrero et al. (2010) as a conceptual framework (Figure 1) to identify distinct maize-based mixed crop-livestock systems and analyzed the key components and suggested the interventions for system transformation. Recently, Stark et al. (2017) provided "a theoretical two-compartment network model" as a conceptual framework to diagnose the agricultural system in the maize-based mixed farming system, their networks and their performance in agroecology. However, Herrero et al. (2010) provided a more pronounced and inclusive model with comprehensive interaction of the components in mixed crop-livestock systems. The interaction in the later one is more inclusive and visible that spans from farming system to landscape and then to regional and global scales. The links between the two systems (crops and livestock) in improving soil nutrients and supplying feed are more noticeable. The mixed crop-livestock system in the CRV and Hawassa Lake Basins is in line with the adopted conceptual framework.

In such systems, livestock provides draft power for farm operations and manure to fertilize the soil, and crops provide residue to feed livestock (Danso-Abbeam et al., 2021; Stark et al., 2017; Lule et al., 2012; Herrero et al. 2010). In addition, income from livestock may be able to complement or fill in the gaps induced by the unreliable and low crop yields experienced in the moisture stress area of the tropics. The trend is in line with CRV and Hawassa Lake Basins study woredas where recurrent drought often forced the reliance of smallholders on their livestock during crop failure. Also, farmers alternate the income they generate from livestock and crops for various livelihood and agricultural activities. The integration between crop production and livestock husbandry provides immense opportunities to ensure sustainable production of the system and safeguard household food and nutrition security. It also increases resource use efficiency, income security, and reduces livelihood uncertainty. For instance, feeding maize stover to livestock in the study areas reduces the trade-off of allocating land for fodder production. In addition, the application of livestock manure also reduces the investment in chemical fertilizers, etc. Such integration at scales promotes healthier system functioning from the farming system to the global level (Figure 1).

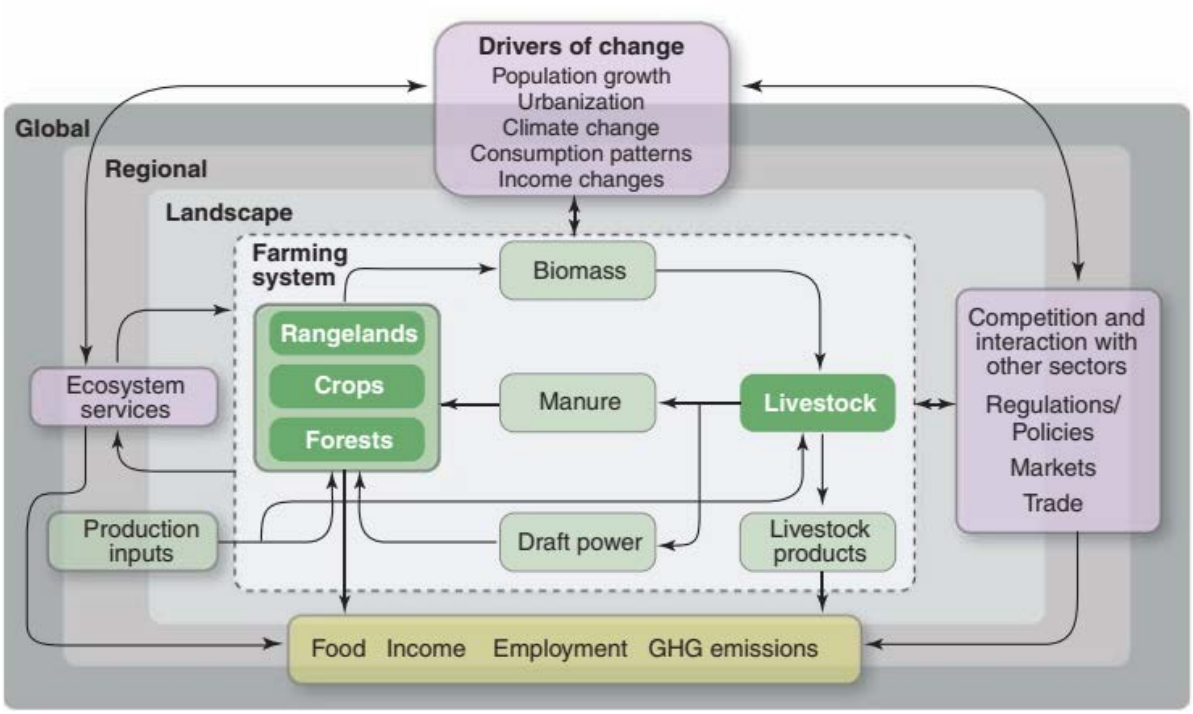

Figure 1 Conceptual framework depicting main interactions in mixed crop-livestock systems. ***Source: adapted from Herrero et al., 2010.***

The application of the framework effectively guided the realization of the study objectives and questions. It enabled the analysis of the crop and livestock interaction and competition for land as a consequence of which the number of livestock was highly reduced because of the progressively diminishing forest and grazing lands in favor of the farmland. Against the growing changes and challenges, the crop-livestock system remains the livelihood option for the smallholders in the study woredas and kebeles. Particularly, the best combination in the interaction allows the smallholders to meet food security, diversity of food, and generate sources of income without compromising the natural resource bases. This further improves the resilience capacity to climate change. However, the sectorial view to production such as focusing either on crops or livestock alone disguises seeing the bigger picture of increasing production and productivity and improving resource use efficiency. Therefore, adopting consistent and inclusive mixed crop-livestock system that comprises innovations or best agricultural practices is indispensable for the component elements to play complementarity roles at scales.

4.Material and methods

4.1 Overall approach, selection and description of study areas

This study was conducted in the Central Rift Valley and Hawassa Lake basins. The study primely focused on two scales: 1) basin scales where the major nature of the system elaborated, and challenges surfaced. This led to the identification of scale 2; 2) selected six study woredas. Accordingly, a literature review analyzing the system, observation of the landscape, and overall features were conducted at basin scales. The selected six study woredas were from the CRV and Hawassa Lake Basins of Ethiopia. The selection was made based on the maize-based mixed crop-livestock systems where maize is the dominant staple food crop, and hot pepper is the main cash crop. In addition, climate variability, potential, and actual suitability for irrigation development as well as the existing safety and security situations experienced in the woredas dictate the selection. Furthermore, consultation with regional actors and the suitability of woredas for the characterization of the mixed crop-livestock system in line with the criteria set by the project were taken into account. The study woredas were suitable for effective data collection and observation of the farming system.

The CRV and Hawassa Lake Basins study woredas are specifically located between 6°55'43.68" to 8°10'38.79" N latitude and 38°5'13.62" to 38°55'19.82" E longitude (Figure 2). The study woredas are situated in three regional states (Table 1). The characterization study further zooms into three kebeles (Jara Hinessa, Lebu Koromo, and Mekibasa Korke) of Hawassa Zuria. The kebeles were selected based on their experience in irrigation development, landscape management, and livestock production systems.

Table 1: Study woredas by farming system and climate pattern

Study Woreda	Regional State	Farming System	Climate zone
Misrak Miskan	Central Ethiopia	Maize based mixed crop-livestock system	Subhumid to humid midland
Sankura	»	»	Dry midland
Wera Dijo	»	»	Dry to subhumid
Adami Tulu Jido Kombolcha	Oromia	»	Dry lowland (semi-arid)
Shala	»	»	Dry lowland (semi-arid)
Hawassa Zuria	Sidama	»	Subhumid to humid midland

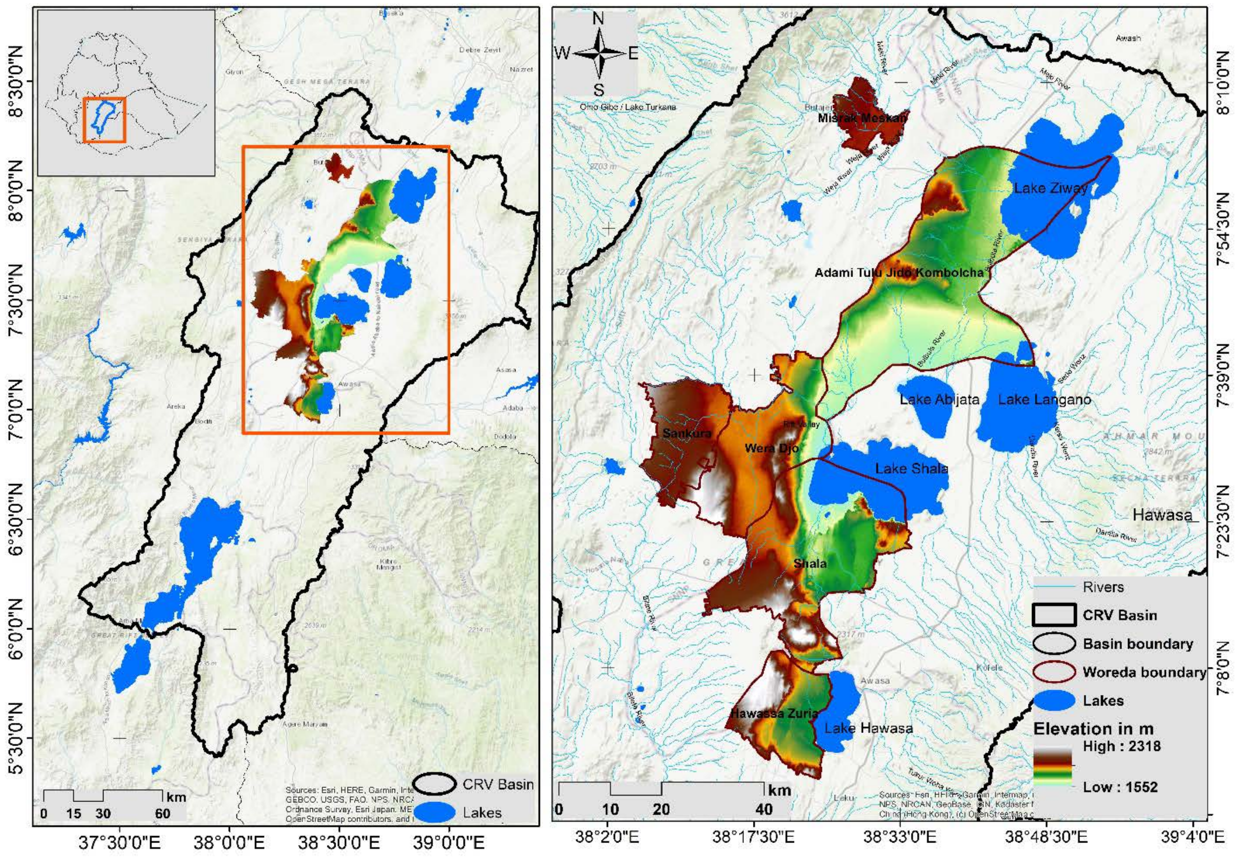

Figure 2 Location map of the study area

The CRV study areas comprises catchments of the four lakes: Ziway (Hara Danbal), Langano, Abjata, and Shala in the eastern and western escarpments of the Arsi and Gurage highlands. The Hawassa Lake Basins is the extension of the CRV separated by the chain of escarpment in the interface between Oromia and Sidama regions. The CRV and Hawassa Lake Basins are renowned for their unique ecology, and natural resources endowment featured by scenic beauty. The study area is characterized by relatively homogenous mixed crop-livestock system with similar crops and livestock. In addition, the study areas is often challenged by climate variability and characterized by the lowest rainfall and the highest mean annual temperature. Land degradation is also rampant showing the fragility of the area. Maize-based mixed farming is a widespread approach that often practices monocropping. In addition, intercropping haricot beans with maize mostly implemented as relay intercropping largely in Hawassa Zuria and slightly in other study woredas. Apart from the main food and cash crops, the study woredas have potential for other cereal and root crops.

4.2 Steps pursued in data collection

Collecting informative and relevant data on mixed crop-livestock systems started with desk literature reviews and consultation of the regional actors. This was followed by focused districts selection, representing the different agroecology of the CRV and Hawassa basins, and the actual interviews and discussions with development agents, woreda experts, model farmers, and members of the community segregated by age, gender, and wealth status. The community-level focus group discussion (FGD) and interviews with development agents were carried out in three case study kebeles of Hawassa Zuria woreda notably Jara Hinessa, Lebu Koromo, and Mekibasa Korke to assess the mixed crop-livestock system from the grassroots (Figure 3). For collecting data from experts, we followed two-step data collection approaches: key informant interviews (KIIs) and expert group discussions. The expert group discussion is synonymous with focus group discussion. The discussion involved experts from the crop, livestock, natural resource management, irrigation, gender, and agricultural extension. The group discussion assists in generating macro-level data related to the mixed crop-livestock system, business opportunities for youths, and women, and sources of finances to run the business, and identify the existing challenges to the system. The expert group is believed to elicit open discussion that allows generation of information that may escape the attention of individuals. It also allows cross-fertilizing ideas and reaching a common understanding that corroborates individuals' views or assumptions. In the KIIs, three experts from crop, livestock, and natural resources were interviewed using a semi-structured interview checklist. The experts were assigned in consultation with the woreda head of agriculture. Furthermore, FGD with model farmers and members of the community, observation, and assessment of the landscape including the biophysical feature, irrigation developments, indigenous or introduced climate smart agriculture practices, and farming systems were conducted. These were further complemented by secondary data collection and validation with relevant experts.

Figure 3 Community Focus Group Discussion Mekbasa Qorke (left) and Jara Hinessa (right) *kebeles*.

The expert group discussion allowed the triangulation of information generated from KIIs. Accordingly, characterization of specific farming systems, components of the system, and their interactions were made from the collective expert opinion and basic data. The two rounds exercise at the woreda level enabled to generate the required information for the study. This was further complemented by KIIs at the zone and regional levels. The secondary data collected on types of crops and livestock gives additional insight into the specific production system adopted and implemented in the area. The process and acquired data assisted in identifying the farm typologies and the component interactions in the farming system. Furthermore, the spatial coordinate reading of points was collected to validate the Landsat data acquired for the analysis of different attributes.

4.3 Spatial data acquisition and pre-processing

4.3.1. Sources of data

To compute changes in land use and land cover, freely available Landsat imageries, which represent continuous records of the earth's surface with better spatial resolution during the last two decades, were used. Landsat Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) for 2002, 2013 and 2023 were used, respectively. The spatial resolution for the Enhanced Thematic Mapper Plus was 30 km by 30 km, whereas the Sentinel images' resolution was 10 m by 10 m. It was downloaded freely from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/), and the detailed spatial characteristics of the satellite images used were summarized in the table (cf Appendix Table 1).

4.3.2 Image processing and classification

Accurate image registration of remote sensing data is necessary to combine different sources during classification. The geometric rectification, radiometric calibration, and atmospheric correction are considered as major components of image preprocessing (Storey et al., 2014).

The spatial and temporal resolution of satellite imagery was adjusted to ensure better Land Use Land Cover (LULC) classification and analysis. A map was prepared before verifying the area by direct observation. The Ground truth information was collected by GPS with the appropriate number of Ground Control Points (GCP) for the study area, and then re-projected to UTM Zone 37N using control points (Appendix Table 3). Recent (2023) satellite data was used during the field data collection and affirmed with existing LULC categories. To take advantage of each, both supervised and un-supervised image classification algorithms were operated and analyzed using geospatial software (mainly ERDAS Imagine 2015 for image processing and ArcGIS 10.7 for mapping and Analysis). Finally, a classification scheme was developed to derive various LULC classes of the study area.

Given that ground data for 2023 were exclusively available, the authors inferred that the accuracy validation for the 2023 classification maps sufficed to meet the required precision levels for that year. Utilizing satellite imagery from the Operational Land Imager and Thermal Infrared Sensor (L8 OLI/TIRS) of 2023, the authors cross-tabulated the imagery with ground data to accurately assess, employing error matrices (confusion matrices). The findings revealed an overall classification accuracy of 87.7%, with an overall kappa coefficient of 0.882 (refer to Annex Table 2). Furthermore, user and producer assessments of each Land Use and Land Cover (LULC) class provided a robust foundation for subsequent analyses of LULC changes. Kappa coefficient results for each LULC class indicated a significant concurrence between classified LULC changes and ground survey data

4.4 Data entry, management, and analysis

LULC change

The classified images were further analyzed using the rate of change, loss and gain across land use categories found in the study area. The percentage change of the area was calculated by the following equation:

$$P = \left(\frac{A_{T2} - A_{T1}}{A_{T1}}\right) \times 100$$

The Gain (Gij) was calculated through the difference between the total value for time 2 (C+j) and the persistence (Cij), using the following equation:

$$G_{ij} = C_{+j} - C_{jj}$$

On the other hand, the Loss (Lij) was the difference between the total values for the time 1 file (Pj+) and the persistence, using the following Equation:

$$L_{ij} = C_{j+} - C_{jj}$$

NDVI

NDVI is a commonly used index to measure the amount of green vegetation in a given area. This helps us determine the density of vegetation and detect any changes in plant health. When interpreting NDVI values, it is important to note that Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1). It is a good proxy for live green vegetation. In sentinel imagery, the density of vegetation (NDVI) at a certain point of the image is equal to the difference in the intensities of reflected light in the red and infrared range divided by the sum of these intensities (Tempa et al., 2024; Tsakmakis et al., 2021). The normalized difference vegetation index in sentinel imagery, NDVI calculated as:

$$NDVI = (NIR - RED|NIR + RED)$$

$$NDVI = (B08 - B04|B08 + B04)$$

Where, NDVI, light reflected in the near infrared (NIR) spectrum and light reflected in the red range (RED) of the spectrum.

NDMI

The Normalized Difference Moisture Index (NDMI) is an index that uses the Near Infrared (NIR) and Short-Wave Infrared (SWIR) bands to measure the moisture content of vegetation (Gao, 1996). The SWIR band is sensitive to variations in both the water content of vegetation and the spongy mesophyll structure in vegetation canopies. On the other hand, the NIR reflectance is influenced by the internal structure of leaves and their dry matter content, but remains unaffected by water content (Ghasemloo et al., 2022). By combining the NIR with the SWIR, the NDMI removes variations induced by leaf internal structure and dry matter content, thus improving accuracy in retrieving the vegetation water content. The NDMI in sentinel imagery is calculated as:

$$NDMI = (NIR - SWIR|NIR + SWIR)$$

$$NDMI = (B08 - B11|B08 + B11)$$

Where, NDMI, light reflected in the NIR spectrum and the SWIR band.

The collected quantitative data from KIIs were also entered, managed, and analyzed using SPSS software and generated quantified outputs describing the system. The output comprises descriptive statistics such as central tendency (frequency, mean and percentage) to assess and communicate the generated information with the project people, stakeholders, and other intended audiences. The qualitative data were transcribed and analyzed by the application of the contextual analysis method to the data sources as per the qualitative analysis methods (Bernard, 2006; Ritchie, 2003).

5. Results and discussions

5.1 Farming system, crop types and cropping calendar

5.1.1. Main crop types and the farming system in the CRV and Hawassa basins

In the CRV and Hawassa bains study woredas, the farming system is characterized by a mixed crop-livestock system in which case maize is the dominant staple food crop followed by wheat, haricot beans, and tef (Table 2). Dixon et al. (2009) gave a working definition of the farming system as a particular type of mixed natural-human system involved in managed crop and livestock production. Therefore, classifying and mapping farming systems is essential to the agricultural development needs in CRV and Hawassa Lake Basins. The classification may depend on the landscape, crop type and cropping practices, socio-economic, and biophysical factors to facilitate development intervention (Sinha et al., 2022). The exercise enables the selection of the types of interventions that suit the farming system with their potential to improve livelihoods.

At the landscape scale, a mixed maize-livestock system is apparent, though, variability in cropping practice is noticeable along the upstream, midstream, and valley bottom of the CRV and Hawassa Lake Basins. The variability is mainly attributed to rainfall and its distribution patterns. For instance, in Shamana area of Hawassa Zuria, Belg rain is received too early in January/February, unlike the vast majority of the study woredas. Furthermore, the northern part of the CRV such as in Adami-Tulu Jido Kombalcha receives summer maximum monomodal rainfall, whereas the other study woredas receive bimodal rainfall which is erratic by its nature across the woredas. Besides, five of the six study woredas (except Shala) have access to irrigation from different sources: rivers, shallow-dug wells, and freshwater lakes.

Table 2: Main crops area coverage in ha by *woredas*, and households (hh), on average

* Irish potato and sweet potato respectively covers **610** and **275** ha in Hawassa Zuria.

The crops grown in the study woredas vary by season. Accordingly, Belg (short rain) crops are

Crops	**Misrak Miskan**		**Sankura**		**Wera Dijo**		**Shala**		**Adami T.J.K.**		**Hawassa Zuria***	
	Total area	Per HH	Total area	Per HH	Total area	Per HH	Total area	Per HH	Total area	Per HH	Total area	Per HH
Maize	3, 470	0.20	5,284.50	0.37	7,247	0.38	21,040	0.52	30,356	1.31	10,267	0.37
Wheat	1,227	0.07	4,700.50	0.33	4,813	0.25	3, 420	0.08	6,126	0.26	---	---
Haricot beans	400	0.02	1,359.60	0.09	935	0.05	16,000	0.40	7,154.50	0.31	3,158	0.11
Hot pepper	650	0.04	2,075.50	0.14	3,150	0.16	593	0.015	765	0.03	901	0.03
Tef	340	0.02	1,304.50	0.09	935	0.05	4,200	0.10	1,040	0.045	53	0.002

Maize, Sorghum, Millet, Irish potato, haricot beans, and fodder crops of the grass family. Whereas *Meher* (long rain) crops are Hot pepper, Irish potato, sweet potato, tef, wheat, barley, field peas, and faba beans. Crops such as Irish potato and haricot beans can be produced twice a year. The area coverage of some of the crops such as sorghum, millet, barley, field peas, and faba beans is relatively negligible as compared to the main crops: maize, wheat, haricot beans, hot pepper, and tef. The types and productivity of crops also vary from woreda to woreda depending on the slight variability in agroecology (that varies from dry lowland to dry and humid midland), soil types, and severity of the biophysical issues and climate change. The yield estimation assessed by the best and least farmers during good and bad seasons for the staple food crop maize and cash crop hot pepper in the study woredas is presented in Table 3 below to show the effects of climate change. In this particular context, the so-called bad season is attributing to climate change that associated with various adversaries. When comparing the staple crop and cash crop yield variation by the best and least farmers in good and bad seasons, there are significant differences. The yield difference for the better-off (best) maize farmer is 2.33 tons equivalent to 41%, whereas, for the resource-poor (least) maize farmers, the yield difference is 1.42 tons equivalent to 51.2%. Similarly, for hot pepper one of the best cash crops in the CRV and Hawassa Lake Basins study woredas, the yield variation by the best and least farmers in good and bad seasons is respectively 57.5% and 60.2%. The yield difference by season is much more severe for resource-poor farmers as compared to the better-off farmers.

In general, categorizing the farm typologies noticed as an essential step in capturing the diversity associated with the farms. It confers the opportunity for introduction, adoption, and scaling out of the technologies by smallholders (Amadu et al., 2020; Bisht et al., 2020). In a similar vein, Sarker et al. (2021), demonstrated identification and characterization of the farming system facilitate technology introduction and dissemination through targeted extension intervention and informed advisory and policy supports. This is in line with agricultural farming cluster formation among smallholders residing in a village with similar land features, crop types, and interest in the current Ethiopia (ATA, 2014).

Table 3: Estimated main food and cash crop (maize and hot pepper) yield by the best* and the least during good and bad seasons (ton/ha)

Woreda	**Maize**								**Hot pepper**							
	Better-off* farmer		**Yield difference**		**Resource poor farmer**		**Yield difference**		**Better-off farmer**		**Yield difference**		**Resource poor farmer**		**Yield difference**	
	Good	Bad	Ton	Percent	Good	Bad	Ton	Percent	Good	Bad	Ton	Percent	Good	Bad	Ton	Percent
Misqan	7.5	4.6	2.9	38.7	3	1	2	66.7	2.4	0.5	1.9	79.2	0.5	0	0.5	100
Sankura	7	5.2	1.8	25.7	2.3	1.2	1.1	47.8	1.8	1.2	1.6	88.9	1	0.6	0.4	40
Wera Dijo	5	3.5	1.5	30	3.5	2	1.5	42.9	1.2	0.6	0.6	50	0.6	0.3	0.3	50
Shala	5.5	2.2	3.3	60	2.8	1.4	1.4	50	3	1.6	1.4	46.7	1.2	0.6	0.6	50
Hawassa Zuria	6	3.5	2.5	41.7	3	1.5	1.5	50	1	0.8	0.2	20	0.7	0.2	0.5	71.4
Adami Tulu …	4	2	2	50	2	1	1	50	1	0.4	0.6	60	0.4	0.2	0.2	50
Sum	35	21	14	246.1	16.6	8.1	8.5	307.4	10.4	5.1	6.3	344.8	4.4	1.9	2.5	361.4
Mean	5.83	3.5	2.33	41	2.77	1.35	1.42	51.2	1.73	0.85	1.05	57.5	0.73	0.32	0.42	60.2

* Best is a better-off farmer that usually use full package of technologies and apply proper management practices.

Dixon, et al. (2009) broadly described the foundational basis to characterize farm typologies. These are rainfall, temperature, soils, length of the growing period, altitude, relief, environmental constraints, land cover, irrigation, permanent crops, arable lands, livestock types, and population. In the CRV and Hawassa Lake Basins, the distinguishing factors are limited relatively to a few determinants because of the location of the study areas. The area manifests similar features notably topography, natural resources endowments, crops, livestock, and climate types. Apart from Shala, the other study woredas produce crops both under rainfed and under irrigation. However, the degree of accessibility and benefit obtained from irrigation vary from woreda to woreda. Unlike the other study woredas with bimodal rainfall, Adami Tulu Jido Kombolcha woreda received summer maximum rainfall. In addition, it is renowned for its widespread irrigation coverage using Lake Ziway and Bulbula River. According to expert group discussion and woreda's basic data, with over 1,200 motor houses for diesel pumps, 7,900 hand-dug wells, 36 solar pumps, and 20 electrically submersible pumps operating in the woreda, Misrak Misqan also has a high potential for irrigation development mainly based on the groundwater. Aside from choosing technology and practices for intervention, Kassa et al. (2011) suggested characterizing the farming system and its component practices guides the agricultural extension actors to avoid a blueprint in adopting technologies in the advisory services. In the mixed system, appropriate crop-livestock interaction that nurtures flows of material, resources, and energy improves smallholders livelihood and health ecosystem functioning.

Similar to crop, diverse as well as large numbers of livestock are being kept in the CRV and Hawassa Lake Basins. In the six study woredas, cattle is the largest in terms of Tropical Livestock Unit/TLU (589,492) followed by equines (48,590), goats (36,112), sheep (21,409), and poultry (19,044) in descending order. Donkeys represent over ninety five percents of the equine population. It provides immense services to the family farmers. Apart from draft power, transportation, and manure for soil nutrients, livestock serve as insurance during times of crop failure and casual emergencies in the household.

5.2 Rainfall distribution and cropping patterns

As stated earlier, apart from Adami Tulu Jido Kombolcha woreda, the other study woredas receive bimodal rainfall. However, the rainfall in all areas is characterized by erratic and erosive feature. Recurrent drought is a typical problem in all the study woredas of the CRV and Hawassa Lake Basins (Kassie et al., 2014). The extreme conditions are detrimental to sustainable crop production. However, its effect is more severe in some woredas. For instance, according to expert group discussion, in Shala woreda, with 80,000 to 140,000 people currently receiving direct relief services, and from the total 40,684 households, 8,000 households with total family members of over 32,000 receiving full aid services. Therefore, climate change in Shala is more appalling as compared to the other study woredas. The Shala problem is further compounded by soil salinity in nine lowland kebeles that barely favor crop production. In Wera Dijo woreda, climate change has severe double effects: drought and flood. For instance, drought experienced in 2016 and 2022 was catastrophic in eight rural kebeles, whereas, floods in five rural kebeles displaced inhabitants in April and June 2019. Recurrent drought in this area has forced the farmers to shift the conventional farming practice by replacing Belg crops with Meher crops. As a coping mechanism in the flood plain areas, the community uses flood diversion ponds to harvest water later used for livestock and home consumption. The inconsistent coverage and unreliability of short rain forced the smallholders to resort to resilient and early maturing crop types. This shows the increasing threat of growing staple food crops under the conventional seasons that used to allow double cropping in the areas.

As maize is the staple food crop, monocropping is the common practice. According to the KIIs, monocropping accounts for 66.7% of the farming practices. Shrinkage of the farmland due to the increasingly growing human population and sharing of the land among the farming family members compel the application of continuous cropping practice. Similar to maize, 93.3% of wheat is produced in a monocropping system. Intercropping of haricot beans in Maize during the Meher season is often, a relay in its type that comes in when maize reaches the physiological maturity. On contrary to maize and wheat, hot pepper is highly rotated every other year. According to expert group discussion, hot pepper rotation accounts for 77.8% over continuous cropping. Compared to other food crops, hot pepper is highly sensitive to diseases such as fusarium wilts, climate variability notably dry and heavy rainfall. Therefore, crop rotation is a compulsory farming practice for hot pepper to avoid soil born and other diseases.

5.3 Characterization of the role of water management in the maize farming system

5.3.1 Irrigated agricultural production

Irrigated smallholder agricultural production is an alternative source of livelihood in the drought-prone areas of the CRV and Hawassa Lake Basins. In these areas, smallholder irrigated vegetable production is instrumental in ensuring access to year-round fresh vegetables in the local and national markets (Etissa et al., 2014). Therefore, it provides income and employment opportunities to the residents. In the area, supplementary irrigation was also used to avoid crop moisture deficit during a shortage of rainfall. Despite the potential opportunities such as the availability of rivers, freshwater lakes, and shallow groundwater, smallholders have faced problems relating to proper management and use of irrigation water (Mekuria et al., 2024; Negasa, 2020; Wendemeneh et al. 2023). The flat topography in CRV and Hawassa Lake basins also forces smallholders to use water pumps for lifting and spreading water to the farm rather than employing natural gravity (Etissa et al., 2014; Makin et al., 1976). This may have cost implications on irrigated smallholder agriculture. As compared to the CRV around Lake Ziway areas, smallholder irrigation development is a recent experience in Hawassa Zuira. As a result, intensive use of Hawassa Lake and the application of improper water management practices is not uncommon (Nagasa, 2020). Overall, irrigation is regarded as an alternative to meet the food security needs of smallholders in these areas and beyond in CRV with improving the existing management practices. As a result, its expansion, proper management and widespread use is commendable.

In this characterization study, five of the six study woredas in the CRV and Hawassa Lake Basins use irrigation for vegetable, food crops, and fodder production. However, the magnitude of fodder production and overall land coverage is negligible. Despite its huge potential and importance as lucrative agribusiness to increase dairy farm productivity and animal fattening, less emphasis is given to fodder production in irrigated areas of the CRV and Hawassa Lake Basin areas. As a result, fodder development using small-scale irrigation is not commonly practiced (Getnet et al., 2017). Lack of awareness, and the perception smallholders are having on the potential economic returns of irrigated fodder production could have been the reason for its under development (Abera et al., 2022; Bezabih et al., 2016).

River diversion, shallow dug wells, freshwater Lakes, stream diversion by traditional means, and spate diversion are used for irrigation development at different scales. Apart from three rural kebeles of Sankura and a few plots of land from 285 hectares of irrigated land in Wera Dijo woreda which farmers use to produces food, fruits and fodder crops, virtually all the irrigated agriculture targeted vegetable crops production for market (Figure 4). According to the expert group discussion, in Sankura woreda, government initiatives of lowland wheat production encountered irrigation water deficit and failure in the 2023 season. The initiative that associated with exhaustive use of water resources had the potential to incite conflict between the upstream and downstream dwellers because of the blockage of streamflow that further has an ecological consequence affecting ecosystem services. Even then, wheat production on small plots of land is in pilot phases in Jata and Sambita *kebele* of Sankura and Wera Dijo *woreda*s, respectively.

Figure 4 . Irrigated maize, fodder and banana production in Jata *kebele* of Sankura *woreda*.

Essentially, furrow irrigation is the method widely used by vegetable growers. According to Etissa et al. (2014), 98.7% of smallholders in the CRV of Ethiopia use furrow method of irrigation. They further remarked, furrow irrigation leads to low uniformity of water application signaling the inefficiency of the method for effective water management and use. The main feature of the assessment and observation of water management in study woredas with particular emphasis in Jara Hinessa and neighboring kebeles are briefly discussed as follows.

In Jara Hinessa kebele of Hawassa Zuria, irrigated agricultural production is practiced over 145 hectares of land using a shallow dug wells near Hawassa Lake. The neighboring 3 to 4 kebeles are also using the Lakeside farmland for vegetable production. Most of the kebeles use shallow-dug wells to irrigate their farmland using diesel pumps. According to the participants of FGD, farmers produce different vegetable crops two to three times a year followed by maize in the Meher season. Vegetables such as cabbage, beets, carrot, tomato, green beans, chilly, garlic, and local kale known as Shana are produced. The income from vegetable production immensely supports the livelihood of the residents. Furthermore, during the last couple of drought years, irrigated farms used to grow food crops.

During this particular assessment, except for the cabbage which they currently sell a head of it for birr 10, they acknowledge the good price the farmers are obtaining for virtually all vegetable crops. For instance, a kg of chilly costs Birr 100 and the same amount of onion is sold for Birr 140 in February 2024. Unfortunately, most farmers simultaneously grow head cabbage instead of diversifying the type of vegetable crops (Figure 5). In Hawassa Zuria, road accessibility and proximity to the regional capital created a wonderful opportunity for the growers to access market. This may not be the case in some CRV woredas in far-flung areas like Wera Dijo. However, vegetable production challenged by numerous problems. Diseases and pests, lack of pesticides and fungicides, and growing adaptation of pests and diseases to the agrochemicals are among other issues (Figure 6). In addition, the soaring fuel price increases production costs. As aforementioned, despite accessing irrigation, most farmers produce high-value vegetable crops and less focus on fodder and its seeds production. The immediate and better income generated from the sale of vegetable crops lure farmers to give priority for these crops.

In the CRV areas such as in Dugda Woreda, the Meki Batu, fruits and Vegetable Producers Cooperative Union is operating. The cooperative as an institution facilitates member farmers' access to agricultural inputs, markets, benefits, and services (Meki Batu Union Report, 2016). Provision of training, access to mechanization and maintenance services, provision of technical and advisory services, and facilitating access to credit are among several benefits and services provided by the union. Despite the organizational development and provision of various services, the production of similar commodities, and unsustainable utilization of water for irrigation are documented as challenges (Meki Batu Union Report, 2016; Jaleta, 2007).

Contrary to the CRV areas, vegetable production in Hawassa Zuria woreda is an emerging agribusiness. As a result, institutions nurturing the sector are still underdeveloped likewise the scope of production. In fact, there is a water users association (WUA) as a supporting institution for irrigation development in Jara Hinessa kebele of Hawassa Zuria woreda. However, WUA in the woreda is not that strong enough to address some basic issues of the member farmers such as shortage of agricultural inputs and farm tools, production market failure, and mounting fuel prices among others.

Figure 5. Cabbage production on large farmlands, Jara Hinessa *kebele*.

Figure 6. Irrigated Maize infested by stalk borer in Jata *kebele* of Sankura *woreda*.

5.3.2 Rainfed agricultural production

In CRV, rainfed agriculture is the main livelihood option for the inhabitants. However, it is challenged by rainfall variability. In the north-central part of the CRV such as in the Adami Tulu Jido Kombolcha area, Meher is the main cropping season that ranges from May to September (Hengsdijk and Jansen, 2006). However, moisture deficit is often experienced because of low rainfall and recurrent drought manifested in the area. This part of the CRV is characterized by a semiarid climate. Among cereal crops, the early maturing maize variety has a huge potential to evade moisture deficit if planted in June than in May (Ademe et al., 2020). In Hawassa Lake basin and other study woredas, rainfed agriculture is practiced during two seasons (Belg and Meher). In general, rainfed agriculture production and productivity in CRV and Hawassa Lake Basins are directly affected by fluctuations in precipitation (Belay et al., 2013; Hengsdijk and Jansen, 2006). Climate variability causes crop failure and shortage of livestock feed which affects livestock production. Summary of the feature of rainfed agriculture in six study woredas are briefly presented as below.

Maize is the main staple food crop in all the study woredas followed by wheat in three woredas (Misrak Miskan, Sankura and Wera Dijo), and haricot beans in the other three woredas of Adami Tulu Jido Kombolcha, Shala and Hawassa Zuria. Belg crops were mainly planted in April, whereas, Meher crops are planted in July. Due to climate change, there are staggered experience. The harvesting time for the two-season crops often overlaps starting from October onwards. However, some early maturing maize, tef, and haricot beans are harvested twice a year. There are some challenges in the mixed crop-livestock system. According to expert group and community FGD, Fall Army Worm is a serious pest for maize production. The worms developed resistance to chemicals and hid themselves under the maize sheath. Fusarium wilt is another disease halting the production of hot pepper. As a result, some farmers replace hot pepper with lucrative perennial crops such as Khat (Catha edulis) and other food crops (Figure 7).

Furthermore, smallholders are unable to access the type of maize variety they require at the right time and at fair prices. Shortage of chemical fertilizers is another challenge to rainfed as well as irrigated agriculture. In another study woreda such as Misrak Miskan and Adami Tulu Jido Kombolcha, experts unveil that irrigation farmers used to apply extra-large quantities of fertilizer beyond the national recommendation to boost vegetable production. That trend also causes a huge demand for chemical fertilizers that induce a shortage of supply in respective woredas. According to expert groups and KIIs, climate change during the last couple of years has caused detrimental yield loss and death of animals because of feed shortage. Shortage of rain is often experienced during the tillering, flowering, and seed-filling stages of different cereal crops and cause irreversible failure in crop production.

Figure 7. *Khat plant* replacing hot pepper and other crops

5.3.3. Complementarity and contradictions of rainfed and irrigated agriculture

There is strong complementarity between rainfed and irrigated agriculture. The income generated from irrigated farming is used to purchase fertilizer and seed for rainfed food crop production. Belg maize is also sold to buy inputs for irrigated crop production. It also serves as food crops and feed both to the family and to their livestock. These show a strong complementarity between the two systems. Furthermore, irrigated plots give over the land for maize production during the Meher season. Maize enjoys leftover fertilizer residue in the soil system used to produce the precursor crops. Therefore, vegetable-cereal crop sequencing partly reduces fertilizer requirement by a succeeding crop. Overall, intensive cultivation and weeding practices during the irrigation seasons reduce weed seedbank, the workload, and the cost of weeding the succeeding crops. Furthermore, in Hawassa Zuria, smallholders feed their livestock over the leftover or discarded cabbage, green beans halium, slimy and damaged products merely as feed supplements.

However, there are contradictory events between rainfed and irrigated crop production. The heavy rain in the upper stream causes erosion and flooding in the valley bottom. The farm is inundated by siltation and debris that buries the farmland and crops on the field. Such issues are common in Hawassa Zuria woreda kebeles, in Simbita Warabe kebele of Sankura and Simbita kebele of Wera Dijo woredas. According to participants of community FGD in Jara Hinessa of Hawassa Zuria, the application of physical soil and water conservation structure subsided the prevailing effects. Flood protection dikes and flood diversion ponds are also used in Wera Dijo woreda to arrest and reverse the harmful effects of heavy rain and flood in the rainy season (Figure 8).

In most woredas, shallow wells are used for irrigation development. Farmer's decision for frequency of irrigation comes based on the observation of the prevailing intensity of heat of the sun and casual observation of the soil moisture. Essentially, the frequency of irrigation in Hawassa Zuria is once in 3 to 5 days. As a management to avoid the movement of soil during pressurized irrigation, farmers reduce the speed of flows of the pumped water by taking it long distances from pumping point using plastic tubes. Around Lake Hawassa, farmers are currently observing yield reduction as compared to the past. This may need more investigation if there is a change in soil property, including soil salinity development due to mismanagement of irrigation and drainage system. According to Wendemeneh et al. (2023), as the farmland is increasingly under irrigation practice, there is a high likelihood of developing salinity. Apparently, poor irrigation and drainage management practices and the use of excessive chemical fertilizers have an implication on soil property. Therefore, on-farm monitoring of salinity build-up over time under irrigated fields is indispensable for timely identifying the issues, and to take corrective measures.

Figure 8. Flood protection dike (left) and flood diversion pond (right) in Wera Dijo *woreda*.

5.3.4. Irrigation scheme management and benefit exchange between irrigation and livestock

As to the irrigation scheme management, all water users including the *kebele* people non-selectively engaged in irrigation scheme management in rural *kebele*s of Sankura district starting from the diversion point in the Bilate River (Figure 9). The other *woreda*s except Shala are using the ground water for irrigation development. Therefore, for the ground water users, scheme management is not part of their mainstream business. The benefit exchange between irrigation farming and livestock production is the supply of feeds/fodder from the irrigation plots to the livestock versus traction force, manure and transportation service from the livestock to the farmland. Furthermore, the income generated both from the sale of irrigated crop production and livestock production is interchangeably used as sources of financial investment to access necessary inputs in the respective sector. Also, the income generated from both sectors supports the livelihood of family farmers.

Figure 9. Irrigation canal cleaned by the community in Bonesha *Kebele* of Sankura *woreda*

The use of irrigation for fodder production is common in Misrak Miskan, Sankura, and Wera Dijo. Fodder grass such as Napier and Desho grass are commonly grown on the farm and as buffer plants (life fence that serve as windbreak) to the irrigated crops field. Napier (elephant) grass does better in the dry midland and lowland than Desho grass (Figure 10a).

In addition, the farmers fed crop residues to their livestock both in green and dry forms, and the leftover of harvested vegetables. On some model farmers' farms, fodder crops such as mixes of alfalfa and Napier grass are grown to feed and fatten animals for market such as in Misrak Miskan (Figure 10b). Overall, the availability of irrigation water enables the production of food and fodder crops that optimize mutual benefits between irrigation and livestock production.

Figure 10. Elephant and Desho grass (a) and mixed alfalfa and elephant grass (b).

5.4 Characterization of livestock production sub-system

5.4.1. Main livestock types and purpose of farming

The livestock subsector is a major contributor to the overall Ethiopian economy. In addition, the sector can be a major contributor to poverty reduction by improving the livelihoods of rural people (Shapiro et al., 2017). Like in the other parts of the country, livestock is a major source of animal protein, power for land preparation, means of transportation, export commodities, manure for farmland and household energy, security in times of crop failure, and means of wealth accumulation in the CRV and Hawassa Lake Basins (Management Entity, 2021). Specifically, cattle are the most important livestock species because they are used for plowing, threshing crops, and providing manure. Goats, sheep, and chicken are also important sources of income, meat, and manure, whereas, equines provide considerable transportation service.

Likewise, in all the six study *woredas*, cattle is one of the dominant species kept by smallholders in terms of number and services followed by goats, sheep, and equines (Table 4). In terms of TLU, however, equines are the second largest animals. According to the KIIs 77.8% and 72.2% of sheep and goats are respectively kept by smallholders in the focus CRV and Hawassa Lake Basins study areas primarily as sources of income. This is followed by breeding for replacement and household security need but is less kept for manure production and use. In a similar vein, farmers kept poultry primarily as a source of income, for replacement and egg production for household consumption and sell. Equines give tremendous services to the household. In most areas, the donkey is considered as a house maiden giving the services of fetching water from long distances that otherwise compel the housewives or children to travel 3 to 6 hours a day fetching water on their own backs (Figure 11). Over 95% of the equine population comes from donkeys followed by horses. According to the KIIs, livestock particularly oxen and equines provide 83.3% of draft and transportation services. Cattle and equine manure/ drops contribution to the soil nutrient valued as next important to the draft and transportation services they provide. In addition, livestock generate income and play a role in investment linkage in crop production. The income from livestock is reinvested in agricultural inputs such as chemical fertilizers and improved seeds. In addition, livestock immensely plays the role of insurance to the family farmer during an extended drought and food insecurity period.

However, when critically analyzing the use of livestock manure for soil fertility amendment, it depends on the size of farmlands and the number of animals kept by a smallholder. Large sizes of farmland give the opportunity to keep many animals, which enables collecting more manure as a nutrient input that covers considerable sizes of farmland. However, regardless of the current soaring price of chemical fertilizers, the use of livestock manure is largely limited to producing garden crops. Zerssa et al. (2021) also uncovers restriction of manure use to home gardens. The main reason is the competing use of cattle manure as sources of energy, and limited manure supply because of reduction of number of animals due to shortage of grazing land. In addition, crop intensification is increasingly growing with emerging irrigation development that necessitates the use of chemical fertilizers. The use of livestock manure as input/feed for vermicompost production is at infant phase in all the study woredas. Essentially, vermicompost is rich in nutrients and light to easily transport to the farm situated in remote areas. The production and use of organic fertilizers such as vermicompost is vital in the farming system where monocropping is frequently implemented to restore soil fertility degradation such as in CRV and Hawassa Lake Basins areas, where crop residue entirely collected to the level it diminishes soil nutrients. The use of organic fertilizers not only improves soil fertility but also drastically reduce input costs in the view of soaring prices of chemical fertilizers (Leta et al., 2020).

Table 4: Livestock population by *woredas* (in Tropical Livestock Unit/TLU)

Animals	Misrak Miskan	Sankura	Wera Dijo	Shala	Adami Tulu Jido Kombolcha	Hawassa Zuria	Total
Cattle	116,048.8	65,492.7	62,650	104,484.1	111,348.3	129,467.8	589,491.7
Goat	7,134.2	3,942.1	5,977.7	5,234.9	9,270.5	4,552.5	36,111.9
Sheep	6,251.4	5,899.7	2,421.6	1,638.2	5,197.9	3,244	21,408.8
Equines	24,440	11,768	9,127	12,382	23,443.5	6,976	48,590
Chicken	12,753.44	1,849.23	924.47	937.15	4,226.83	2,580	19,044.29

Sources: Annual report (2023) of respective woreda livestock population.

Figure 11. Donkey, an important animal for fetching water, draft and transportation service.

5.4.2 Sources of feed for livestock production

In the mixed crop-livestock system of the CRV and Hawassa Lake Basin areas of Ethiopia, crop and livestock production are the two pillars of the agriculture sector. Afforestation, land resources and forest management are crosscutting issues to safeguard natural resources, reduce erosion, ensure environmental sustainability and healthy ecosystem functioning (Mekuria et al., 2020). For livestock production, crop residue particularly maize stover is the main source of feed (Geberemedhin et al., 2007). They further stated more than two-thirds of the maize stover collected is used for livestock feed. Despite the immense contribution of maize stover as feed for the livestock, insignificant efforts were exerted to improve its quality and intake by research and development actors.

In the study woredas, farmers collect and store crop residue around their homestead. According to the KIIs, maize stover covers over 83% of cattle feed. To improve the intake, farmers chop the maize stover before feeding it to their animals. A few farmers introduced improved varieties of planted fodder species such as Elephant grass, Desho, Bracharia, Rhodes, and Desmodium around their homestead. These are often feed to the animals during the wet season. Elephant grass is the dominant fodder species widely used as livestock feed in dry midland and lowland areas using cut-and-carry systems. Elephant grass usually planted in the periphery of other croplands. It is also planted to rehabilitate the gully and stop its expansion. In addition, farmers in Hawassa Zuria use elephant grasses as construction materials particularly for roof making and thatching. According to community FGD, the rainy season allows the growth of annual and rejuvenation of perennial species. As a result, there is plenty of livestock feed from June to October. However, in November, despite the availability of adequate feed, crop residue dries out and reduces the palatability and intake from that month onwards. The critical livestock feed shortage time is in the dry season from December to May when livestock largely rely on preserved maize stover and other supplies from either market or irrigated lands.

The common means of accessing extra livestock feed is via purchase. In Hawassa Zuria woreda, a few farmers purchase grass from the woreda office of Agriculture fodder multiplication center. Again, the better-off farmers purchase a heap of maize stover from farmers who do not possess cattle. In addition, they purchase maize stover from mechanized private farm centers that are operating in the area. Usually, the price of a heap of stover is negotiable based on the size. When the critical feed shortage is experiencing from December to May, the crop residue of maize is used as the main feed. As mechanized private investors are operating in the Hawassa Zuira woreda, it creates the opportunity for better-off farmers to easily access livestock feed on cash during the dry season. Therefore, access to crop residue is limited during extended drought and due to lack of financial resources. In Sankura and Shala, the government supplied feed aid when the feed supply is insufficient because of an extended drought period. According to KIIs, grazing grass contributed 83.3% and 88.9% for sheep and equines, respectively to their total estimated feed supply. About 94.4% of goats' feed comes from browsing vegetation.

However, regardless of the preference and feeding habit of the animals, feeding virtually all livestock species is limited to the homestead areas. Despite the availability of some common grazing and browsing land such as in Mekibasa Korke kebele of Hawassa Zuria, it is limited to serve as a livestock-wandering site as it denuded of vegetation. As a result, livestock roaming is also limited to the homestead and private farmland. Meaning, the common land supposed to serve as a grazing and browsing area does not adequately provide edible grass, bushes, or shrubs. In a few kebeles of the study woredas, area exclosures are available for cut-and-carry feeding systems.

According to the KIIs, the current development policy and initiatives advise allocating mountains for development and discourage fallowing the farmland. As a result, except for a few smallholders in Shala woreda, farmers do not reserve private farmland for growing pasture. The increasing human population compels farmers to adopt and exercise intensive farming practices. In most of the study areas, there is no communal grazing land. Furthermore, the existing population dynamics, and development initiatives to ensure food security compel livestock production to rely highly on crop residues and other feed supplements.

In all the study woredas, maize stover is the main crop residue used by the farmers to feed their animals in green and dry forms followed by other crop residues according to the potential of the study woredas. According to FGD, women play key role in selecting the type of feeds for animals. Thus, they select maize cobs or sheaths (the softest and more palatable parts of the stover) and fed to calf and dairy cows as compared to dry cows (Gebremedhin et al., 2007). Essentially, farmers select the feed they supplement by livestock types. In addition to feed selection, women play the leading role in supplying the feed to the different livestock types. Livestock under a fattening program are given the priority to feed relatively better-feed parts or types.

Treating maize stover increases their palatability. Feed treatment to improve intake and digestibility is low in the CRV and Hawassa Lake Basin study areas. Aside from the lack of knowledge and skills, the practice of treating crop residue is limited largely because of the lack of accessibility to inputs such as Molasses, Effective microorganisms (EMO), and Urea. Regardless of the prevailing constraints, experts in Shala Woreda strive to replace Molasses with grams of dissolved sugar in a liter of water.

The better-off and knowledgeable farmers feed their animals with sugarcane, chopped enset, and wheat bran as concentrate feed. Farmers purchase 50 kg of wheat bran for Birr 1,300. The same amount of wheat bran fed to two dairy cows and their calves for ten days. In Misrak Miskan, wheat bran is barely accessible because of high demands from private dairy farmers in the urban and peri-urban areas surrounding Butajira city, and less supply of the byproduct by the flour factory. Furthermore, leftover or discarded fruits and parts of vegetables are fed to the animals in the irrigated areas.

5.4.3 Types of breed and livestock breeding techniques in study areas

Local breeds are the common animals in Hawassa Zuria and other study woredas. The number of local breeds in Ethiopia comprises 98.2% of the total cattle population (Gebrehiwet, 2020; CSA, 2017). Different breeding techniques are being applied to improve cattle breeds: regular artificial insemination work, estrous synchronization campaigns, bull services, the introduction of heifers, and the use of sexed hormones. According to expert group discussion, the different breeding techniques are immensely used in the Sankura district of the Silte zone. However, bull services are suggested as more effective for conceiving the cows. As a result, about 10% of the breeding improvement in Sankura woreda is implemented via bull services. Artificial Insemination (AI) including sexed hormones is often not that successful. As a result, there are few crossbreed cattle such as in Hawassa Zuria woreda. The failure is attributed mostly to heat stress, feed shortage, and technical inefficiency of the AI technicians. Apart from the AI services, the estruses synchronization campaign is implemented once a year from October to November in all study woredas. The activities are implemented via public mobilization. However, the outcome of the campaign work is often unreliable. According to KIIs, in most cases, the campaign fails to consider feed availability, physical fitness of the local breeds, prevailing weather conditions, and associated requirements against the trends of counting the number of jobs accomplished. Gebrehiwet (2020) also suggested poor infrastructure, lack of a trained workforce, poor heat detection skills, poor feeding and management of dairy cows/ heifers, and improper use of AI are some of the challenges to the effectiveness of crossbreeding in Ethiopia.

According to participants of expert group discussion, bull services are widely available in Sankura, Wera Dijo, and Hawassa Zuria woredas. In Sankara woreda, each Farmers Training Centre has a bull for breeding services. Despite the access to crossbreed heifer, the number are limited. In general, shortage of liquid nitrogen, and failure of conception with AI dissuade smallholders from crossing their animals. However, there has been persistent efforts by experts and other stakeholders to create interest via awareness creation fora at varies level.

The ongoing effort in breeding improvement is believed to increase milk production per head of animals and reduce the number of animals kept by the smallholders. As a result, the pressure that could have been exerted on the meager supply of feed will gradually decline giving a positive pathway transiting the mixed crop-livestock system with harmony. Indeed, the effort should be complemented by proper health care and the introduction of improved fodder production under rainfed and irrigated farming.

5.4.4 Livestock fattening and marketing

A few farmers are occasionally engaged in fattening animals as sources of income and employment opportunity. Usually, the cull out oxen from farming services are fattened and sold. Livestock feed shortage is challenging to expedite the fattening activities. Concentrate and sugarcane are often used to fatten the bullock in a tethered manner. Currently, medium-sized fattened male animals are sold for Ethiopian birr 40,000 to 50,000. The good ones sold from birr 60,000 to 70,000 and this indicate the significance of fattening animals to generate lucrative income. There are four livestock markets around Hawassa Zuria Woreda within a radius of 10 to 30 km. These are Tukur Wuha, Hawassa, Tula, and Shamana. The last one is in the Hawassa Zuria woreda. The residents prefer Tikur Whua market as it brings on board customers from neighboring regions. Farmers do not access reliable livestock market information. Management Entity (2021) associated lack of market information with the informal marketing system. Essentially, the livestock market is seasonal. Even though the price varies by the plain and holiday seasons, respondents of the FGD recognized livestock market prices as reasonably improving. Apart from oxen, shoats are also fattened and sold. Goat and sheep demand less investment cost as compared to cattle. Average-sized goats are sold for birr 10 -12,000, whereas, the sheep are sold for birr 6 -7,000. In Wera Dijo, two primary cooperatives have been established on goat fattening. The initiative would enable to fetch sustainable market and motivate other farmers to adopt the approach.

According to the FGD, livestock marketing is usually the role of the men particularly when the household is led by the men. A few of the men are transparent to their partners about the selling price but the others are not. This evidence attesting more men's control over some of the resources than the women do. In livestock management activities, all household members, including the children, are involved. According to Obosha (2020), men are specifically involved in herding, harvesting forage, marketing, and taking livestock to health centers. Women mostly participate in providing feed to the livestock, watering; take care of the sick and young animals, and cleaning the animal shelter. In general, our finding is in line with Obosha (2020). Fattening activities and access to the market reduce livestock stock by expediting selling the older animals and replacing them with new ones. This enables smallholder access to additional and series sources of income and improves their livelihood.

5.5.5. Dairy in the CRV and Hawassa Lake Basins

As local dairy cows give only 2 liters or less of milk a day, it is largely used for household consumption. Selling fresh milk is not a tradition in Hawassa Zuria and other study woredas. Rather they sell the by-product of churning sour milk known as Arera. A liter of Arera is sold for Birr 40. According to Management Entity (2021), there is no formal dairy product marketing in remote areas of Ethiopia. The children and the family consume goat milk. Of course, the latter are consuming goat milk with coffee. According to participants of community FGD, the number of goats possessed by smallholders and production per head is small to market the milk. In general, there are no milk marketing nor dairy producers' cooperatives in the woredas except few dairy farmers operating in Dore Bafana and Hawassa city. Similarly, there are no milk collection and processing centers.

5.5.6. Challenges in the current livestock production system

The challenge in livestock production is inextricably linked with the challenge of crop production. The changes and challenges in the current mixed crop-livestock system are mainly climate change and variability largely associated with drought that affect crop and livestock production. As a result, farmers often lost their farm animals including oxen to the recurrent drought. Disease and pests are other associated problems the smallholders are facing in crop and livestock production. In livestock production, Blackleg (*Colostridial myositis*) and Anthrax (Bacillus anthracis) are the main health issues common in Hawassa Zuria. The disease occurs when animals get body weight or a little fatter. The outbreak often happens from September to November every other year. According to participants of FGDs, disease outbreaks coincide with relatively high available feed supply. However, in contrast to the claim of participants of the FGD, Management Entity (2021) remarked that because of the expansion of farming and shrinkage of grazing lands, the feed resource base in terms of both quality and quantity is declining. This in turn leads to susceptibility of animals to various infectious pathogens and parasites. Other researchers suggested that recurrent drought, such as the one that occurred in the CRV and Hawassa Lake Basin areas during the last consecutive years, can exacerbates the occurrence of diseases (Addis et al., 2014; Catley et al., 2014). Vaccination supports the animals against the possible disease incidence. However, the time of vaccination may not be in advance of the disease outbreak. For instance, in 2023, animals in Hawassa Zuria get vaccinated in December.

Shortage of agricultural inputs particularly improved seeds and fertilizers severely affects production and productivity. It is further compounded by climate change-related problems that reduce farmers' resilience to the climate change (Zerssa et al., 2021). In general, there is a huge mismatch between the supply and demand of agricultural inputs. Even though the seed is supplied by the Woreda Office of Agriculture, farmer cooperatives and registered agro-dealers, a shortage of the variety of seeds the farmers demand (such as pioneer varieties of Limu, Shone, etc.) expose farmers to extremely expensive price on the black market. According to KIIs and FGD, 12.5 kg of maize seeds for a half hectare costs birr 10,000 -13,000. They further suggested, climate change induces a change in practices and cropping patterns. For instance, in the past, hot pepper was a very lucrative cash crop that allowed smallholders to access inputs from its sale but in recent years soil borne diseases such as Fusarium wilts and drought forced the farmers to replace the crop largely with Khat (Chat) and other crops. However, hot pepper remains the number one cash crop in Central Ethiopia region three woredas (Misrak Miskan, Sankura, and Wera Dijo) by application of crop rotation measures. Regardless of applying appropriate cropping practices, hot pepper production succumbs to climate change such as drought and heavy rain. The nexus of challenges in crop production directly or indirectly affects livestock production. Even then, livestock remains to serve as insurance or buffer to the household when recurrent drought and adverse climate change experienced. This was evident in the CRV and Hawassa Lake Basin areas during the last consequent drought years. Thus, livestock serve as a potential asset to generate income when annual crops partly or totally failed.

5.6. Distinct features of mixed maize-livestock systems in the CRV and Hawassa Lake Basins

5.6.1 Interaction between crop and livestock in mixed system

According to KIIs, in the chain of resource flows and trade-offs between crop and livestock subcomponents, livestock provide 83% draft power for land preparation, and 77.8% manure that is often used via the application of farmyard manure (FYM) to the farmland (Figure 12). Even if there is a bit of competition for household energy, it is highly insignificant in the study areas. In addition to maize stover, wheat and tef straw, and haricot beans haulms are other sources of feed for the livestock, though their supply is low and site specific. A few farmers also grow maize by broadcasting in Belg season so that they harvest and feed their animals entirely as green feed and leave the land over to the succeeding Meher crops such as haricot beans. Allocating cropland for fodder production is a complementary role played between the crop and livestock production. There is also an investment or benefit linkage between crops and livestock. On one hand, farmers sell livestock to purchase agricultural inputs, food crops, and livestock feed for different livestock herds. On the other hand, when the crop is in surplus production, the crop serves as a source of cash to cover various household and farm expenses. Seldom, the grain is fed to the animals to expedite the fattening process for the market. Usually, farmers feed shriveled and pest affected grain to the animal. Overall, there is a swapping tendency between crops and livestock in serving as sources of cash income and supporting livelihoods. Therefore, in the mixed crop-livestock system, apart from power, transport, and contribution to soil fertility management, income from livestock may be able to buffer low crop yield in dry-prone areas. According to the Royal Society (2009), the synergy between crop production and livestock husbandry sustainably contributes to increased production by increasing resource use efficiency and improving productivity. This, in turn, can increase the resilient capacity of stakeholders while maintaining environmental services.

However, the existing trends vary from farmer to farmer based on the possession of livestock and the farm size to support the animals. For instance, farmland possession varies from woreda to woreda. In Hawassa Zuria, it varies from less than 0.25 ha to over 3 hectares of land per household. In Wera Dijo, the possession of land varies from 0.5 to 4.5 hectare. Regardless of a few out layering farmers, the majority in Wera Dijo possess 1 hectare of land per household, on average. In fact, the size of land possessed by farmers is inconsistent across study areas. Ownership of the farm size is further reduced in highly populated woredas. Hence, the number of livestock kept by farmers varies by land size and accessibility to adequate feed sources. Financial sources of a farmer also determine the type of livestock to be possessed.

As a synergy and trade-off between crops and livestock, about 5-10% of farmers allocate croplands for fodder development on top of using crop residue. Therefore, the integration between crop and livestock is so immense in addressing the livelihood needs of the smallholders. As described earlier, in some woredas such as Shala, smallholders allocate part of their cropland to grow livestock feed. However, these days all land is urged to be tilled as a policy direction to ensure the food security needs of the family farmer. In general, a catchword-saying "mountain for development" has been entrenched as a guiding principle to grow crops that discourages fallowing the land either to restore soil fertility or to maintain it as a grazing reserve. This direction may neglect livestock as an important component of the mixed system, though, livestock serves as insurance during times of crop failure and transits the household from the hard season to the better one.

Figure 12. Spread over of farmyard manure in the farmland, Hawassa Zuria.

5.6.2 Factors affecting the interaction and sustainability of mixed maize livestock system

Soil or land degradation affects biomass production, which reduces both food, and feed production. Exhaustive collection and use of the crop biomass is detrimental to soil fertility and soil health. Continuous grain production and collection of stover for livestock feed year and again mine the soil nutrients. Eventually, the practice causes soil degradation. As cited in the preceding section, with the aim to maximize production and ensuring food security, fallowing the farmland to either regenerate the potential productivity or to sources feed for animals was discouraged as policy direction. Allocation of the communal land to investors, youth groups, and landless farmers as is the case in Sankura woreda deprives livestock access to common resources and compels their reliance entirely on crop residue around the homestead (Figure 13). In most of the study woredas, land fragmentation is not a serious problem to distract farmer's focus. In some cases, however, it imposes slight pressure on the farmer not to apply proper management practices during the growing season and causes inconvenience in harvesting crops and transporting crop residue to the place of storage and use.

Figure 13. Tethered ox feeding on maize stover and cobs, Jata *kebele* of Sankura *woreda*.

Climate change is, in addition, a pervasive and severe problem experienced by farmers in most areas. It causes low biomass production, food and feed shortage. As it reduces groundwater sources, it influences the use of supplementary irrigation as an alternative practice to grow crops for subsistence during the shortage period. In most of the study *woreda*s, drought is more severe. In others such as Sankura, Wera Dijo, and Hawassa Zuria flood is also another serious issue triggered by climate change. In addition to harming human and livestock populations and displacing the residents once in five to eight years, the debris and siltation in the valley bottom create inconvenience to farming operation. The siltation can displace the Lake water and have lethal effects on aquatic life. Along with climate change and climate variability, disease and pest outbreaks are very common. These issues are frequently experienced during drought period. According to KIIs and consultation with zonal officers, among the different diseases and pests experienced on different crops are Maize Necrosis Lethal Disease (MNLD), Fusarium wilts of hot pepper, wheat and tef head smut, wheat rust, maize fall armyworms, cutworms, stalk borers, aphids on cabbage and haricot beans, and invasive birds are the most common ones. On top of the aforementioned factors, the application of improper agricultural practices such as continuous cropping and frequent tillage practices are other problem for smallholder production. In general, the networks of issues are negatively affecting the mixed maize-livestock system and its sustainability.

5.6.3 Suggested strategies against the issues of mixed maize-livestock system

The main strategies suggested by respondents of KIIs have both crop and livestock dimensions. Essentially, identifying and introducing CSA in mixed crop-livestock systems in erratic and uneven rainfall distribution areas of the CRV and Hawassa Lake Basin areas of Ethiopia is indispensable in building the resilience capacity of smallholders against climate change. Adopting the introduced crop and livestock CSA technologies and practices has great potential to counter the posited adversary in the drought-prone areas of the CRV and Hawassa Lake Basin areas of Ethiopia. Apart from access to CSA technologies and practices, farmers' access to knowledge, skills, and information for increasing productivity and adaptation to change is essential. Against the prevailing drought problems and livestock feed shortage expert groups suggested the following points:

- Improve livestock breeds and reduce the number of animals in favour of intensification.
- Improve collection, preservation, and management of crop residue to increase palatability or intake through the application of various feed management practices.
- Introduce improved fodder species, and over sowing the existing grass types in area exclosure with new, nutritious and resilient fodder/grass species to the agroecology and
- Increase farmers' awareness of the anticipated transformative options mainly via the development agents in the study woredas and kebeles.

Furthermore, as a coping mechanism against recurrent drought and moisture stress, the respondent farmers in the FGD suggested the desirability of replacing the *Belg* crops with short-growing crops such as haricot beans, tef, Irish, and sweet potatoes during the *Meher* season. These crops are early maturing and are relatively resilient to moisture stress.

5.7. Seasonal soil moisture and vegetation analysis in the CRV and Hawassa Lake Basins

The Central Rift Valley of Ethiopia experiences significant variation in soil moisture deficit and vegetation cover across its elevation zones. This deficit, or the difference between the water needed for optimal plant growth and the water available in the soil, poses a challenge for farmers in the region (Ademe *et al*., 2020). The vegetation cover challenges are also linked to the moisture availability and other socio-economic pressures on the natural vegetation. The soil moisture deficit and vegetation cover show differences in agroecological zones such as highland, midland, and lowland (Girma *et al*., 2023). Examining the soil moisture and vegetation cover analysis is important to plan interventions that fit the region's current soil moisture and vegetation cover realities.

The climate in the highlands is generally cooler and receives more rainfall. However, soil moisture deficits can still be a concern due to lower temperatures and higher evapotranspiration rates. Vegetation in the highlands is typically dominated by grasslands and pockets of woodlands. Here, communities often rely on practices like rotational grazing to manage pastures and prevent overgrazing, which can exacerbate soil moisture loss (Chimdesa, 2016). Additionally, they may employ techniques like rainwater harvesting and terracing to capture and conserve precious moisture for crops.

Temperatures rise as we descend into the midlands, and rainfall becomes more erratic. Soil moisture deficit becomes a major challenge, leading to reduced vegetation cover. Here, drought-resistant crops like sorghum and millet become dominant. Coping mechanisms in the midlands often focus on diversification. Communities may plant a variety of crops with different water needs, ensuring some yield even in low-rainfall years. They may also adopt water-saving irrigation techniques like drip irrigation to make the most of available water resources (Abomsa *et al*., 2020).

The lowlands of the CRV are the hottest and driest. Here, the soil moisture deficit is most severe, and vegetation is sparse, often consisting of shrubs and drought-tolerant grasses. In these harsh environments, pastoralism becomes the primary livelihood. Coping mechanisms focus heavily on herd mobility, where communities move their livestock to areas with available grazing/browsing and water sources. Additionally, they may cultivate drought-resistant crops during short periods of enough rainfall.

Although farmers in the CRV have developed coping mechanisms to deal with soil moisture deficit, the challenges posed remain significant. It is crucial to focus on interventions into drought-resistant crop varieties, improved irrigation methods, and wider access to water resources in order to ensure the long-term sustainability of agriculture in this important region. By understanding the variations in soil moisture deficit and vegetation across the CRV's elevation zones, we can develop targeted strategies to support sustainable land management practices and improve the resilience of local communities in the face of water scarcity.

5.7.1 Normalized Difference Moisture Index (NDMI) Analysis

In Ethiopia, drought is the main agricultural problem. The CRV and Hawassa Basins is highly vulnerable due to its arid and semi-arid lowlands that are frequently affected by droughts (Biazin & Sterk, 2013). The probability of dry spells lasting 5 days is over 75%, even during the rainy season, whereas 30-day dry spells do not exceed 50%, even during the dry season (Tura, 2017). Crop yield reduction, crop failure, and pasture reduction are the most common degradations in the region (Sime & Aune, 2019). Belachew *et al*. (2022) found that between 2004 and 2009, the average yield gap for maize in the CRV region was between 4.0 and 9.0 t/ha, and for wheat, it was between 2.5 and 4.7 t/ha. Low productivity is mainly attributed to unproductive cultivars, inadequate application of nitrogen and phosphorus in farm fields, and increased vulnerability to biotic and abiotic stresses such as diseases, drought, and soil acidity. Above all, crop production is challenged by the prevailing soil moisture deficit owing to recurrent drought.

Soil moisture regimes were identified using the Normalized Difference Moisture Index (NDMI) values. The NDMI value indicates the amount of soil moisture and water bodies present. High NDMI values (closer to 1) indicate more moisture, while low NDMI values (closer to -1) indicate less moisture (Strashok *et al*., 2022). The CRV region has two planting seasons, *Meher* (long rain): June and July, and *Belg* (short rain): April and early May identified through field surveys. Soil moisture regimes during the planting season was assessed using NDMI. Based on the NDMI values during the *Meher* and *Belg* seasons in the CRV region, three moisture regimes were identified (Figure 14). These regimes are i) bare soil moisture regime (NDMI value of -1 to -0.2); ii) water stress moisture regime (NDMI value of -0.2 to 0.4); and iii) canopy without water stress moisture regime (NDMI value of 0.4 to 0.93).

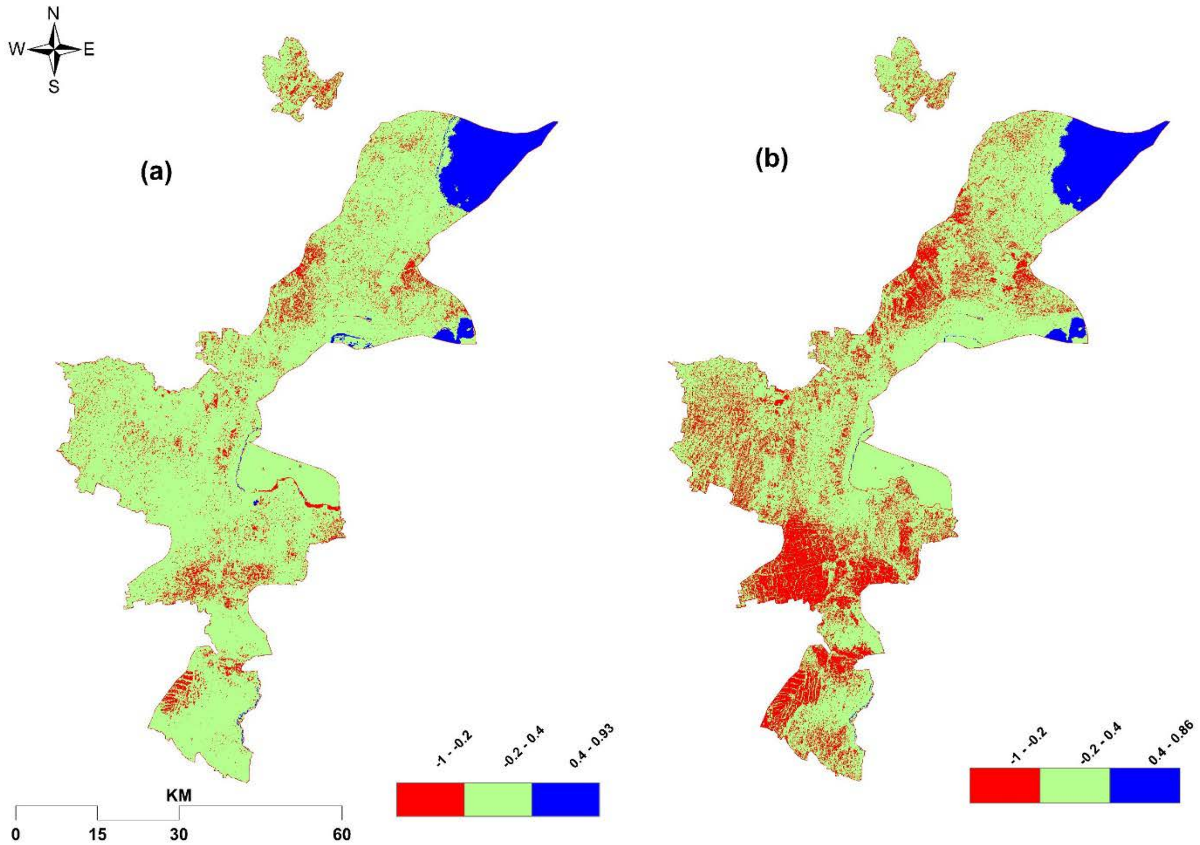

Figure 14. Normalized Difference Moisture Index (NDMI) of *Meher* (a) and *Belg* (b) in the CRV region

During the *Meher* season, approximately 84% (275,734.68 hectares) of the study area experienced soil moisture stress, while around 9% (29,940.98 hectares) had bare soil without any moisture. Only 6.48% (21,196.71 hectares) of the study *woredas* had enough soil moisture for planting crops (Table **5**). Even though *Meher* is the long rainy season in the CRV region, soil moisture stress affected about 93.5% of the area. This figure is even worse considering that the CRV lakes are there in the study areas, which can exaggerate the NDMI values and, hence, the soil moisture regime of the area.

Although *Belg* is a short rainy season in the CRV region, it is still one of the maize planting seasons. As Table **5** shows, a significant portion of land, around 24.85% in the *Belg* season, exhibits bare soil conditions. Moreover, 68.95% of the area was under soil moisture stress during this season. Only about 6% of the region had a sufficient amount of soil moisture to practice mixed farming. This indicates a lack of vegetation cover, which can be due to factors like fallow periods, series of drought episodes, or soil erosion (Tura, 2017).

These situations of soil moisture regimes during the *Meher* and *Belg* seasons imply that soil moisture stress is one of the core factors affecting mixed maize livestock farming in the CRV region, and Hawassa Lake Basins study *woredas*. According to Wolteji *et al*. (2022), droughts of various forms are frequent in the region, leading to crop failure and decreased production. As a result, it may be necessary to assist farming with irrigation and implement agricultural practices that improve soil moisture retention.

Table 5. Soil moisture regimes during the *Meher* and *Belg* seasons in the CRV region

Soil moisture regime	NDMI value	*Meher* area (Hectare)	%	*Belg* area (Hectare)	%
Bare soil	-1 – -0.2	29,940.98	9.16	81,220.54	24.85
Water stress	-0.2 – 0.4	275,734.68	84.36	225,369.27	68.95
Canopy without water stress	0.4 – 1	21,196.71	6.48	20,282.56	6.21
Total		326,872.37	100	326,872.37	100

The research findings suggest a significant transformation within the CRV region's agricultural systems. This transformation appears to be linked to the combined application of various agronomic practices and intervention technologies. These practices, such as minimum tillage, intercropping, crop rotation, and other conservation-focused agricultural techniques, seem to be having a positive impact. The results indicate that these methods may be contributing to the preservation of soil moisture. Through the minimization of disturbance and promoting a healthy soil ecosystem, these practices could potentially extend the availability of moisture throughout the crucial growing season, potentially leading to improved crop yields and overall agricultural sustainability in the CRV region.

5.7.2 Normalized Difference Vegetation Index (NDVI) Analysis

Ethiopia's heavy reliance on rain-fed agriculture in a fragile ecosystem makes it highly vulnerable to climate change. The CRV region exemplifies this challenge, as it faces increased flooding, droughts, land degradation, and competition for water resources due to climate variability and human activities (Meshesha *et al*., 2012). While adaptation strategies like watershed management and improved agricultural practices are in place, some researchers, such as Chimdesa (2016), stressed community participation and focusing on vulnerable sectors like agriculture and water to enhance food security and water availability and combat land degradation.

The Normalized Difference Vegetation Index (NDVI) is an important tool used in remote sensing to evaluate vegetation health, density, and biomass productivity across large areas. The NDVI values range from -1 to +1, where high negative values indicate water bodies and barren land, low positive values correspond to shrubs and grasslands, and high values (nearing +1) represent dense, healthy vegetation such as forests (Akbar *et al*., 2019). Because NDVI can assess vegetation health, it is a valuable metric for estimating aboveground biomass productivity in a specific area over a specified period. Biomass production was assessed during the planting season using NDVI. Based on the NDVI values during the *Meher* and *Belg* seasons in the CRV region, four classes were identified (as shown in Figure **15**). These classes are i) water body (-1 to -0.28); ii) built-up and bare land (-0.28 to +0.14); iii) sparse vegetation area (+0.14 to +0.27), and iv) dense vegetation area (above +0.27 to +0.86).

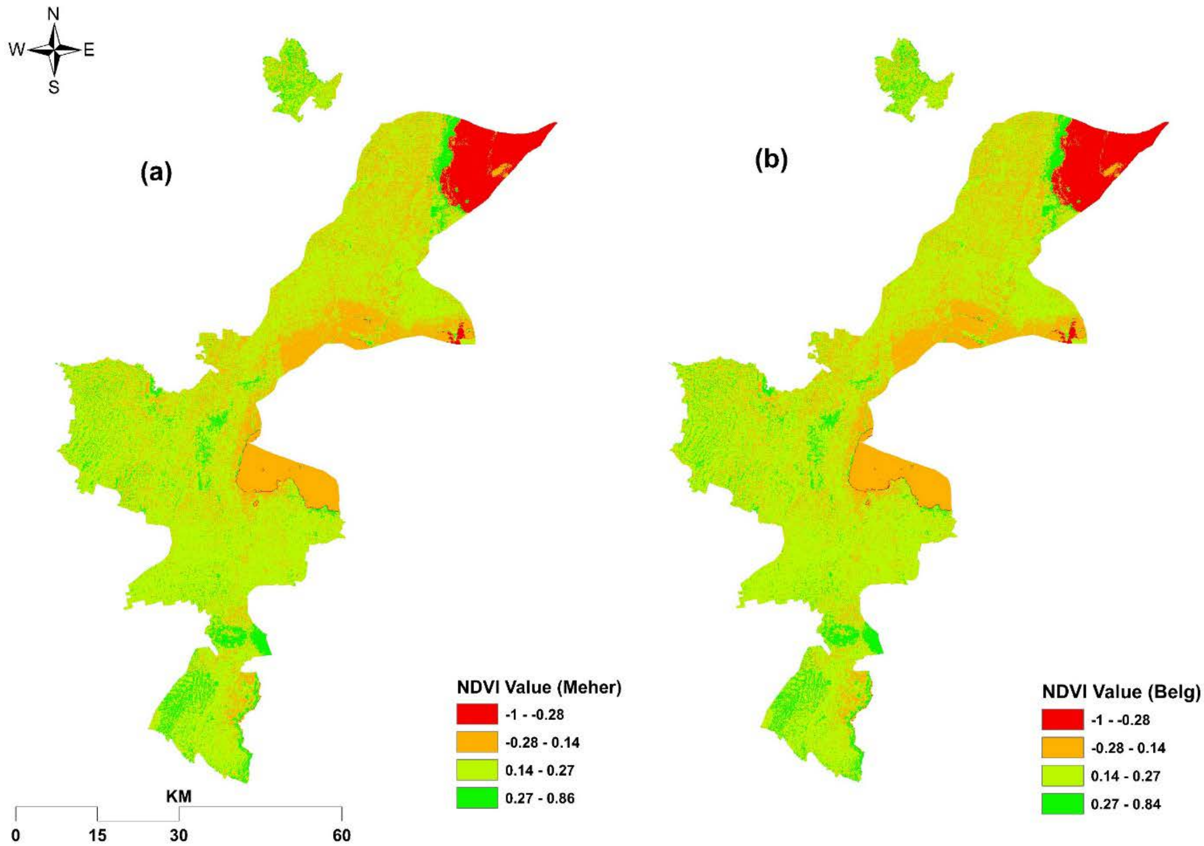

Figure 15. Normalized Difference Vegetation Index (NDVI) of *Meher* (a) and *Belg* (b) in the CRV region

The following analysis depicts Figures **15** (a) and (b) that portray the NDVI class between two seasons in the CRV. As is evident, the difference between the two seasons is not significant. It is pertinent to note that the time lapse between the two sets of images was only a month, which explains the absence of a substantial distinction. Table **6** presents a breakdown of the land use within the area under consideration. On one hand, sparse vegetation dominates the area, accounting for 60.57% of the total land area. On the other, water and dense vegetation cover only 5.47% and 8.14% of the area, respectively. Built-up and barren land occupies a significant portion of the area, representing 25.82% of the total land area. This is consistent with our finding in major land use land cover changes (Figure **16**), where barren land is part of our major land use class in the CRV. The extent of vegetation cover directly influences the rate of biomass production (Balata *et al*., 2022). As vegetation cover diminishes, so too does the total photosynthetic capacity of the ecosystem, leading to a decline in biomass production (Wang *et al*., 2022).

Reduction in vegetation cover presents a significant challenge for mixed agriculture and livestock production systems. The decline in biomass productivity and forage availability leads to decreased livestock carrying capacity and potential nutritional deficiencies in animals (Zhao *et al*., 2023). Additionally, reduced vegetation cover in the study area accelerates soil erosion and degradation, further hampering future productivity in the mixed farming system (*Feng et al*., 2022).

Table 6. NDVI classes during the *Meher* and *Belg* seasons in the CRV region

NDVI class names	NDVI values	*Meher* area (ha)	%	*Belg* area (ha)	%
Water	-1 – -0.28	17,890.01	5.47	17,873.91	5.47
Built-up and barren land	-0.28 – 0.14	84,473.64	25.84	84,393.80	25.82
Sparse Vegetation	0.14 – 0.27	197,941.03	60.56	197,980.91	60.57
Dense Vegetation	0.27 – 0.86	26,567.69	8.13	26,623.75	8.14
Total		326,872.37	100	326,872.37	100

The significant increase in built-up area and barren lands, by 25.8%, and the substantial rise in the proportion of sparse vegetation, reaching 60.5% (Table 6), within the CRV region have concerning implications. These land-use changes will likely cause a decline in biomass productivity, the total amount of organic matter produced by plants in a given area. This decrease in biomass will directly impact forage availability, feed sources for grazing animals, and the livestock system. Reducing forage will strain the ability to raise livestock in the CRV region. In short, converting land for development and degrading existing vegetation could significantly reduce the feed available for grazing and browsing animals. This can lead to malnutrition, lower milk and meat production, and even strain on the land's carrying capacity, meaning the number of animals the land can support.

5.8 Land use and landcover change, and its implication on mixed maize-livestock system

5.8.1 Trends of LULC change in the CRV and Hawassa Lake Basins study areas

In CRV and Hawassa Lake Basins, forests, and grasslands have been changed to farmland and other land use forms. According to Hassen (2017), the original vegetation in the CRV region included dense acacia-based grasslands. The rapid conversion of forest and grasslands to cultivated lands and the long-term repeated tillage culture destroyed the soil's biological, chemical, and physical properties. Which in turn reduced the capacity of the soil to buffer water supply during droughts and frequent dry spells. These impact the mixed maize cropping system and overall agricultural performance in the region. In this regard, understanding the trends in the LULC change, their implications on the mixed agriculture system, and future scenarios of the degradation challenges will be helpful.

The CRV and Hawassa Lake Basins study *woredas* have undergone numerous natural and human-induced transformations. LULC changes in the areas have intensified in the last two decades, largely due to population pressure, impacts of climate change, and urban expansion (Bekele *et al*., 2019). One of the significant LULC changes in the study areas is the expansion of cultivated land. The expansion of cultivated land is driven by population growth and increasing food security needs, often at the expense of natural vegetation such as grasslands, woodlands, shrub lands, and wetlands (Mekonnen *et al*., 2023).

According to Table **7** and Figure **16**, the LULC change in the region during the last two decades (2002-2023) indicates a significant expansion of cultivated land. The area of cultivated land has experienced the most significant growth, expanding by 58,349.68 hectares (17.85%) between 2002 and 2023, which is an average annual increase of 2,778 hectares (0.85%). This expansion likely occurred at the expense of other land cover types, particularly grassland, shrub, and bushland. On the other hand, grassland and shrub and bushland exhibited substantial losses, declining by 18,987.12 hectares (5.81%) and 33,709 hectares (10.31%), respectively, between 2002 and 2023. The built-up area showed a notable increase of 3,507.84 hectares (1.07%) over the entire period, indicating growing urbanization. The waterbody area remained relatively stable in the two decades.

Table 7. Major LULC changes in hectare and percent in the Central Rift Valley region (2002-2023)

Major LULC class	LULC (2002-2023)						LULC changes (2002-2023)						Rate of LULC change	
	Area 2002 (ha)	Area (%)	Area 2013 (ha)	Area (%)	Area 2023 (ha)	Area (%)	2002-2013 (ha)	%	2013-2023 (ha)	%	2002-2023 (ha)	%	2002-2023 (ha/yr.)	2002-2023 (%/yr.)
Cultivated land	183,188	56.05	224,193	68.6	241,537.68	73.91	41,005	12.55	17,344.68	5.31	58,349.68	17.85	2,778.56	0.85
Bare land	12,561.9	3.84	17,141.66	5.25	5,248.01	1.61	4,579.76	1.4	-11,893.65	-3.64	-7,313.88	-2.24	-348.28	-0.11
Forest land	7,897.41	2.42	4,801.76	1.47	6,855.96	2.1	-3,095.65	-0.95	2,054.21	0.63	-1041.45	-0.32	-49.59	-0.02
Grassland	26,306.13	8.05	12,761.38	3.90	7,319.01	2.24	-13,544.75	-4.14	-5442.37	-1.67	-18,987.12	-5.81	-904.15	-0.28
Built-up area	1,669.39	0.51	2,306.87	0.71	5,177.23	1.58	637.48	0.20	2,870.36	0.88	3,507.84	1.07	167.04	0.05
Shrub and bushland	60,229.88	18.43	30,959.53	9.47	26,520.76	8.12	-29,270.35	-8.96	-4,438.77	-1.36	-33,709.12	-10.31	-1,605.20	-0.49
Water body	35,019.66	10.72	34,708.17	10.62	34,213.71	10.47	-311.49	-0.10	-494.46	-0.15	-805.95	-0.25	-38.38	-0.01
Total	326,872.37	100	326,872.37	100	326,872.37	100								

The LULC changes observed during the two phases of the period (2002-2013) and (2013-2023) showed variations. In the first phase, the cultivated land expanded by 12.55%, while in the second phase, it only increased by 5.31%. Similarly, the bare land increased by 1.4% in the first phase but decreased by 3.64% in the second phase. On the other hand, grassland, shrub and bushland both decreased significantly in the first phase by 4.14% and 8.96%, respectively, as compared to the second phase.

The most notable changes in the CRV region's LULC between 2002 and 2023 were the expansion of cultivated lands and built-up areas and the reduction of shrubs, bushlands, and grasslands. This means that other land use and land cover types, such as shrubs, bushlands, and grasslands, were converted into these categories. The extent of these conversions is noteworthy, as it suggests a significant shift in the way land is being used in the CRV region.

The expansion of cultivated lands likely reflects an increase in agricultural activity, which could be driven by factors such as population growth, changing dietary patterns, and economic factors (Said *et al*., 2021). The conversion of shrubs, bushlands, and grasslands into cultivated lands may have involved practices such as deforestation and plowing, which can have negative consequences for biodiversity, soil health, and ecosystem services.

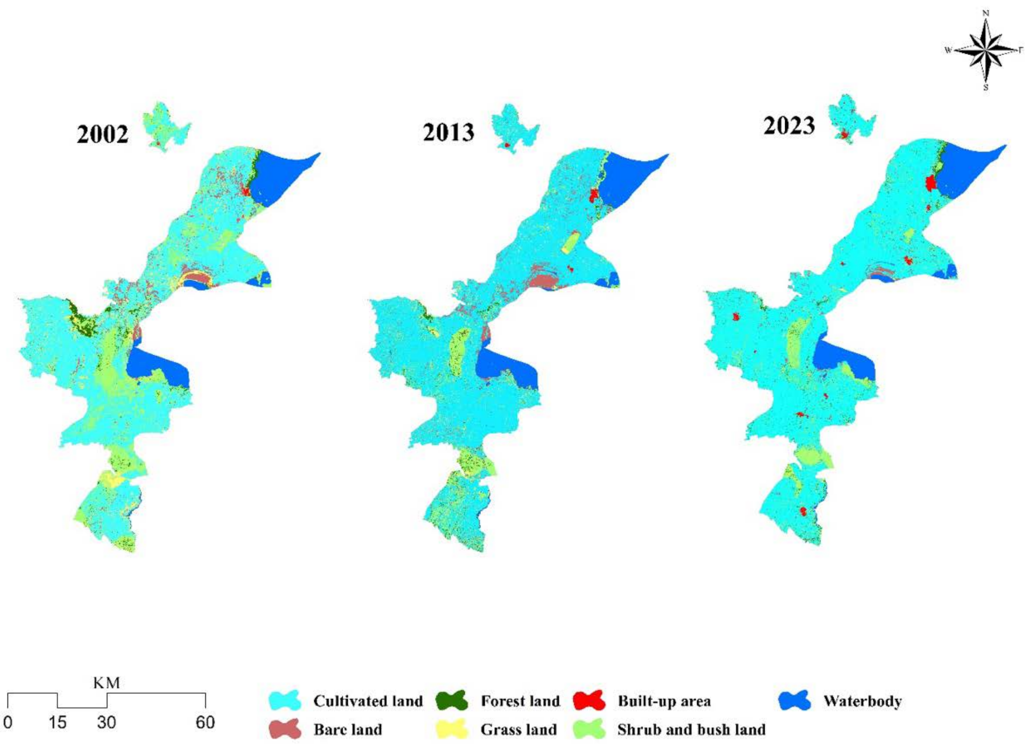

Figure 16. The LULC change map of 2002, 2013, and 2023 in the CRV region.

The growth of built-up areas, on the other hand, suggests an increase in urbanization within the CRV region. This could be due to factors such as rural-to-urban migration, settlement, and infrastructure expansion (Jellason *et al*., 2021). The conversion of natural land cover types into built-up areas can lead to habitat loss, fragmentation, and increased air and water pollution, which have implications for both mixed maize livestock farming and pasture for the livestock.

The gain-loss matrix presented in Table **8** indicates that the LULC in the study area has remained persistent and shifted over the last 21 years. The CRV region showed a significant change in the amount of LULC that experienced loss and gains during this period. Cultivated lands, shrubs and bushlands, and grasslands were the most prominent LULC classes in the study area. The diagonal entries in Table **8** show the proportion of LULC classes that remained unchanged between 2002 and 2023. Like other similar studies, it is found that all LULC categories remained relatively persistent during the study period. Around 66.3% of the area showed persistence, while the remaining 33.7% underwent a transition from one land use category to another. This indicates that change dominates the persistence in the study area.

Table 8. Gain and loss in LULC in the Central Rift Valley region (2002-2023)

	2002 area in hectares (percent)									
	LULC class	Cultivated land	Bare land	Forest land	Grassland	Built-up area	Shrub and bushland	Waterbody	Grand Total	Gain
2023	Cultivated land	163,920.36(50.15)	10,310.79(3.15)	4,537.05(1.39)	21,421.82(6.55)	912.81 (0.28)	39,968.82(12.23)	465.18(0.14)	241,536.84(73.89)	77,616.48(23.75)
	Bare land	1,772.08 (0.54)	1,382.45(0.42)	216.18 (0.07)	625.05(0.19)	36.24(0.01)	767.89(0.23)	448.12(0.14)	5,248.01 (1.61)	3,865.56(1.18)
	Forest land	2,786.22 (0.85)	73.38(0.02)	1,341.70(0.41)	622.61(0.19)	47.87(0.01)	1,948.24(0.60)	36.51(0.01)	6,856.52 (2.10)	5,514.83(1.69)
	Grassland	3,952.26 (1.21)	266.19(0.08)	282.86 (0.09)	1,137.01(0.35)	35.80(0.01)	1,615.92(0.49)	28.24(0.01)	7,318.27 (2.24)	6,181.26(1.89)
	Built-up area	2,581.88 (0.79)	343.99(0.11)	90.82(0.03)	456.25(14)	494.77 (0.15)	1,178.13(0.36)	31.30(0.01)	5,177.15 (1.58)	4,682.37(1.43)
	Shrub and bushland	8,165.11 (2.5)	175.66(0.05)	1,311.46(0.40)	2,039.15(0.62)	140.13 (0.04)	14,605.75(47)	84.76 (0.03)	26,522.02(8.11)	11,916.27(3.65)
	Waterbody	10.08(0.00)	9.44(0.00)	117.33 (0.04)	4.39(0.00)	1.77(0.00)	145.11(0.04)	33,925.68(10.38)	34,213.8 (10.47)	288.12(0.09)
	Grand Total	183,187.99(56.04)	12,561.90(3.84)	7,897.38(2.42)	26,306.28(8.05)	1,669.39(0.51)	60,229.87(18.43)	35,019.78(10.71)	326,872.37(100)	-

	Loss	19,267.63(5.89)	11,179.45(3.42)	6,555.69(2.01)	25,169.27(7.7)	1,174.62(0.36)	45,624.12(13.96)	1,094.10(0.33)	-	-

Cultivated land showed the highest persistence of 50.15%. However, this dominance was mainly due to its higher share in 2002, covering 56% of the study area. The highest gains (23.75%) were recorded in cultivated land, followed by shrub and bushland (3.65%), while the highest losses (13.96%) were recorded in shrub and bushland, followed by grassland (7.7%). Gains in bare land and cultivated land in the study area were likely due to substantial changes in other LULC transitions. This was mainly related to the loss of shrubs and bushland, and grasslands. The results are consistent with studies from other regions in the country, where cultivated lands are continually expanding at the expense of other land use/cover types, particularly natural vegetation (Alemayehu *et al*., 2019; Damtew *et al*., 2022). However, a study by Adugna *et al*. (2017) in North-Eastern Wollega reported the opposite, where agricultural land is abandoned and naturally rehabilitated to the existing environment.

Studies show that the increase in cultivated land in the country has a double-edged sword effect on livestock and biomass productivity (Mekuria *et al*., 2021). While increased farmland might suggest more fodder for animals, the reality is often a decline. Conversion of shrub and bushland, crucial grazing areas for livestock, into cropland leads to habitat loss and reduced availability of nutritious browse and grazing species (Fenetahun *et al*., 2019; Habte *et al*., 2020). This shrinks the grazing land base, forcing animals onto already stressed grasslands, leading to overgrazing and degradation (Bekele *et al*., 2021). Furthermore, the loss of vegetation cover reduces biomass production, a vital source of animal feed during dry seasons (Sintayehu *et al*., 2020). Moreover, the loss of woody vegetation disrupts nutrient cycling, jeopardizing long-term soil fertility and the ability to sustain both crops and livestock (Archer *et al*., 2017). Therefore, while agricultural expansion might hold promise for food security, the consequences for the livestock sector must be considered. It will be important to encourage sustainable grazing practices and careful planning of livestock feed production at landscape scale to avoid jeopardizing the very foundation of Ethiopia's livestock sector and the critical ecosystem services provided by biomass.

There are opportunities for project intervention in the Central Rift Valley of Ethiopia, which has the opportunity to tackle critical LULC changes. By understanding the drivers of deforestation and degradation, like population growth and agricultural expansion, interventions can promote sustainable land management practices (Gebretsadik, 2018). This could involve introducing techniques like crop rotation and terracing to reduce soil erosion. Additionally, projects could focus on reforestation efforts and community education to raise awareness about the importance of preserving natural habitats. Working with local stakeholders, project interventions can create a win-win scenario, balancing economic development with environmental sustainability in the Central Rift Valley region of Ethiopia.

5.8.2. Implications of impacts of LULC change on the sustainability of mixed maize-livestock system

Addressing land cover change challenges in Ethiopia's CRV region requires a multi-pronged approach. One crucial strategy is the implementation of sustainable land management practices, such as crop rotation, terracing, and rainwater harvesting (Telles *et al*., 2022). These techniques can help improve soil health, increase vegetation cover, and reduce erosion. Additionally, promoting reforestation efforts with native species and incorporating trees into farmlands (agroforestry) can enhance biomass production and create vital grazing corridors for livestock. Furthermore, investing in research and developing drought-resistant forage crops can ensure animal food availability year-round. Finally, strengthening land-use planning and policy reforms is essential. This includes zoning regulations to limit unchecked expansion of built-up areas and incorporating community participation in land management decisions to foster a sense of ownership and encourage sustainable practices (Halecki *et al*., 2023).

The changes in LULC have significant implications for mixed maize-livestock farming, which is a common agricultural practice in the CRV and Hawassa Lake Basins (Gebremedhin *et al*., 2007). The expansion of cultivated lands may provide more land for maize production, but it could also come at the expense of the availability of grazing land for livestock. This could lead to challenges for farmers in maintaining the balance between these two components of their mixed farming systems.

Over the past 21 years, the CRV region has experienced a significant increase in the size of cultivated land by about 2,778.56 hectares per year and an increase of about 167.04 hectares per year in the built-up area (Table **7**). This implies that there has been a high population pressure and movement to urban areas in the region. Similarly, high population pressure outside the region and the allure of opportunities in urban areas are driving a movement trend away from the CRV region (Kabiso *et al*., 2022). This rural-to-urban migration can have a complex impact. While it may alleviate some pressure on the region's resources, it can also strain the capacity of urban centres and reduce the agricultural workforce in the CRV, potentially impacting food security and the local economy. The other reason for the expansion of the cultivated land could relate to the expansion of irrigation in the study area, which has been a common agricultural practice in the CRV areas. Unfortunately, this expansion of the cultivated land could result in soil degradation - one of the area's biggest challenges for mixed farming systems. The cultivated land has been subjected to continuous operations, leading to soil nutrient depletion and, ultimately, the need for more land to enhance crop production.

On the other hand, the grassland, shrub and bushlands decreased by 904.15 hectares per year and 1,605.2 hectares per year, respectively, in the study area from 2002 to 2023 (Table **5**), implying a reduction of forage and fodder for livestock. This implies the decrease in biomass production and livestock productivity as grassland, shrub and bushland sources feed to grazer and browser animals in the CRV and Hawassa Lake Basin areas. The shrinkage of the grassland, shrub and bushlands also suggests overgrazing has been the other challenge in the region, which contributes to soil degradation and nutrient depletion. Moreover, the expansion of cultivated land in ecologically sensitive areas and the demand for additional grazing areas due to the shrinkage of the grasslands, shrubs and bushlands could be linked to damage to the ecology and ecosystem services of the study area. As a result, it may have complicated the mixed maize-livestock system in the CRV and Hawassa Lake Basin areas.

5.8.3 Current challenges and future potential scenarios of the LULC changes

Observing the LULC changes, the rate of change, and the gain-loss trends over the past two decades in the CRV region, current land use land cover related challenges such as loss of natural habitat, land degradation, unsustainable land use practices, and high rate of change over cultivated lands and grasslands can be pointed out. The indicator for the loss of natural habitat was the high level of decline in shrub and bushland (10.31%) and grassland (5.81%) that can be linked with the conversion of these ecosystems to other uses, potentially impacting biodiversity and ecosystem services. The increase in bare land by 3.64% between 2013 and 2023 could indicate land degradation, which can lead to decreased soil fertility, reduced water infiltration, and increased dust storms in the study area. The rapid expansion of cultivated land by 17.85% between 2002 and 2023 might raise concerns about unsustainable agricultural practices that could deplete soil nutrients and water resources in the long run, which are indicators for unsustainable land use practices.

Predicting the future is complex and depends on various factors. However, based on the observed LULC trends of the past two decades, some potential future scenarios could emerge. The expansion of cultivated land and shrinkage of grasslands often results in soil degradation and decreased productivity for the mixed crop-livestock system in the region. Hence, the first potential scenario will be business-as-usual. If current trends continue, we might see further loss of natural habitats like shrub and bushland, forests, and grasslands, leading to environmental degradation and biodiversity loss. Additionally, land degradation and unsustainable agricultural practices could become more prominent. Due to these circumstances, the implementation of sustainable natural resources management will be the other future scenario of LULC changes in the CRV and Hawassa Lake Basins. With a focus on sustainable natural resources management, policies and practices could be implemented to protect natural habitats**,** combat land degradation, and promote sustainable agriculture. This scenario could involve promoting practices like agroforestry, land rehabilitation, efficient water management and other climate-smart agricultural practices.

The other future scenario of the LULC change in the CRV region and Hawassa Lake Basins will be linked with policy and technological advancements in the region. Technological advancements in agriculture and land use management, coupled with effective policies, could lead to increased efficiency and reduced pressure on natural resources. This potential scenario could involve precision agriculture, introduction of improved crop varieties, and stricter regulations to ensure sustainable land use practices

5.9 Characterization of landscape management

5.9.1 Drivers of land degradation

Tree cutting and clearing of remnant forest for fuel wood and construction are the main problems widely experienced in Hawassa Zuira and other *woreda*s in the CRV. According to KIIs, there was no replacement planting during the past few decades. Fritzsche *et al*. (2007) attributed the environmental change in the CRV region of Ethiopia to human activities. The main drivers of degradation are population growth, conversion of vegetation into farmland, and increasing short-term socio-economic needs (Mekuria et al., 2024). Bekele *et al*. (2019) also specified the main drivers of LULC change such as fuel wood extraction, overgrazing, charcoal making, and climate change. Meshesha *et al*. (2012) also pointed out that high livestock population growth as compared to the carrying capacity of land and application of improper agricultural practices contribute to LULC change. The problems are further aggravated by climate change and the underdevelopment of market and rural infrastructure that consistently affect the livelihoods of the farmers.

Failure to strictly implement the communal land management rule gives way to persistent deforestation and overuse of available resources. As cited earlier, the consequence of deforestation accelerates erosion, and floods from the surrounding watershed, mainly from the eastern and western escarpments of the CRV and Hawassa Lake Basins. In severe cases, it exacerbates gully formation and siltation in the valley bottom. The deforestation and intensive charcoal production currently experienced in Adami Tulu Jido Kombolcha *woreda* are reminiscent of insecurity reigning in the areas that largely aggravate the biophysical problems.

The fragile sandy loam and clay loam soils in the CRV and Hawassa Lake Basin area give ways for gully formation that reduce the size of farmland along the erosion/flood lines. Overall, yield reduction and livestock feed shortage are the common issues experienced because of the increasingly growing land degradation and climate change. Despite the area-exclosure adopted in some hillside areas (Figure 17), the need for grass for roof thatching, and livestock feed shortage because of climate change and extended dry season accelerate the encroachment and overuse of the protected areas. Landscape alteration is attributed to population growth. According to the expert group discussion, population growth is concurrent with religious traditions that promote polygamies such as in Shala and neighboring *woreda*s.

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Figure 17. Area exclosure along the hillside in Lebu Koromo *kebele*, Hawassa Zuria.

5.9.2 Commonly applied landscape management practices

Physical soil and water conservation (SWC) is the main approach and strategy pursued to arrest the prevailing issues of land and water movement and allows *in situ* moisture conservation. Therefore, in terms of importance, the community widely uses physical SWC structures to manage natural resources. Since recent years, this is followed by tree planting through initiatives such as the *green legacy,* and area exclosure. Integrated Soil Fertility Management (ISFM) and agroforestry practices are also regenerative and environmentally friendly practices suggested by respondents of KIIs, in that order. Furthermore, to promote *in situ* water harvesting during plenty time, farmers use family ponds, flood diversion ponds and different water harvesting technologies/practices such as cut-of-drain, level bunds with tie ridges, level fanya juu, half-moon terraces, gabions and trench in the hilly *kebele*s of Misrak Miskan, Sankura, Shala, Hawassa Zuria and the other study *woreda*s. Flood diversion pond and protection dikes are important structures in the valley bottom of Sankura and Wera Dijo *woreda*s. The use of conventional practices such as digging *Dichire* for *in situ* moisture conservation and flood protection associated with biological barriers is suggested as good practice in Sankura *woreda*. To ensure the reliability and sustainability of the conservation practices, smallholders understanding need to be improved so that the effects of erosion and run-off can be minimized. As a future strategy, promoting further area exclosure in hillside common lands, strengthening its protection, and intensifying tree planting as part of the government policy is commendable.

Public mobilization has been employed as an *ad hoc* project organization to engage and benefit free labor once a year for one month (Leta *et al*., 2018a). However, in most cases, annual watershed management *nikinake* is a nominal activity politically motivated and receives public attention among several development and political actors. Logically, the campaign repeatedly targets more of a common land as compared to the individual farmlands (Figure 18).

Figure 18. Physical structures placed on common land year and again.

Furthermore, repetition of the same technology /practice year and again on the same farmland but reported as a new activity is the most common experience. Whereas, combining biological barriers to the physical structure, the so-called biophysical lacks focus and sustainability. A harsh climate, free grazing, and non-strict system adopted to safeguard the managed site affect the sustainability. Smallholders also make unreserved efforts to protect their farmland. For instance, they plant elephant grass, sugarcane, and banana along the flood line to reduce the speed of flows, stop gully formation and its expansion that eat to the heart of the farmland, and to effectively use the available moisture (Figure 19).

Figure 19. Elephant grass and sugarcane planted to protect flood and gully expansion.

As part of land management practice, considerable areas of land were put under area exclosure in all study *woreda*s. The largest is in Shala *woreda* where 6,207 hectares of land put under area exclosure in ten micro watersheds. In these area community based organization formed to protect and benefit from natural resources. Smallholders in the region are aware of the benefits of area exclosure. However, the shortage of firewood and pastureland remains a challenge to its sustainability (Tilahun *et al*., 2016). A prototype approach that build resilience to climate change is the youth groups formed in Lebu Koromo *kebele* of Hawassa Zuira to access degraded land for rehabilitation and use. As a result, they rehabilitated the gully area by planting *Napier grass*. Apart from reclaiming the degraded land, they benefited from cutting and selling the grass as livestock feed. Such an approach is a model that inspire unemployed youth groups to engage and simultaneously rehabilitate gully and generate income.

As described in an earlier section, watershed management activities have been implemented at the community level by engaging different categories of the community inclusive of gender and age categories since 1998. Individual farmers also implement various practices on their farms collectively or on their own. However, sustainability is challenging because of the free grazing system, and inadequate awareness that is associated with intentional dismantling of the structures (Leta *et al*., 2019). As a result, the degree of erosion, runoff and land degradation does not that subside to the extent expected regardless of human labor and technical investments for decades now. Challenging encroachment and stealing of the grass from the common land or area exclosure is compounded by extended drought and shortage of livestock feed.

5.10 Agribusiness opportunities and sources of finances for women and youths

Women and Youth prefer irrigable vegetable production, poultry, and fattening of sheep and goats as an agribusiness opportunity to generate income. However, access to farmland and loans affects their efforts. In Hawassa Zuria *woreda*, there are several youth groups formed to engage in business enterprises. However, lack of access to loans halts their efforts. Omo Micro Finance was the potential institute to provide loan services in the Sidama and Central Ethiopia region but it stopped extending its usual services because of a lack of financial resources. According to the community FGD, the microfinance institute encountered a financial deficit. Neither Omo nor Sidama Bank provides loans for women and youths for business creation at this particular time.

5.11 Innovation and best practices to transform the mixed crop-livestock system

Innovation is the process of applying new or existing knowledge in different forms and contexts to do something better than it currently appears (World Bank, 2012). Essentially, innovation is not entirely an impeccable venture or a panacea against the multifaceted problems of smallholders. There might be some limitations. The adoption and widespread use of technologies or innovations can be challenged by various factors notably access to financial resources, farmers literacy level, level of awareness, interest and motivation of smallholders to uptake the innovation, and a significant commitment and knowledge about crops and livestock. However, the adoption, incremental and effective use of new best practices or innovations can bring a shift in conventional practices, and reduce uncertainty. As compared to the extent of benefit it provides, the use of innovation/technologies in mixed crop-livestock system may relegate the application and use of organic inputs such as manure. Also, promotion of specialization and crop intensification advises judicious use of chemical fertilizers, and other agrochemicals to control or manage disease and pest outbreaks.

Regardless of the various features it may comprises, adopting innovation and technologies promotes a mixed crop-livestock system. The intensification such as in livestock realized via breed improvement, reduce the number of livestock to match with the supporting capacity of available and accessible feeds. However, intensive farming often cause soil and environmental degradation (Sekaaran, 2021). Therefore, integrating and striking the balance between adopting innovations vs. agricultural intensification could play a significant role in mitigating the anticipated repercussions. For instance, the conversion of livestock manure into vermicompost simplify the use of organic fertilizers in intensive farming. Despite some envisaged challenges, modernizing the mixed crop-livestock system through adoption of innovation is indispensable. Hence, adoption of innovations fitting to the mixed crop-livestock system believed to maximize smallholder's returns from their limited cropland area and resources. A specific list of technologies suitable for the CRV and Hawassa Lake Basins are profiled in the Appendix section of this report. In Table 10 below, we briefly present suitability of the technologies suggested for intervention. The lists of interventions are believed to assist in transforming the mixed maize-livestock systems.

Table 10: Technologies/ practices suggested as intervention for transforming mixed crop-livestock system in the CRV and Hawassa Lake Basins.

Project	Technologies / practices	Technology Suitability by *Woredas*					
		Misrak Miskan	Sankura	Wera Dijo	Shala	Adami Tulu Jido Kombolcha	Hawassa Zuria (Dore)
Ukama Ustawi (UU)	Minimum Tillage	√	√	√	√	√	√
	Vermicompost	√	√	√	√	√	√
	Crop rotation	√	√	√	√	√	√
	Intercropping	√	√	√	√	√	√
	Solar Pumps for irrigation	√	√	√	X*	√	√
	Area exclosure	√	√	√	√	√	√
	Agroforestry	√	X	√	X	X	√

*marks unsuitability of the technology for specific site.

5.11.1 Climate Smart Agriculture technologies/ practices for crop production

In the CRV and Hawassa Lake Basins of Ethiopia, climate change is severe with an increasing reduction in the resilience capacity of the community residing in the area. Pereira (2017) reported the declining adaptive capacity of the community to climate change/climate variability in Africa. As over 85% of Ethiopians are an agrarian society, recurrent drought, and climate variability are an episode often faced and detrimentally affect the livelihoods of the community. The problem is more severe in the CRV and Hawassa Lake Basin areas. Climate-smart agriculture is an alternative agricultural practice that assists in developing the resiliency capacity of the community against climatic adversity (Ngara, 2017). Sound science and practice, and proper investment in agriculture are vital in developing resiliency against the looming change and challenges owing to demographic changes, associated needs and climate changes that trigger fierce competition for land and water (Herrero et al., 2009).

The introduction and adoption of CSA practices are vital to develop resilience against climate change. In the study areas, as an adaptive practice, the local community diverts the sudden flood to their farm to use for spate irrigation and growing perennial crops such as sugarcane and banana (Figure 20). Since the sediment buries the small cereal crops, farmers opt to grow larger crops. In addition, when short rain intercepted, the farmers learned to plant resilient crops such as Orange flesh sweet potato, Irish potato, haricot beans, and tef. These crops are relatively hardy, fast maturing, and are tolerant to moisture deficit. Therefore, crops with short phenology are planted to evade the shortage of rainfall. Apparently, shifting the crops from Maize to others during unreliable rainfall period serves as an alternative to food insecurity owing to crop failure.

Even then, most smallholders are looking for early maturing and adaptive varieties of maize rather than resorting to crops other than the staple maize since it is the common staple food crop to most people residing in the CRV and Hawassa Lake Basins. Therefore, the use of drought-tolerant germplasm, adaptive livestock species, crop and livestock diversification, and intensive use of agronomic practices such as intercropping, crop rotation, and integrated soil fertility management practices increase productivity and stability of production, and reduce risks of failure.

Strong institutions in agricultural extension advisory services, knowledge and information sharing, and products linkage to lucrative and sustainable markets are essential. Furthermore, meteorological information is of paramount importance to the smallholders inhabiting the CRV and Hawassa Lake Basins. Accessing information and early warning via relevant institutions enable the farmers to prepare themselves against the anticipated threats by putting in place protective measures such as digging cut-off-drain, building protection dikes, and check dams.

Figure 20. Sugarcane production using flood diversion (spate irrigation).

Introducing and nurturing ISFM technologies, and strengthening intercropping haricot beans within maize, which is in fact less common in Misrak Miskan and other study *woreda*s in the three regional states is essential. Integrated Soil Fertility Management technologies and other agronomic practices such as vermicompost and crop rotation are also useful technologies/innovations to be adopted and scaled out in the region. Ali *et al*. (2023) also documented ISFM, conservation agriculture, and soil and water conservation practices as the main CSA practices in the CRV and Hawassa Lake Basins of Ethiopia. Also, intercropping as an agronomic practice not only improves soil fertility but also avoids risks of crop failure. As an environmentally friendly good practice, farmers in Sankura *woreda* learned to divert flood or erosion to their farm and drain out when it is surplus in the farm. This has both the inlet and outlet to and out of the farm. In irrigation farming, adopting precession agriculture that allows saving water and the use of stress-tolerant early maturing varieties of crops, scheduling proper irrigation timing, and the use of mulching are some of the beneficial practices that increase adaptation to climate change (Tran *et al*., 2019).

As a regenerative practice to the prevailing climate change and climate variability, respondents in Shala *woreda* stated the importance of introducing early maturing, pest and disease, and drought tolerant high-yielding varieties of crops. Specifically, respondents suggested Melkassa-ii is a good maize variety under drought conditions whereas pioneer varieties such as Limu and Shone are the best under ideal climates. In expert and community focused group discussions, the desirability of suitable germplasm was reiterated. However, the paradox lies in farmers' preferences. They used to seek a variety of crops that do well under good conditions regardless of the drought they are frequently experiencing in the recent years. Likewise, in Sankura *woreda*, *Meher* season, wheat production is challenged by rust when climate change and drought are experienced. The wheat variety known as Kingbird is more tolerant to the rust outbreak. However, regardless of the beneficial traits of Kingbird, farmers are excited to have Ogolcho and Qaqaba varieties, which were devastated by rust during the previous seasons but do well under ideal condition.

As communicated in Shala *woreda*, farmers highly need maize for food. About 70% of haricot beans are produced for market as sources of cash income. Hence, despite the early maturing and resilience of beans to climate change, farmers grow less of this crop as a replacement crop during the time of adversity. Monocropping of maize is therefore a challenging tradition that halts shifting the cropping practices from the conventional to the resilient ones.. Their high-yielding traits per unit area during good seasons and less disease incidence won the hearts and minds of smallholders.

As exchanging the crop types makes both humans and livestock beneficiaries under unfavorable climates, changing the mindset of farmers is important to assist them in adopting a resilient variety of crops and CSA practices to avoid risky ventures. The following practices are suggested as crop-related CSA to optimize resilience to climate change and related challenges:

i. Introduce and scale out the use of organic fertilizer such as vermicompost and FYM.

ii. Application of crop rotation that enables improving soil structure and fertility, minimizes disease outbreaks, and improves resilience to adverse climate.
iii. Implement intercropping that is believed to reduce risks of crop failure and improve soil fertility
iv. Crop diversification to improve the productivity of the main crops and ensure food and nutrition security through diversifying household diet, and
v. Adopt and implement conservation agriculture as well as minimum tillage practices that promote moisture conservation.

Climate-smart agriculture technologies / practices for livestock production

In similar trends to crop CSA, experts suggested important livestock production-related CSA in the group discussion. Breed improvement via the introduction of improved breeds of cattle, and continued keeping resilient and highly productive local sheep and goats under adverse circumstances were noted as vital. Promoting crossbreed cattle, reducing the livestock population, and intensifying the management practice are also commendable. Essentially, maize stover is collected and preserved well on the farm and at the homestead in all the CRV and Hawassa Lake Bains (Figure 21). However, feed treatment to increase its palatability is largely missing. The following lists of recommendations merit adoption and scaling out to foster adaptation against climate change and associated problems.

i. Intensify goat breeding as goats are more adapting to climate change and feed shortage as compared to the other animals. Goats can rely on browsing different vegetation. Under harsh weather conditions, their lightweight has less repercussion on detaching the fragile soil even if they are kept and driven from place to place in large numbers.
ii. Breed improvement, reduce the number, increase productivity, and make livestock production friendly to the environment and available resources.
iii. Introduction and intensification of improved fodder production and use under rainfed and irrigated agriculture by increasing smallholders awareness on the economic benefits of producing fodder and its seed for use and marketing.
iv. Apart from proper harvest and storage, the application of appropriate management and/or treatment practices using different techniques and inputs is believed to improve the intake of crop residue, and
v. Awareness raising on the different livestock production techniques is equally important to build the resilience of smallholders in the study *woreda*s.

Figure 21. Preserved crop residue (maize stover) for livestock feed.

5.11.2 Strategy to transform and ensure sustainability of mixed crop-livestock system

In the CRV and Hawassa Lake Basins, a mixed crop-livestock system is conventionally implemented. Beneficial agricultural practices are barely integrated into the system. According to FGD and KIIs, few practices associated with the farming system in a disintegrated manner. Rather, the maize-based monocropping system is the mainstream practice that may have less contribution to transforming the mixed system and ensuring its sustainability. Nurturing a tradition of integrating three or more innovations and agricultural inputs simultaneously on the same farm improves soil nutrients, soil health, and system productivity in general. Therefore, combining different innovations by temporal and spatial sequences could create synergy and ensure the sustainability of the mixed system.

In the CRV and Hawassa Lake Basins, the intercepted bimodal rainfall creates an enabling environment to rotate the short rain crop with long rain under consistent conditions. Deviation of the seasonal cycle can still be bridged by applying relay intercropping during the later stage of the main rainy season. Overall, a strict combination of agronomic practices (such as minimum tillage, crop rotation, and intercropping), and vermicompost production and use along with other recommended agricultural inputs could improve soil health and production on a sustainable basis. Thus, the combined use of resilient agronomic practices is believed to increase production, and remain friendly to the environment and ecosystem.

On top of promoting the use of organic fertilizers (such as the use of vermicompost, improved compost, and farmyard manure), introducing proper management and use of crop residue reduces the depletion of soil organic matter that is prompted by continuous mining and overuse as livestock feed, fuel, and for other purposes. Interventions comprising a comprehensive approach and technologies believed to arrest and reverse the prevailing situations (see lists of profiled technologies/protocols in the Appendix).

Another innovation with overlaying component technologies friendly to the landscape in the upstream-downstream relation is the application of area exclosure. Promotion of its integration with physical soil and water conservation structures, enrichment tree planting, over-sowing with nutritious grass or legume fodder species, and beekeeping create ecological, economic, and social benefits to the resident community.

Solar pump for irrigation is another environmentally friendly technology that can serve as an alternative to promote irrigation development in water-stressed areas of the CRV and Hawassa Lake Basins. Essentially, the basins are characterized by unreliable crop-growing seasons due to recurrent droughts experienced in the area. Integrating practices by introducing annual and perennial crops could boost the return accrued from irrigation and a mixed crop-livestock systems. In the irrigated area, intensification of trees and fruits (such as in agroforestry), production of fodder and food crops, and the best use of power and manure from the livestock increase the benefit from the mixed system.

6. Conclusion and recommendations

This particular study aims to characterize distinct maize-based mixed farming systems, identify the key components, their interactions, and core innovations with the potential for system transformation in the mixed crop livestock system. The CRV and Hawassa Lake Basin features similar biophysical and socio-economic conditions. It shared similar landscape, crop and livestock types, climate conditions, and vegetation covers. Recurrent drought is common every other four years. In recent years, however, the trends have shifted to prolong the drought periods. The region features relatively homogenous mixed crop-livestock system. Maize is the main staple food crop followed by wheat, haricot beans and tef. Hot pepper is the cash crop widely grown in the six study *woreda*s. Cattle is the leading animal in terms of the number and services it provides followed by goats, sheep and equines. Under normal conditions, the region intercepts bimodal rainfall that allows double cropping a year. However, the erratic and erosive rainfall experienced in the region strongly challenging smallholder crops and livestock production.

Recurrent drought experienced over subsequent years is associated with several crop and livestock production problems. Crop and livestock disease, pests, and invasive birds were among other factors contributing to crop failure and shortage of livestock feeds. Apparently, maize stover is the main livestock feed. Therefore, feed shortage linked directly with crop failure.

Biophysical problems are also common because of increasing human and livestock populations, encroachment and forest clearing for farming, construction, charcoal production, overgrazing, and application of improper agricultural practice. These further aggravated by climate change that is often associated with drought, torrential rainfall with resultant erosion, flood, gully formation and mass movement of the detached fragile soil from the upland to the valley bottom. As a result, land degradation are so rampant threatening the future of inhabitants.

Apart from the climate change and associated problems, shortage of agricultural inputs particularly suitable germplasm and chemical fertilizers are the challenging issues. In addition to inaccessibility, the soaring prices of agricultural inputs, and shortage of financial resources to invest in inputs and groundwater development to expand irrigation agriculture as an alternative farming during the off-season are among numerous problems. Thus, the multifaceted problems limit building resilience against climate change and related adversity.

Based on the findings, we suggest the adoption and widespread use of crop and livestock-related climate-smart agricultural practices in the mixed system allow resilience building. Adopting and nurturing appropriate mixed systems builds synergy, and plays a complementary role to one another in investment and agri-food systems. Also, the integration transiting family farmers during difficult years. In addition to adopting proven innovation and best agricultural practices that match with the agroecology and emerging problems, the use of solar pumps, area exclosure, vermicompost, minimum tillage practice, intercropping, crop rotation, crop diversification, and intensification of agroforestry in suitable agroecology are vital for the project intervention.

Livestock-breed improvement with the introduction of improved fodder species and good management practices are commendable. The introduction of resilient and tolerant germplasm to climate change, pests, and disease is essential for farmers to have resorts, and growing adaptation to climate changes. Furthermore, enabling smallholder access to irrigation facilities, improving their skills and knowledge through training and experience exchange visits for operating irrigation technology, and implement proper irrigation schemes and water management are vital. Also, intensifying natural resources management practice mainly through area exclosure with a commitment to ensure its sustainability assists in developing coping mechanisms against the actual and imminent threats of climate change. Linking farmers' produce to a sustainable market source is another important requirement to reduce the impact of crop and livestock market failure, improve livelihoods, and build farmers resilience against emerging changes and challenges.

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8. Appendices

Appendix Table 1. Description of used satellite images

Satellite/ Sensor	Path/Raw	Acquisition date	Year	Spatial resolution
Enhanced Thematic Mapper +	168/055 168/054 169/055	26/02/2002 25/02/2002 01/02/2002	2002	30*30m
Operational Land Imager (OLI)	168/055 168/054 169/055	01/12/2013 01/12/2013 08/12/2013	2013	30*30m
Operational Land Imager (OLI)	168/055 168/054 169/055	20/02/2023 20/02/2023 20/02/2023	2023	30*30m
Sentinel		2023-06-04 2022-11-03	*Meher* Planting *Meher* Harvesting	10*10m
Sentinel		2023-02-01 2023-10-05	*Belg* Planting *Belg* Harvesting	10*10m

Source: https://earthexplorer.usgs.gov/ and https://www.copernicus.eu/en/access-data/conventional-data-access-hubs

Appendix Table 2. Accuracy assessment matrix of the image classification

Reference Data of 2023									
Classified Data	Cultivated land	Bare land	Forest land	Grassland	Built-up area	Shrub and woodland	Water body	Row Total	User Accuracy
Cultivated land	46	1	0	1	1	1	0	50	92.0
Bare land	1	44	1	1	2	1	0	50	88.0
Forest land	1	3	40	0	1	3	2	50	80.0
Grassland	2	2	0	41	1	2	2	50	82.0
Built up area	2	0	2	2	42	1	1	50	84.0
Shrub and woodland	1	3	0	1	0	45	0	50	90.0
Waterbody	1	0	1	0	1	0	47	50	94.0
Column Total	54	53	44	46	48	53	52	350	
Producer Accuracy	85.19 %	83.02 %	90.91%	89.13%	87.50 %	84.91%	90.38 %	350	
Overall Classification Accuracy						0.87143			
			KAPPA	0.882986627					

Appendix Table 3: Ground Control Points (GCP) data in the five study woredas and kebeles

SN	Woreda	Major land use	Latitude (DDM)	Longitude (DDM)	Elevation (m)	Remark
1	Hawassa Zuria	*Woreda* Office	7⁰ 2'9.906"	38⁰ 21' 32.628"	1721	*Woreda* office of Agriculture
2	»	Kebele office	7 6 2.46	38 22 57.978	1717	Farmers Training Center (Mekbasa Korke)
3	»	Maize plot	7 6 5.244	38 22 49.2	1724	Harvested maize plot, Mekbasa Korke *kebele*
4	»	*Kebele* office	7 3 5.316	38 21 12.99	1693	Lebu Koromo *kebele* office/FTC
5	»	Harvested maize plot	7 3 3.546	38 21 10.254	1689	Lebu Koromo *kebele*.
6	»	Area exclosure	7 2 59.995	38 28 41 726	1810	Lebu Koromo *kebele* area exclosure.
7	»	Irrigated farm	7 1 34.07	38 28 6.238	1670	Vegetables farm in Jara Hinessa *kebele* .
8	»	Kebele office	6 59 6.124	38 24 31.926	1682	Jara Hinessa *kebele* office.
9	»	Khat (chat) farm	6 58 21.072	38 24 29.118	1704	Converted farmland from hot pepper to Khat.
10	»	Land Management	6 58 23.892	38 24 21.612	1747	Hillside terrace and area exclosure.
11	Shala	Land Management	7⁰ 16'43.458"	38⁰ 21' 41.364"		Arjo *kebele*: area exclosure and physical soil and water conservation structure.
12	»	Maize stable and crop residue	7 17 19.032	38 24 56.94	1663	Bekele Daya *kebele*, hips of maize stover and harvested maize plot.

13	»	*Woreda* Office	7 17 41.586	38 21 13.866	1895	Shalla *Woreda* Office of Agriculture.
14	Sankura	Irrigated maize farm	7^0 28′19.062″	38^0 8′ 36.27″		Jata kebele irrigated maize farm and other perennial crops such as banana & fodder.
15	»	Area exclosure	7 29 10.506	38 5 50.659	1881	Bonesha *kebele* near Bilate river.
16	»	River Diversion	7 29 23.616	38 5 17.658	1884	Bilate river diversion point and canal
17	»	Land management	7 28 4.338	38 7 30.618	1879	Trench in tef plot, Regdina Kore *kebele*.
18	»	Area exclosure	7 27 30.774	38 7 43.98	1855	Regdina Kore *kebele*, beekeeping integrated.
19	Misrak Meskan	Maize farm	8 5 46.398	38 23 15.044		Harvested maize plot in Bati-Lejano *kebele*.
20	»	Solar pump	8 5 45 .024	38 25 50.226	1847	Dobena- Gola *kebele* (Mr. Ibrahim Redi).
21	»	Irrigated coffee/ banana	8 5 36	38 25 50		Dobena Gola *kebele* (Dirshaye Gute farm using solar pump technology).
22	»	Irrigated tomato	8 6 7	38 26 6		Dobena Gola *kebele*.
23	Wera Dijo	*Woreda* Office	7 27 56.968	38 13 32.046	1983	*Woreda* capital (Beshano) since 2019.
24	»	Maize plot	7 30 1.698	38 16 17.352	1179	Bando-Choloksa *kebele* (Harvested sample plot).
25	»	Flood diversion community pond	7 30 4.308	38 16 43.054	1783	Bando *kebele* (constructed by GCF project).

26	»	Flood protection Dike	7 33 54.486	38 14 57.96	1791	Simbita *kebele* (flood protection dike) borderline with Simbita Warabe *kebele*.
27	»	Solar pump	7 33 58.722	38 15 3.138	1780	Irrigated cabbage production in Simbita *kebele* (Mr. Dubala Hasan farm).

9. Profiling of priority interventions/technologies

Intervention 1. Minimum tillage

Minimum tillage is a method of establishing crops with minimum soil disturbance, in contrast to conventional tillage involving plowing or other cultivation practices. It is a tillage practice aimed at creating a favorable soil environment for germination, establishment, and plant growth with minimal soil disturbance. It reduces or avoids full plowing operations (MoA & CDE, 2016).

Therefore, minimum or reduced tillage practice plowing the whole field as lightly as possible, just to break up hard pans or compacted layers and facilitate the germinability. This can be used with crops such as haricot beans, potato, tef or wheat (MoA & CDE, 2016). Furthermore, minimizing tillage reduces the oxidation of soil carbon, leading to higher soil carbon contents and increased water and nutrient holding capacity (Burgess *et al*., 2019). As stated by Leta *et al*. (2020), minimum tillage coupled with line seeding, intercropping, and management of crop residues yielded multiple benefits such as mitigating the risks of soil loss to flash erosions, reduced decomposition of organic matters and promote carbon storage.

Conventionally, frequent tillage is common land preparation practices. However, it subjects the soil to splash, rill, and gully erosion. The emerging mechanization services reduce tillage frequency that enable farmers to take up the minimum tillage practices including by oxen.

Suitable types of minimum tillage is till-plant system:

- Tillage and planting are done in one operation.
- This method is most suitable on sandy loam soils with mechanization.
- This operation is ideal for large cereals, and large seeded legumes.

Advantage:	Disadvantage:
• Cost effective and time saving in field operation. • It reduces frequent soil disturbances and exposure to wind and soil erosion. • Reduces soil decomposition rate and emission of carbon back to the atmosphere. • Good in clay and clay loam soils where it is difficult to create optimum condition in the seed zone. • Reduced soil temperature and increase soil moisture in some soil types.	- Lack of mechanization, as well as high operational cost. - Weed infestation. - Problem of germination for small cereals such as tef. - Low awareness and lack of trust by smallholders.

Intervention 2. Vermicompost

Vermicompost is the product of the decomposition process using various species of worms (https://qcat.wocat.net/en/summary/7103/). Vermicompost is one of the ISFM technology packages. This compost is known as humus and is produced through worms digesting and excreting organic matter (Figure 22). Earthworms are very good at transforming dead plant materials and livestock manure into excellent humus. The excrement of the worms has high nutrient levels and a growth-promoting effect on the plants (Organic Exchange, 2009). During preparation, there is no heating phase, which would kill the worms. Earthworms are very sensitive to changes in **moisture** and **temperature**. They need a continuous supply of food and protection from ants, birds, and chickens. Compared to ordinary compost making, it needs maximum precaution and care.

Vermicomposting is the process by which worms are used to convert organic materials (usually wastes) into a humus known as vermicompost. The process is an aerobic, bio-oxidation, non-thermophilic process of organic waste decomposition that depends upon earthworms to fragment, mix and promote microbial activity.

Figure 22. Vermicompost production. Photo: Gerba Leta

Earthworm culturing procedures

Build or purchase a worm bin:

The worm bin is the enclosure in which the worms will live; it holds the bedding and food scraps, regulates the amount of moisture in the bedding, and blocks light (which is harmful to worms). Worm bins can be made from plastic or wooden. In Ethiopia, wooden boxes are preferred because they are more absorbent and provide better insulation (MoA, 2016). The preferred size is 50cm (length) x 50cm (width) x 20cm (height) with holes (0.5cm diameter on the top, bottom and sides of the bins). A bin about 30 cm high by 60 cm wide by1m long, together with about 6000 worms will be able to process about 25-50kg of waste weekly. Make sure that there is good drainage in the containers so the worms do not drown.

Purchase the worms:

In most parts of Ethiopia, worms are available on sale. Of course, the price per kg depends on negotiation. The attention paid to vermicompost production by bureaus of agriculture in several regional states create enabling environment to access vermiworms.

The worm bedding:

The worm bedding is prepared from the material that worms will live in. It can be made from any carbon-rich organic matter such as paper, hay, equines manure, sawdust, leaves, etc.

Keep the bedding moist:

Worms can only live in a moist environment, so you need to make sure the bedding is sufficiently moist. Hence soak the bedding in water to give it a consistency of a damp sponge.

Add the worms:

Add worms by scattering them onto the bedding. Close the lid to block any light. Give the worms about a day without adding food scraps to work their way into the bedding. It is estimated that there are approximately 2,200 adult worms per kg. To consume and convert 1kg of waste in a week, you may need approximately 2kg of worms. If you don't have that many worms to start, it just takes a bit longer to consume the waste. The worms multiply in meantime. If you give proper conditions, they will double their number in 2-3 months.

Add food to the bin:

Fruit leftovers, plant leaves, crushed eggshells, papers, and pre-fermented manures are suitable for worms. Manures are the most commonly used feedstock. Manure from equines, cattle, sheep, and goats and a small amount of poultry manure is generally considered the best natural food for red earthworms. If manure contains excess urine, it has to be drained before use. ***Meat, dairy, fish, bones, onion, oil, fresh manure, hot spices, vinegar and citrus, and sauces are not suitable food for worms***.

Any processed food at home, raw materials with plastic, and meats are also unsuitable. It is best to feed worms 1 to 2 times a week rather than on a daily basis. Too much uneaten food can lure insects, and lack of food forces worms to move out. Bedding materials should cover the worms (3-6 cm thick) while they are feeding.

Harvesting:

Harvest the earthworm beds regularly to optimize worm production. After approximately 2-3 months, the contents of the soil bin will begin to look like rich black soil than the bedding as it started. Move the entire contents of the bin to one side: fill the empty side with new bedding and begin to bury food waste in the new bedding. Within a shorter time, the worms will migrate to the new food source, and you will be able to remove the worm casting from the other side of the bin.

Five essentials for rearing worms:

Hospitable living environment (the bedding); a food source; adequate moisture (60-70% water content); adequate aeration (since the worms are breathing aerobically) and protection from extreme temperature (10-35^{0}c) and predators.

Intervention 3. Crop rotation

Crop rotation means changing the type of crop grown on a particular piece of land from year to year (Figure 23). It improves soil structure, increase soil fertility, control weeds, pests and disease. Crop rotation compel choosing the right crops and crop combination such as deep rooted with the shallow one (meaning heavy feeder with light), and cereal with legume species. Accordingly, farmers might grow cereals in the first season, followed by legume in the second season, then an oil or tuber crops in the third season (RELMA & MARD, 2005).They can then plant cereals again in the following season. Leguminous crops are especially important in rotations because they fix atmospheric nitrogen and bind it in the soil, restore soil fertility and reducing the need for synthetic fertilizers and pesticides. It contributes to the mitigation of the effects of climate change.

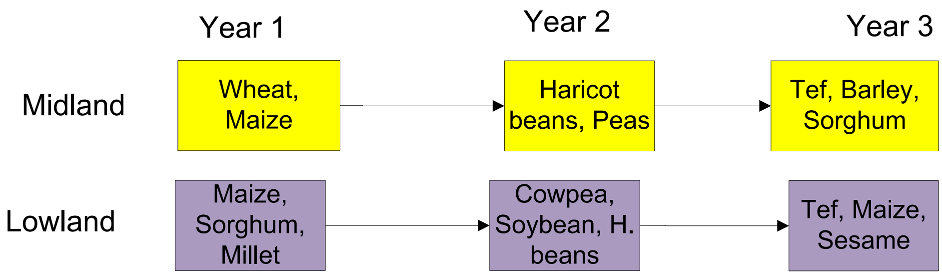

Figure 23. Sample crop rotation in midland and lowland agroecologies

The term includes both cyclical rotations, in which the same sequence of crops is repeated indefinitely on a field, and noncyclical rotations, in which the sequence of crops varies irregularly to meet the evolving business and management goals of the farmer. Apparently, crop rotation provides many benefits for agricultural production. Most of them are associated with building healthier soil, breaking disease, weed and pest life cycles. It increases organic matter in the soil, improves soil structure, reduces soil degradation, and can result in higher yields and greater farm profitability in the long-term. Also, it increases level of soil organic matter, enhances water and nutrient retention, and decreases synthetic fertilizer requirements.

Advantages of crop rotation:	• Limitations to crop rotations
• It improves soil structure • It increases soil fertility • It helps control weeds, pests and diseases • It reduces risk of crop failure because of drought	• Lack of adequate and right varieties of crops for rotation. • The tradition of rotating cereal crops with oil and root crops. • Shortage of enough land to grow staple crops • Lack of seeds of the other crops.

Intervention 4. Intercropping

Intercropping is a cropping system involving the growing of two or more crops on the same piece of land at the same time or in temporal sequences

(https://qcat.wocat.net/en/summary/7068/). This farming practice is a popular crop production system used by smallholders in the tropics. Intercropping systems can include either in - or between-row intercropping, strip intercropping, mixed intercropping, and relay intercropping, the choice depends mainly on the characteristics of various crops in spatial distribution, rainfall patterns and farmer's cropping goals. In **mixed intercropping**, the seeds of two or more crops are sown with no particular arrangement. In **row intercropping** the main crop and intercrop are grown in separate rows, for example, haricot bean and maize. In **relay intercropping,** a second crop is planted after the first crop has reached its reproductive stage of growth, but before it is ready for harvest. This is the most common practice in the CRV and Hawassa Lake Basin areas.

An important reason for intercropping is the improvement and maintenance of soil fertility. An example is when a cereal crop such as maize is intercropped with legumes such as haricot beans, cowpea, mung bean, or soybean (Figure 24). Leguminous crops fix nitrogen thereby reducing the fertilizer or compost demand of the companion crop. Therefore, making the right crop choices is important for intercropping.

Various researchers have reported considerably higher yields from intercropping compared with a pure stand. This can be measured through the "land equivalent ratio" which describes the relative land area required under sole cropping to produce the same yield as under intercropping. Intercropping has been regarded by many farmers as a technique that reduces risk in crop production. It can be an ideal cropping system for carbon sequestration since intercropping can enhance biomass accumulation both above and underground. Intercropping systems extract fewer nutrients from the soil than do single crop plantings per unit area of land if cereal is intercropped with legumes.

Intercropping maize with beans

- Efficiently use the available space, and improve soil fertility via nitrogen fixation.
- Improve production and productivity.
- Reduce risks of failure to various factors.
- Planting companion crops depends on moisture status. Under good rain, the simultaneous planting of large cereals & beans benefits the latter.
- Row intercropping simplifies management & harvesting more than the mixed types

Figure 24. Intercropping of maize with haricot beans. Photo: Gerba Leta

Advantage and disadvantage of intercropping

Advantage:	Disadvantage:
- Improve effective resource utilization such as land, labour, and inputs. - Insure against total crop failure under unfavourable weather conditions, and pest outbreaks. - Improve and maintain soil fertility as the combination is mostly cereal with legumes. - Pest levels are often lowered in intercrops, as the diversity of plants hampers the movement of certain insect pest and in some cases encourages beneficial insect populations. - Reduce soil erosion, lower soil surface evaporation & reduce weed infestation.	• -Intercropping is not always suited to a mechanized farming system. • -It is time-consuming, as it requires more attention and management. • •

Intervention 5. Solar pumps for irrigation

Currently, diesel pump is widely used in the CRV and Hawassa Lake Basin areas of Ethiopia to pump rivers, groundwater, and fresh water lakes for irrigation development. Oil-based pumps are highly vulnerable to the escalation of fuel and oil prices. As compared with solar pump technology, diesel pump is not environmentally friendly because of carbon dioxide emissions that contribute to greenhouse gas and climate change. Therefore, solar pumps seems a future pump in Ethiopia. The CRV and Hawassa Lake Basin areas are characterized by the lowest rainfall and the highest mean annual temperature. This exhibits low cloud cover and a clear sky during most part of the year. The situation creates huge potential for the adoption of solar pump technologies. The recurrent drought and unreliable food crop production via rainfed agriculture necessitate resorting to irrigation farming to ensure the food security need of the inhabitants in the area. Therefore, intensification of irrigation farming is of paramount importance to complement the prevailing gaps. Hence, solar pumps have the potential to help meet household and agriculture-related water needs (Bhandary *et al*., 2020).

In the study *woreda*s of Misrak Miskan and Wera Dijo, solar pump technology is expanding (Figure 25). There are also pilot practices in Adami Tulu Jido Kombolcha *woreda*s. However, high initial investment costs, technical failure, and lack of maintenance services in time are some of the factors discouraging prompt adoption of the technologies. In an expert group discussion, parts such as the charge controller, sensor, and cables are often damaged. Particularly, rodents damage the latter one. Lack of accessing maintenance services and delays in supply of parts were communicated.

Therefore, the adoption and widespread use of solar pumps with accessible spare parts and maintenance services make the lives of smallholders easy. In the existing Ethiopian Agricultural Development Policy, irrigation farming is the pillar of the government initiative to boost crop production and ensure food security for the growing population (A Home Grown Economic Reform Agenda, 2019). As a result, increasing involvement of the public and private sectors is expected to increase in familiarizing and publicizing solar pump-based irrigation development that is friendly to the environment and economical in the long-run. For the adoption and pervasive use of solar pumps, Bhandary *et al*. (2020) suggested blended finance, that is, a combination of government and private sector infrastructure project funding is required to bring solar pumps to scale.

Figure 25. Ibrahim Redi solar panel (left) and Dirshaye Gute (right) solar-powered drip irrigation piloted by the support of IWMI in Dobena Gola *kebele* of Misrak Miskan. Photo: Gerba Leta

Challenges	Potential opportunities
- Lack of spare parts and technicians when desirable. - High initial investment cost. - Low skills and knowledge to operate the pumps. - Lack of responsive local service providers and/or accountable dealers.	- Availability of shallow groundwater in most of the study woredas (within the range of 4-9 meters deep). - Climate change and increasing need for irrigation as an alternative farming. - Emerging awareness and need to use irrigation and commercialize agricultural products such as vegetable, fruits, Khat, etc., to meet the growing demands of urbanization. - Increasing interest in fattening programs that need fresh fodder production via irrigation.

7.

Intervention 6. Area exclosure

Climate change is the outcome of human activities on natural resources. Forest clearing and improper agricultural practices are the drivers for the degradation of natural resources. Soil erosion is the main causes for the global loss of farmlands (Mathewos and Mamo, 2023). The effects reduce farmers' access to safe farmland, grazing, and water. Government and non-government initiatives on area exclosure have been put in place in Ethiopia for a long time (Mekuria *et al*., 2020). It has become a common means of restoring degraded land in the country (Mathewos and Mamo, 2023). These days, community understanding of protection and safe utilization of forest, land, and biodiversity in exclosure has been improved. However, the shortage of firewood and pasture is still affecting the effective implementation of the concept and principle of area exclosure. "The tragedy of commons" in using communal resources is another important issue documented in the CRV and Hawassa Lake Basins of Ethiopia where there is an unequal distribution of benefits from the exclosure (Tilahun *et al*., 2016; Ostrom, 1990). Similarly, Gordon (1954) stated no one values wealth that is free for all. As a result, a lack of uniformity in understanding and implementing the concept and principle of area exclosure is not uncommon.

However, the increasing episodes of recurrent drought demonstrated the effects of unfriendly human activities on natural resources. The situation incites the communities to expand and place new areas under protection. The emerging ambition needs to be supported by a strong institution that allows community's development of a sense of ownership and accountability with binding bylaws that govern and enable the participants to equally access the benefits from protected areas. Essentially, equity to resource use motivates members of the engaged community to feel confident and accountable to remain the guardians of the resources (Lockwood *et al*., 2010).

Recognition of the ownership of the protected areas by the surrounding community or members of the community-based organization (CBO) reinforces the development, protection, and efficient and effective use of the area exclosure. Increasing community awareness on the growing drivers and dynamics of climate change and its consequences, their duty, and accountability in arresting and reversing the improper actions imposed on the environment and its resources is vital. This enables the devolving of the role of environmental protection to the end users. Therefore, delineation of the new area exclosure and mapping of the endowed resources enables future tracking of the trends of changes over the year. Furthermore, documentation enables to claim for anticipated benefits such as from payment for environmental services (PES), carbon sequestration funds, and conservation of biodiversity since area exclosure would have global benefits in this regard.

The area exclosure makes the community benefit from the tangible and intangible assets drawn from the exclosure. Therefore, ensuring the youth and women's participation is commendable to make inclusive resource sharing among all categories of the community that avoids conflict of interests. Promoting off-farm activities such as beekeeping strengthens protection and creates an enabling environment for forest regeneration (Figure 26). Enrichment planting with tree species and over-sowing the existing grass with regenerative, palatable, and nutritious forage grass is commendable. Therefore, the development intervention expedites the restoration capacity of the degraded areas. Eventually, protecting the hillside areas improves the absorption capacity of rain, and reduces soil erosion, flood, and sedimentation in the valley bottom. In general, area exclosure generates substantial benefits that range from farm level to landscape and global scales.

Figure 26 Area exclosure in Wera (left) and Sankura (right). Photo: Gerba Leta

Intervention 7. Agroforestry

Agroforestry is the intentional mixing of trees or shrubs with crops, animals, and pastures. The practice is to create environmental, economic, and social benefits. It is a unique land management approach for people who care about working lands and natural resources. Agroforestry practices provide opportunities to integrate productivity and profitability with environmental stewardship resulting in healthy and sustainable agricultural systems that can be passed on to future generations (Figure 27). The leaves and branches of trees and shrubs help filter and absorb air pollutants including dust particles and moisture droplets. Agroforestry is a practical, low-cost alternative for food production as well as environmental protection (Steppler and Nair, 1987). In the CRV and Hawassa Lake Basin areas, this technology is suitable to a few *woreda*s such as Misrak Miskan and Wera Dijo because of suitable weather.

Desirable characteristics of species: **-**Easily established that requires minimum labor for planting, maintenance & propagation. -Fast growing to become promptly deliver benefits for the farm family. -Nitrogen-fixing legume species contributing to crop nutrition. - Deep root system to draw water & nutrients. - Easy to propagate, & high biomass producers, palatable, provide more green manure, & high survival percentage. - Adaptable to close spacing like in hedgerows. - Good sprouting & positive response to pruning. - High coppicing and pollarding capacity.

Figure 27. Agroforestry system in Sidama region. Photo: Gerba Leta

Advantage of Agroforestry	Disadvantage
- Fulfilling the basic needs of food, fuel, fodder and timber - Conserve soil and water as a barrier and via covering the ground. - Maintenance of soil fertility - Controlling salinization and waterlogging - Moderate microclimate around the trees (Balasubramaniyan & Palaniappan, 2000). - Alternative land use for marginal and degraded lands.	- Competition in areal spaces and shading effects on the undergrowth. - Permanently occupy the space and makes the shift to other crops difficult.