Characterizing and tailoring climate change adaptation practices into a diversified agroecosystem

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Research Article

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Abstract

Smallholder farmers require viable adaptation strategies for climate change. Adaptation project might be mal-practiced unless it considers the local diversity. This paper argued that the challenge of agriculture in developing countries in general and Ethiopia, in particular, is much diversified and thus interventions require a systematic shift to specific agro-ecosystems. In light of this, we used agro-ecosystem analysis to design locally appropriate adaptation strategies specific to Rib watershed in Ethiopia. The agro-ecosystem uses three inputs of agro-climatic zoning, soil type and terrain analysis, and farming systems. We used primary data collected from 383 randomly selected farm-households. The survey data was supplemented by key-informant interviews, focus group discussions and secondary data. We characterized and mapped the study area in two distinct groups of agro-ecosystems: Fogera plain and Libo-Farta highlands. The finding portrayed that across these agro-ecosystems, there was considerable difference in the: potentials, constraints, crop type, income distribution, and soil type. We found blanket application of the same strategies irrespective of these heterogeneities. The income distribution shows that the poorest 20 percent of the population share about 5 percent of the income. Relatively the plain has less income inequality with 38.3 as compared to the highlands Gini coefficient of 42.8. Looking only at the average distribution of income does not reveal the inequality. It is important to disaggregate into the specific agroecosystems. The study identified that drainage projects, fruit trees, and fishing are among the prioritized adaptation strategies for the plain while conservation structures, irrigation, agroforestry are tailored to the highland areas. It is important to consider diversities before intervention.

1. Background

Climate change has brought substantial welfare losses around the globe [1]. It is disproportionately impacting smallholder farmers in developing countries. It jeopardizes crop productivity and aggravates food insecurity situations in many areas. It is reducing rain-fed agriculture yield by up to 50% and total agricultural gross domestic product by 2 percent to 9 percent [1-4]. Given the known negative impacts of climate change, various mitigation and adaptation strategies have been practiced [2]. African farming areas have been described at a continental scale under thirteen main categories [5], but such simplification masks the need for huge local diversified adaptation. There are limitations to introduce and implement appropriate adaptation options and hence partly contributes to poor agricultural performances in Africa [6]. This is because adaptation per se requires a deeper understanding of a wide range of issues [3, 7]. There has been a growing demand for the agro-ecosystems analysis for the formulation of methods by which this can be achieved [8]. Effective local tailored adaptation can be designed with agroecosystem analysis. Local adaptation refers to specific decision-making processes concerning the allocation of agro-inputs and management practices at the farm and plot level, thereby recognizing production objectives, resource endowments, and soil fertility conditions [5]. Many agro-ecologists argued that strategies that abandon conventional monocultures, and favour diversity in temporal and spatial schemes found to be a viable path for increasing productivity, specialization, resilience to climate change

and shocks as well as regulation of constraints such as weeds, pest, diseases [9-11]. Some also argue that improvement in input and use efficiency by itself will not only be effective in addressing the challenge of agriculture. Instead, the farming system must be redesigned with a set of ecological characteristics [12, 13].

Ethiopia is one of the Sub-Saharan African countries dominated by subsistence small-scale farmers whose livelihood depends on less than 2 hectares of land (Agricultural Transformation Agency [14]; Ethiopian Ministry of Finance and Economic Development [15]. Agricultural performance is primarily constrained among others by degradation, unreliable weather conditions, and the use of underdeveloped technology [16, 17]. Cognizant of this, the study was conducted in Rib watershed of Northwest Ethiopia and is framed to address three issues. Firstly, various adaptation practices are being undertaken in the country aimed to cope with the impact of climate change, reduce land degradation and rehabilitate the ecology [18-20]. However, the contribution of these practices is marginal [21] and the aforementioned problems have persisted. Thus, it is important to examine the issue and indicate the way-out. Secondly, the importance of multidisciplinary (tailored) adaptation practices has been known long but hasn't yet been properly in place in Ethiopia. Policymakers are showing more interest in adaptation discussions at the international and national level [22]. There is limited knowledge in the study area in clearly understanding and characterizing the specific agro-ecosystem and socio-economic groups, as the effect of climate change and its adaptation strategies differ across localities. There has been little discussion of how this approach could be used to help smallholder farmers adapt to climate change [23]. However, these debates lack sound linkages to the day-to-day practice of local-level adaptation to climate change. Induced top-down adaptation decision-making processes have become inadequate, due to its inability to create appropriate solutions for local communities. It is necessary to bridge this gap; bottom-up approaches may produce the best results by building on local experiences and knowledge [24]. As a result, identifying which adaptation practice could be considered for the respective agroecosystem at locality being informed with the identification of associated potentials and constraints.

Thirdly, the other studies conducted in Ethiopia have mainly focused on specific elements of farming system emphasizing on the social and institutional setting, skills of farmers, farmers' interaction, rather than attempting to integrate diversified issues such as climate, soil type, topography and farming system, inter alia [25]. Moreover, the vulnerability of the area is well investigated by different authors, see [18-20, 26, 27]. However, there is paucity in clearly indicating how farmers at the local level can design adaptation strategies. The work closest to this study is [28] that conducted an agroecosystem analysis in Choke Mountain of Ethiopia. However, the scope of our study is broader with the consideration of equity component (income distribution) in the agroecosystem analysis. Thus, in this study, we argue that the challenge of agriculture in Ethiopia is much diversified and interventions require a systemic shift from blanket based to specific and contextualized agro-ecosystem characteristics. Thus, the objective of this study was to characterize and uncover the diversified agro-ecosystem of Rib watershed in northwest Ethiopia. Specifically:

- To characterize the important components of the agro-ecosystems

- To identify potentials and the key constraints for crop production within the agro-ecosystems and
- To identify and propose suitable adaptation options for the different agro-ecosystems

This paper aims to contribute at least in two ways. Firstly, it provides empirical evidence on how climate change adaptation strategies can be designed at local level. It clarifies the importance of the link between local experience and policymaking. Local evidences are important as Ethiopia is aspiring to build climate-resilient economy. Secondly, it investigates the potentials, constraints, and classifies the diversities of the agro-ecosystems groups that can inform local decision makers.

2. Materials And Methods

2.1 Description of Study Area, Rib Watershed

The study was conducted in Rib watershed, Amhara Region, Ethiopia. It is located between 10°43' and 11° 53' N latitude and 37° 47'E and 37° 54'E. It has a drainage area of about 1586 km² and the elevation ranges from 1676 to 4,135 meters above sea level (m.a.s.l). The landscape of the watershed is highly rugged with a high mountain range on the south and closely dispersed hills and their escarpments in the central and northern parts of the watershed (Water Works Design and Supervision Enterprise [29]). The river intersects local administrative boundaries namely, Ebnat, Farta, Libo Kemkem and Fogera *Woredas*^[1]. According to the Central Statistical Authority 2014 projection, about 181,813 households share the watershed.

Woina Dega (Subtropical zone) and *Dega* (cool zone) are the dominant traditional agro climate zones. *Dega* traditional climate zone has an average temperature of about 16 °C and annual rainfall between 1200 and 2200 millimetres (mm) with an elevation between 2300 to 3200 meters. *Woina Dega* average temperature is 22°C with annual rainfall between 800 and 1200 mm and an average elevation between 1500 to 2500 meters (Ethiopian Ministry of Agriculture [30]). The watershed receives a unimodal rainfall with June, July, August and September being the rainy months. The peak flow occurs in August with a monthly average flow of about 52m³/s [31]. The potential of the area in terms of land use is cultivation 85.7%, grassland 12.53%, and afro-alpine 1.5%, shrubland 0.21% and urban 0.06% (Ministry of Water, Irrigation and Electricity [32]).

There were three basic reasons for selecting Rib watershed. Firstly, it is the second largest watershed in the country and is vulnerable to environmental degradation, flood, crop pests, hailstorm and erratic rainfall (Amhara Regional State [33]; Ethiopia Ministry of Water and Energy [34]). Secondly, previous studies concluded that unless further research and urgent measures are taken, the Rib watershed may lose the remaining soil and productivity potential, and end in high intensity of poverty (See for instance, [25]. The erosion is a threat to the Ethiopian grand renaissance dam, which is located at the lower catchment of Rib watershed. Within the watershed, because of the existence of ecological diversity, it is challenging for local actors to design adaptation interventions. Thirdly, the study area has been skipped by researchers maybe because of its topographic challenges for conducting research.

2.2 Data Source and Collection Methods

This study employs both primary and secondary data. Primary data was collected through a household survey questionnaire, key informant interview and focus group discussion. The household survey questionnaire was designed to gather information about the household heads' demographic characteristics, yield, farming system and constraints of crop productivity. The questionnaire was administered by interviewing the heads of farm households for the fact that most of them cannot read, write and understand the questions. Trained enumerators travelled to the household home to interview and record their responses. Data collectors were given a day-long training to introduce the objective and format of the questionnaire. Fourteen key informant interviews were held with *Woreda* agriculture office experts and *Kebele*^[2] development agents. They had provided information on the specific village characteristics and challenges of crop production.

Five focus group discussions (FGD) with farmers were conducted in each traditional agro climate zone. Other FGDs were also conducted with *Kebele* development agents (DAs). These were purposefully selected with the consideration of their experience. They shared their experiences about the potentials and constraints of crop production of the local agro-ecosystem. The discussion was moderated by the researcher with pre-developed interview guides. All participants' ideas and experiences were properly entertained.

Crop yield Secondary data was collected from the Ethiopian Central Statistical Agency (CSA [35]). We relied on Ethiopian national metrological agency (NMA [36]) data on mean annual precipitation and temperature. The soil type and terrain were collected from EMoWIE and the soil properties from the Food and Agriculture Organization (FAO) harmonized world soil database. United States Geological Survey (USGS) data was used to characterize the slope of the study area,

2.3 Sampling

In ordered to select sample household heads, the research followed a multistage sampling technique. Firstly, Rib watershed was stratified into *Dega* and *Woina Dega* traditional agro-climatic zones. Secondly, within each agro climate zone, *Kebeles* were randomly selected and the sample size was proportional to household size. The complete list of the farm household heads was collected from the *Kebele* administration. Thirdly, the sampling unit, households, were selected through systematic random sampling. With these procedures, from a population of 80713 households, according to [37] p-179, the sample size was determined to be 383 (Table 1). Given other supportive primary and secondary data, the sample size is reasonably representative of the population.

Table 1 Proportional Sample Size Distribution

Agro-climatic zone	Number of <i>Kebeles</i>	Total Household size by 2014	Sampled <i>Kebeles</i>	Proportional sample size
<i>Dega</i>	11	15278	Ata Sahrna	73
<i>Woina Dega</i>	40	65435	Woji; Tiwha;;Kokit; Agela; Tara; Bura; Angot; Yifag; Hiruy; Tsegur	310

Source: (Researcher Survey, 2016)

2.4 Method of Data Analysis

The characterization of potentials, constraints and climate change adaptation options has adapted the method of [28] that was originally designed as agroecosystem analysis by [8]. The characterization passes three phases. As shown in figure 1, the first phase, the definition of agro-ecosystems, was made through three inputs. The first is agro-climatic zoning based on mean precipitation, temperature and altitude which is usually termed as traditional climatic zoning. The second phase is soil type and terrain analysis and the third is the distribution of farming systems. Farming systems were further characterized using the dominant resource base and livelihood of the agro-ecosystem. The soil type and terrain analysis follows the FAO revised land evaluation framework [38] and was mapped using Quick Geographic Information System (QGIS).

Figure 1 explains the how the various factors of agro-climatic zoning, soil and train analysis, the farming system defines the agroecosytem. After defining the agroecosystems, pattern, productivity, and equity and sustainability analysis finally enables to design context specific adaptation strategies. Source: Adapted from [28]

After the agro-ecosystems classification follows through pattern, equity, productivity and sustainability assessment [28]. Pattern analysis is used to identify constraints and opportunities while the productivity and sustainability assessment focused on the ability to maintain productivity through overcoming constraints. Sustenance was measured by the reciprocal of the coefficient of variation in productivity. Productivity was measured using annual yield per hectare. The suitability of the soil was rated with natural fertility, texture and terrain. Equitability looks at how productivity or income is distributed within the agro-ecosystem [8] and we have shown it using Gini coefficient. The income is defined as the sum of farm and nonfarm income. Gini coefficient is commonly used in income and wealth distribution studies due to the convenient Lorenz curve interpretation. The Lorenz curve presents the cumulative percentage distribution of population on the horizontal axis and the income on the vertical axis. The income recipients are categorized into five segments and the Lorenz curve portrays how much percentage of income goes to respective five quintiles. The Gini coefficient ranges from zero (perfect equality) to one (perfect inequality) and high-income inequality ranges from 0.5 to 0.7 and relatively equal distributions from 0.20 to 0.35 [39]. Thus, the Lorene curve analyses the per capita income across five equal groups of quintiles whereby each group consists of 20 percent of the sample population [40]. The equitability

analysis employed the World Bank Automated DEC Poverty Tables (ADePT) software. The statistical report was made using SPSS-20 software. Finally, the third phase develops the options of adaptation strategies for the agro-ecosystems.

[1] Next to region and zone, it is the third hierarchy of administrative structure in Ethiopia.

[2] The lowest administrative hierarchy of Ethiopia.

3. Results And Discussion

Characteristics of the Sampled Households Based on the data collected from the household survey, it is revealed that about 80% of sampled farmers are married, 5% not married, 8.6% are divorced while 6.8% are widowed. The education level profile of respondents showed that 38.7% illiterate, 53.5% read and write while the remaining 7.8% had completed primary school. In terms of gender, it is evident that about 19% of the households were headed by females. Further classifying the sampled households based on the traditional climate zone of their areas, the data showed that 80.9% of them live in *Dega* (cool zone) while the remaining 19.1% are from *Woina Dega* (Subtropical zone).

Table 2 Means of Livelihood of Respondents

Means of livelihood		Agro-ecosystem		
		Fogera plain	Libo-Farta Highlands	Total
Agriculture	N	99	282	381
	%	20.0	57.1	77.1
Small business	N	21	42	63
	%	4.3	8.5	12.8
Seasonal work/migration	N	0	9	9
	%	0.0	1.8	1.8
Relative/remittance	N	2	19	21
	%	0.4	3.8	4.3
Aid	N	0	8	8
	%	0.0	1.6	1.6
Other	N	9	3	12
	%	1.8	0.6	2.4
Total	N	131	363	494
	%	26.5	73.5	100

Percentages and totals are based on multiple responses.

Source: (Researcher Survey, 2016)

The majority of the farmers rely on mixing crop production and livestock rearing. Livestock rearing includes ox, cows, sheep, goat, horse, etc. Parallel with agriculture, farmers run small businesses such as

eucalyptus tree trade, livestock trade, grinding mill, etc. As informed by FGD discussant farmers, some farmers also migrate to labor demanding cash crops production areas such as Metema, Quara, Tach Armachiho and Humera. These areas are famous in the production of sesame and pay *Birr*[1] 150 to 200 /day/labor. This wage rate is higher than the study area rate of *Birr* 90/day/labor.

Concerning the production system, the survey data showed that households depend on manual labor and animal traction (traditional ox-horse drawn) tillage system. *Wonfel* and *Debo* are the common labor sharing mechanisms among farmers. *Wonfel* is a revolving system of working together with equal time labor share among voluntary groups of farmers. *Debo* is also mutual assistance among neighboring farmers, friends and or relatives. In *Debo* system, a farmer requests his neighbors, relatives or friends to support him through labor, oxen or both, and in return, this farmer has a responsibility to work some other day for these farmers from whom he received the assistance. *Senbetie* is also a social as well as a religious attachment that orthodox Christian farmers rotationally prepare food and drinks, took to churches and then they eat and pray together. These systems are practiced across the whole study area.

3.1 Characterization of Agro-ecosystem of Rib Watershed

With the methodological procedure described under section 2.4, the study area is classified into two agroecosystems: the plain and the highland. The agro-ecosystem of the study area is systematically subdivided into two zones as Fogera plain and Libo-Farta highlands (Table 3). This classification is made through the participation of farmers and experts'. The primary purpose of agroecosystem analysis is to identify potentials and constraints aimed to design effective intervention strategies. The agroecosystem analysis is contextual and might be diversified even at village level. For instance, because of the diversity in elevation, soil type and socio-economic characteristics of Choke Mountain watershed in Blue Nile Highlands, [28] identified six agro-ecosystems as Lowland and valley fragmented, Midland plains with black soil, Midland plains with brown soils, Midland Sloping and, Hilly and Mountainous highlands and Afro Alpine.

Table 3 Characterization of Rib Watershed Agro-ecosystems

Agro-ecosystem	Traditional climate zone (MoA,2000)	Dominant Farming system	Major crops		Major soil type and color
Fogera plain	<i>Dega</i>	Rice based	Rice, Maize,	Teff,	Fluvisol and Vertisols (Black: <i>Tikur, Bunama/Walka/kotcha</i>)
Libo-Farta highlands	Dominantly <i>Woina Dega</i> with limited <i>Dega</i>	Fragmented maize, finger millet	Teff, barley,	Maize, Teff and Barley	Luvisols and Leptosols (Reddish and Whitish: <i>Keyate, Nechatie</i>)

Source: (Researcher Survey, 2016)

3.1.1 Fogera Plain

Fogera plain is categorized as *Dega* traditional climate zone which is located to the west of Lake Tana. Using the extracted satellite digital image from the United States Geological Survey [41], it is evident that the area is dominantly classified under gentle slope. With the local meteorological stations, the annual temperature in the area ranges from 13 °C to 27 °C and the rainfall is approximately between 900 to 1400 mm/year. Fogera plain has a unique swampy feature and Rice is the dominant crop produced in the area. Following Rice, the other major growing crops in this area are Teff, Maize and *guaya*. Shesher and Welela are the largest wetlands in the area. As informed by the local community, Shesher usually dries in the months of either February or March; whereas Welela in April and May. In some years, Welela remains wet the whole year if there is a high inflow of Rib river. These wetlands support the livelihood of the local community through the provision of fish. When it retreats in the dry season, the residual moisture is used for producing crops such as *Guaya*, Teff, Rice, Lentil, Sunflower and peas. The plain grass is the main source of fodder for livestock. The area is well known in Fogera milk cow species. According to FGD participant farmers, the area is highly benefited from river sediment brought from highland areas of Farta and Libokemkem.

As shown on figure 2, the dominant soil type is Eutric Fluvisols with a sandy loam texture. The other is Vertisols that have clay texture and cracks during the dry season which makes it difficult for tillage and the movement of people and livestock. Animals usually fall in the cracks and broke their legs. A similar problem of these kinds of soil was also reported in Tana basin by [42]. We attempted to assimilate FAO soil classifications with the local naming of soils. It is possible to do that as farmers have the knowledge of identifying soil color and its respective degree of suitability for each crop. Laboratory approaches are costly and time-consuming and while spectroscopic approaches have demonstrated substantial progress in recent years, ultimately, indirect approaches, e.g., based on local soil fertility evaluation schemes, are likely to be important diagnostic tools [43]. As a result, in both agro-ecologies, farmers had identified three types of soil. The first is *Keyate* (Reddish in English) characterized by moderate fertility and depth. The second type is *Tikur (walka) kotcha* (black soil) of high fertility with deep depth and has stickiness behavior in the rainy season. Because of the water logging behavior, farmers usually plow late and harvest after an extended period as compared to the neighboring dry land. The third type is *Nechatie* (Whitish) found in degraded areas and has very low fertility and inadequate depth. A similar study was conducted by [44] and identified six types of soil attributed to soil color, depth, stoniness, fertility status, texture, and workability. These were *Borebor*, *Chincha*, *Deshen*, *Keyattie*, *Walka* and *Yeguassa Afer*. This doesn't align with our classification as *Chincha* refers to landscape dominantly degraded land covered by rocky stone and is uncultivable, and *deshen* is to mean sediment. The rest classifications are in harmonious with this study. As reported in figure 2, the soil type is characterized as Eutric Leptosols (38%), Chromic Luvisols (35%), Eutric Fluvisols (26.5%), Haplic Luvisols (0.40%) and others 0.1%.

Figure 2 Map of Major Soil Classification of Rib Watershed

Figure 2 shows the major soil type of Rib Watershed for both Fogera plain and Libo-Farta highland. Source: (Extracted from [32])

Farmers reported that *keyate* is more conducive for Barley, Maize and Wheat, and *tikur kotcha* (*walka*) for Teff and Rice. Thus, as shown in table 4, farmers adjust their crop production based on the color of the soil as it has fertility implications. Accordingly, majority of farmers sow Maize, Barley and Wheat on *keyate*; Teff and Rice on *tikur kotcha*. *Tikur* (*kotcha*) has water logging behavior and is conducive for Rice. Farmers who did not own either of the soil types simply sow crops irrespective of the type of soil.

Table 4 Soil Type and Respective Suitable Crops

Soil Type by Colour	Maize		Teff		Barley		Wheat		Rice	
	N	%	N	%	N	%	N	%	N	%
<i>Tikur/kotcha</i> (black)	134	47	166	63.1	52	31.1	45	31.9	104	81
<i>Keyate</i> (Redish)	139	48.8	86	32.7	98	58.6	79	56.1	23	18.0
<i>Nechate</i> (whitish)	12	4.2	11	4.2	17	8.4 10.2	17	12.1	1	0.01
Total	285	100	263	100	167	100	141	100	128	100

Source: (Researcher Survey, 2016)

Apart from agro-climatic zoning and farming system analysis, [8] presented soil and terrain as an approach for agro-ecosystem classification. In this regard, land slope, soil texture, soil fertility and soil erosion are important components of pattern and productivity analysis. As depicted in table 5, Fogera plain is characterized as dominantly flat sloped, blackish soil and ranging from moderate to high fertility. About 7% of farmers reported severe problem of soil erosion which is also linked to the slope of the land. About 3% and 65% of households own steep and flat land, respectively[1]. The slope is mapped in figure 3.

Table 5 Soil Type, Fertility and Erosion in Respective Agro-ecosystem

Characteristics		Agro-ecosystem					
		Fogera plain		Libo-Farta Highlands		Total	
		N	%	N	%	N	%
Land slope	Flat	66	65.3	28	9.9	94	24.5
	Moderate	32	31.7	160	56.7	192	50.1
	Steep	3	3.0	94	33.3	97	25.3
	Total	101	100	282	100	383	100
Soil color	<i>tikur/kotcha</i> (black)	68	67.4	142	50.3	210	54.8
	<i>key/</i> (Redish)	32	31.7	129	45.7	161	42.0
	<i>nechate</i> /whitish	1	1.0	11	3.9	12	3.1
	Total	101	100	282	100	383	100
Soil fertility	Degraded	11	12	156	65.5	167	50.6
	Moderately fertile	39	42.4	59	24.8	98	29.7
	Very fertile	42	45.7	23	9.7	65	19.7
	Total	92	100	238	100	330	100
Soil erosion	Very high	7	7.3	156	56.9	163	44.1
	Moderate	52	54.2	72	26.3	124	33.5
	Low	37	38.5	46	16.8	83	22.4
	Total	96	100	274	100	370	100

Source: (Researcher Survey, 2016)

Potentials and constraints: Fogera plain is water logging and has a high potential for rice production. It has the possibility of producing two to three times per year. The wetland area is promising for fish breeding and harvesting. Previous studies [29, 34] as well as key informant experts had confirmed the availability of high irrigation potential and presence of high underground water. The major challenges of agriculture in this agro-ecosystem are excessive flood, siltation, hail and erratic rainfall. The detail is presented in section 3.3.

3.1.2 Libo-Farta Highlands

Libo-Farta highland is mountainous with diversified topographies across Libokemkem and Farta *Woreda*. The highland of Libokemkem is *Woina Dega* whereas Farta has both *Woina Dega* and partly *Dega* climate zone. Eucalyptus is the major vegetation of the area. The major growing crops in this area are Teff, maize, wheat, barley, chickpea, pea, finger millet and potatoes. The production of papaya, banana, lemon fruits; and spices such as garlic, red onion, fenugreek, black cumin, bishops weed are also common. The production of these spices is mainly for the market. The dominant soil types in Libokemkem area are Chromic Luvisols and Eutric Leptosols whereas in Farta area is Eutric Fluvisols. Haplic (Chromic Luvisols) are prone to erosion and compaction [42]. Referring to table 5, in this agro-ecosystem, farmers rated the dominance of degraded land characterized with steep to moderate slope. About 57% of farmers reported severe problem of soil erosion, that 33% of households own steep and 56.7% moderately steep

land. As shown in figure 3, the extracted satellite digital image from [41] showed that the entire study area elevation ranges from 1772 to 2847 m.a.s.l.

Figure 3 Map of elevation of Rib Watershed

Figure 3 shows the elevation of Rib Watershed for both Fogera plain and Libo-Farta highlands, with the elevation range of 1772 to 2847 meters. Source : Extracted from [41]

Bulk density is an important measure for root growth and soil permeability for the soil-plant-atmosphere system and can be done as part of fertilizer or irrigation management plans [45]. The critical value of bulk density for restricting root growth varies with soil type but in general bulk densities greater than $1.6 \text{ g}^{-\text{cm}^3}$ tend to restrict root growth [46]. We extracted the FAO (2017) database and indicated that Rib watershed the bulk density ranges from 1.24 to $1.42 \text{ g}^{-\text{cm}^3}$ that falls in the normal threshold.

Soil texture affects its water holding capacity, water movement, gas exchange, tillage, and nutrient retention capacity. These are important for the health of plants. The acceptable quality threshold for sand and silt is less than 70% and for clay is 30% [47]. However, the study area covered by Haplic Nitisols had a clay percentage beyond the threshold. Thus, in such occurrences of high silt or of sand and clay, large amounts of organic matter improve the physical characteristics of the soil.

An important dimension for developing appropriate plot-level recommendations is the proper diagnosis of soil fertility-related constraints [43]. From table 6, the pH characteristics of the study area range from 5.3 to 6.5. According to [48], soil with pH between 4.5 to 5.5 is categorized under very acidic soils suffering from toxicity and some crops are not tolerant of it. Some highland areas had moderate acidic soil, which is the case in Eutric Fluvisols. Otherwise, the rest of the study area had a normal pH level. Soils with organic carbon of less than 0.6% are considered poor in organic matter and require fertilizer to be productive.

Table 6 Soil Characteristics of the study Area

Soil unit Name (FAO)	Eutric Fluvisols	Haplic Luvisols	Chromic Luvisols	Eutric Leptosols
Reference Soil Depth (cm)	100	100	100	30
Topsoil Silt Fraction (%)	27	25	22	30
Topsoil Clay Fraction (%)	49	21	27	20
Topsoil Sand Fraction (%)	24	54	51	50
Topsoil USDA Texture Classification	clay (light)	Sandy clay loam	sandy clay loam	loam
Topsoil Reference Bulk Density (kg ^{dm³})	1.24	1.42	1.38	1.42
Topsoil pH (H ₂ O)	5.3	6.5	6.4	6.5
Topsoil Salinity electric conductivity (EC _e) (dS ^m)	0	0	0	0.1
Subsoil pH (H ₂ O)	5.4	6.7	6.5	-
Subsoil Salinity (EC _e) (dS ^m)	0	0.1	0	-

Source: [48]

Potentials and constraints: Libo-Farta highland has a high potential for bee farming and fruit plantation in the large protected areas and as well in the existing forests such as Alemsaga. Moreover, though its ecological disturbance, the area is highly endowed with eucalyptus that can be used for timber production. The undergoing construction of Rib dam for irrigation is promising in transforming the livelihood of the farming community. The major constraints of crop production in this agro-ecosystem are identified as soil erosion, erratic rainfall, land degradation, deforestation and blanket application of the same fertilizer irrespective of the property of the soil. The detail is presented in section 3.3.=

3.2 Agro-ecosystem System Properties: Pattern, Productivity, Sustainability and Equity

After defining the agro-ecosystems, the respective complex system properties can be captured by the four system properties of productivity, pattern, sustainability and equity [8, 28]. Referring to productivity, the dominant crops yield specifically Teff, maize, barley, wheat and rice is summarized in table 7. The mean yield of maize and Teff in Libo-Farta highlands exceeds Fogera plain. According to FGD participant farmers, this happens because high surface water remained on the plain farmland and limits the yield of these crops. It is important to recognize that climate, input use and soil suitability create yield difference across agro-ecologies. The mean yield difference between agro-ecologies is significantly different for maize and Rice at $P < 0.01$. *Yegoba ruz* (local rice species) was grown in dry areas of Libo-Farta highlands. This rice species didn't demand more water.

Table 7 Major Crop's yield in each Agro-ecosystem (quintal/hectare in 2016)

		Agro-ecosystem		
		Fogera plain	Libo-Farta Highlands	Aggregate
Maize	Mean	25.94	21.64	22.94
	CV	.34	.432	.409
	N	86	199	285
Teff	Mean	10.97	13.87	13.37
	CV	.918	.579	.633
	N	45	218	263
Barley	Mean		17	17
	CV		.588	.588
	N		167	167
Wheat	Mean		18	18
	CV		.611	.611
	N		141	141
Rice	Mean	36	20	61
	CV	.444	.6	.278
	N	65	63	128

Source: (Researcher Survey, 2016)

The pattern of yield in the last five years [35] for Maize, Rice and Teff showed a slight increment (Figure 4). However, Wheat production was declined in 2013 but since then yields have consistently improved. According to FGD discussants, this happened as a result of heavy hail during the harvesting season of these crops. Due to the absence of data, the yield trend for rice starts as of 2014.

Figure 4 indicates the pattern of yield crops for five years. Source: (Compiled from [35])

The per capita production of crops is calculated as yield per number of respective crop holders (Figure 5). The per capita production of rice initially increases from 14.25 to 17.45 and then in 2015 and 2016 dropped down to 14.5 quintals. The per capita yield of Wheat and Teff increased during the years 2012 to 2014, but slightly decreased after 2014. There was a continuous oscillation in the case of barley. These patterns indicate that the per capita productions for all crops except maize are not stable.

Figure 5 presented the percapita production (output/hectare/household) of crops from 2012 to 2016 Source: (Compiled from [35])

The other important component of agroecosystem analysis is the issue of equity in terms of the income distribution. Equitability or the relative degree of income inequality or distribution within each agro-ecosystem is analyzed using the Lorenz curve. As depicted in figure 6 and table 8, the Gini coefficient of the study area was 41.7. It lies in the range of fairly high-income inequality distribution.

Table 8 Distribution of Population across Quintiles

	Population Percentage by Quintiles				
	Q1	Q2	Q3	Q4	Q5
Fogera plain	16.6	18.6	18.2	22.6	24.2
Libo-Farta Highlands	20.8	20.7	20.5	19.2	18.8
Total	19.8	20.1	20.0	20.0	20.1
Male	16.8	20.1	19.6	21.6	21.9
Female	37.6	20.6	22.3	10.1	9.4
Total	19.8	20.1	20.0	20.0	20.1
	Number of Population by Quintiles				
	Q1	Q2	Q3	Q4	Q5
Fogera plain	23	19	19	19	21
Libo-Farta Highlands	70	60	54	49	49
Total	93	79	73	68	70
Male	65	65	58	60	63
Female	28	14	15	8	7
Total	93	79	73	68	70

Source: (Researcher Survey, 2016)

The existence of the variation was partially reflected by the high-income gain by some farmers from irrigation and gender disparity. This is also confirmed by the two-sample T-test. That is, the income of households that have irrigation is significantly higher than those without irrigation with $P < 0.000$; and income by females is also significantly lower than males with $P < 0.0009$. The Lorenz curve showed that the poorest 20 percent of the population share close to 5 percent of the income and the second quintile share of income is 11 percent. The poorest 80 percent of the population share of income is about 55 percent and the top richest 20% of the community i.e. the fifth quintile income share is 45 percent.

Figure 6 Lorenz Curve

Figure 6, this Lorenz curve reflects the income distribution of the sampled households. The red line is the line of equality and the blue line is the actual income distribution. ource: (Researcher Survey, 2016)

It is important to analyze how this inequality is attributed within and across the agro-ecosystem. The decomposition^[1] analysis into Fogera plain and Libo-Farta highland showed the presence of inequality within the subsample. Relatively Fogera plain has less income inequality with 38.3 as compared to Libo-Farta highlands Gini coefficient of 42.8. The within-group, between-group and overlap inequality are 26.3, 1.3 and 14.1 respectively. This has an important policy implication to focus on within-group than the between inequality. The within-group inequality is high and the between-group inequality is low, and such occurrences might bring social instabilities within the community [40]. Thus looking only at the overall inequality does not reveal the potential problem.

About 17 percent of the population in Fogera plain and 20.8 in Libo-Farta highlands fall in the first quintile. This implies that more of the population in the Libo-Farta highlands falls in the poorest quintile compared to the Fogera plain. Moreover, about 24 percent of the population in Fogera plain and 18.8

percent in Libo-Farta highlands lay in the fifth quintile. As one move to higher income quintiles, the proportion of female household heads share had decreased. Thus, the largest proportion of the population in the lowest quintile belongs to households headed by females. The income distribution is skewed to the right with the median falling close to 45 thousand *Birr*. However, the distribution of land, the main source of income, within the study area falls in the fairly equitable region with Gini coefficient of 26.6. The land distribution was held in the second half of the 1990s. Nevertheless, there are large numbers of landless youngsters that their livelihood is mainly dependent on their parents' land or any other form of crop sharing.

3.3 Constraints and Proposed Strategies

The pattern of crop production in the past decade in each agro-ecology was reported by farmers. As summarized in table 9, 55.4% of the respondents mentioned that crop production has decreased, 31.9% stated an increase while 11.4% reported that they didn't observe any change. The remaining 1.3% did not recognize the pattern of change. Disentangling within agro-ecosystem showed that 48.5% of those in Fogera plain and 58.2% Libo-Farta highland households had reported the decrement of production across periods.

Table 9 The Last Decade Pattern of Production and Constraints

Category		Agroecosystem					
		Fogera plain		Libo-Farta Highlands		Total	
		N	%	N	%	N	%
Past Production	Decreased	49	48.5	164	58.2	213	55.6
	increased	32	31.7	89	31.6	121	31.6
	no change	18	17.8	26	9.2	44	11.5
	I do not know	2	2.0	3	1.1	5	1.3
	Total	101	100	282	100	383	100
Major problems of stagnation and decrement	climate variability	43	87.8	146	89	189	88.7
	crop disease	14	28.6	42	25.6	56	26.3
	degradation	20	40.8	58	35.4	78	36.6
	lost improved seed	5	10.2	36	22	41	19.2
	other	0	0.0	1	0.6	1	0.5
	Total	49	100	164	100	213	100

Frequencies are not consistent as respondents report more than one problem.

Source: (Researcher Survey, 2016)

The critical constraints of crop production differ across agroecosystems in that in Fogera plain are excessive flood, siltation and hail; whereas in Farta-Libo highlands, soil erosion and land degradation are the major ones. Erratic rainfall, hail and lack of agricultural inputs and infrastructures are the common challenges in both agro-ecologies. Finally, the major reported problems are thematically classified as climate variability/change, agricultural land degradation, agricultural extension issues and

infrastructures. These constraints reported by farm households are triangulated with the FGD discussant farmers and key informants. Each constraint is discussed as follows:

a. Climate Change and Variability

Recurrent drought, erratic rainfall and flooding are the identified climate-related agricultural production constraints. The survey report and FGD participants indicated that about seven recurring droughts had occurred since the second half of the twentieth century. This has weakened the production potential of the area at different times. Siltation as a result of excessive flooding is a challenge to Fogera plain. It is indicated that surface water from heavy rainfall or irrigation should be removed from the plot within 24 hours for root crops and three days for any rice species [42]. However, the case in the study area is beyond this threshold. The study of [49] also pointed out that flooding is the major problem of the downstream of Rib catchment. The years 1996, 1998, 1999, 2001, 2003, 2006 and 2015 are reported among the most severe flood events. As shown in figure 7, the report of CSA on crop damage published in various years in the study area, also shows that a large number of the farming community was highly affected by excessive rainfall, shortage of rain, flood, hailstone, pest and disease.

Figure 7 Damaged Crop Areas in Hectare and the Cause of Damage in the Study Area

Figure 7 shows the amount of damaged crop land in hectare and the respective causes from 2014 to 2016. Source: (Compiled from [35])

b. Degradation, loss of biodiversity and blanket practices

Libo-Farta highlands are highly exposed to degradation. With the exception of some places such as churches and government-protected forests, the vegetation cover has been destroyed. In these areas, few indigenous trees such as *Tid* (Junipers procera), *Wanza* (cordin) and *Grar* (Acacia) are available. These are common in Tara Gedam forest in Libokemkem and Alem Saga in Fogera–Farta border. The area has been cultivated for a long time which results in degradation and reduction in productivity. Fallowing for recovery is very difficult as farmers have small per capita farmland. There is a shortage of farmland where the average landholding in the area is found to be close to one hectare (Ha). This also limits the size of grazing land and livestock fodder; whereby the crop residue serves only for three to four months. The government is trying to address the problem through natural resource conservation by mobilizing the community's free labor. The agriculture experts mentioned that various governmental and non-government organizations such as Cooperative for Assistance and Relief Everywhere (CARE), Food for Hungry International (FHI), Norwegian Agency for International Development (NORAD) had involved in the conservation works of the area. However, it was challenged by farmers due to various reasons such as opposition to supply free unpaid labor and thought of farmland wastage by the structures. As a result, the structures are not properly protected and become out of use within a year. In earlier times, participant farmers at structure work were supported with a food for work program. The use of the same species of plantations regardless of the difference in climate, application of the same fertilizer regardless of the soil

type, construction of the same SWC structures regardless of land slope, and even the growing of low yield crops regardless of alternative high yielding crops are also the blanket practices and challenges identified in the study area.

The context is different in Fogera plain. The natural resource of Fogera plain biodiversity is under exploitation due to population pressure and traditional farming system. The plain is difficult to cultivate during the rainy season. Using satellite image as studied by [50], the size of the wetland had significantly diminished from time to time. From 1973 to 2011, the size of the wetland shrunk by about 7%, which is transformed to agriculture and settlement. The study of portrayed that Shesher wetland shrunk from 1557 Ha to 136 Ha and Welela from 298 to 159 hectares, within a period of 20 years. The triangulations with the local farmers also corroborated this fact. The shrinkage of the wetland is described as a good opportunity for plowing and a source of grass for livestock. The major causes are withdrawal of Rib river water for irrigation, sedimentation coming from upper stream of Rib river to Shesher, and plowing of the wetland coast. There was no strict and defined ownership for the area. Farmers also reported that it was considered as a public good. Moreover, the construction of levee along Rib river bank disconnected the flow of water to the wetlands, where the natural rainfall is not sufficient to sustain it. The agriculture experts reported that this had resulted in the loss of functions, products and attribute services of the wetland.

c. Agricultural Extension Related constraints (Crop Pests, Weeds and Diseases)

The government of Ethiopia has trained and placed development agents within each *Kebele* administration. Farmers reported the presence of frequent problems in accessing inputs like fertilizer, insecticide and improved seed. FGD participants described that:

We can't find inputs easily and timely. For example, in 2015 urea arrived in July, two months late after we sow. It is always delayed and is impossible to find within the required season of production. Thus, it is common to use local seeds and sow without fertilizer. In some circumstances, improved seeds are sensitive to drought and yield less than the local varieties.

This statement was triangulated by the survey; for example, in the El Nino year of 2015, the mean yield of improved Teff is significantly lower than the local variety in the study area. The other major challenge is pest attack and weed that is also reported by [51] as a common problem in the grand Lake Tana basin. Farmers and development agents identified, birds and rats, insect pests of cutworm on Teff, aphid on root of pepper and vegetables, *Ageda korkur* (on maize), Africa *guaya* worm, shoot-fly, grasshopper, bull worm on chickpea as the major constraints of crop production. The reported common crop diseases were white root/ rot on peppers and chickpeas, late blight on potatoes, *wag*, *kishkish*, *akochir*, head blast on finger millet and rice, septoria on wheat, rust on Barley, wheat and maize. The severe crop weeds in the area are *three egir eshoh (bajaji)*, *Zemed begde*, *Gelmit*, *Amekela*, *enboch*, *Nech lebash (partinum)* and *Yenug anbesa*. The common livestock diseases occurring in the area include contagious bovine pleuropneumonia (lung disease), lumpy skin disease, *fengil* (hen diseases), *gendi*, foot and mouth disease of sheep and goat pox. Farmers complained development experts didn't have better information

about these pests (diseases) than farmers themselves do. The price of inputs is also increasing across period and becoming unaffordable for the majority of the farmer. The price of urea/quintal before five years was 300 *Birr* while in 2018 it is 850 *Birr*.

d. Infrastructure challenges

The other key problem is lack of road and an accessible market. The major means of transport for crop marketing in the area is the donkey. Outside the highways, it is difficult to load perishable vegetables and other crops to the village and town market. Generally, the features, constraints, potentials and proposed actions are summarized and presented in table 10. It indicates the existence of variation in the level of risk/constraint implying the need for diversified options for strategic intervention. The potential options could address the problem of low livelihood, build adaptive capacity and create positive externalities [52].

Table 10 Summary of Potentials, Constraints and Strategic Options of the study Area

Agro-ecosystem	Features, production potentials and options	Major constraints	Some proposed strategies /Adaptation options/
Fogera plain	<ul style="list-style-type: none"> • Rice oriented production • Double production possibility • underground water, • Irrigation • Fish • Milk cow species 	<ul style="list-style-type: none"> • excessive flood/ water logging • siltation • Extension related (disease, pest, weed..) • Climate variability/change 	<ul style="list-style-type: none"> • localized drainage projects; Structures such as grass strips • fruit trees, vegetables • Livelihood diversification (crop, fish..) • irrigation • access and application of improved inputs
Libo-Farta Highland	<ul style="list-style-type: none"> • Largely subsistence based and not necessarily for market • Forest development and fruit, fattening, bee farming • Timber production (high eucalyptus ...) • Irrigation 	<ul style="list-style-type: none"> • Erosion and Degradation • Extension related (disease, pest, weed..) • Climate variability/change 	<ul style="list-style-type: none"> • agro forestry/ timber • irrigation • conservation structures ; closure and afforestation of degraded land • Organic matter utilization (compost: manure, plant residues...) • Livelihood diversification (crop, small business...) proper access and application of inputs

Source: (Researcher Survey, 2016)

4. Conclusion

One of the rationales of this study was to characterize agroecosystem and identify the potential and constraints of crop production that can be used as an entry point of intervention. The agro-ecosystem of the study area is systematically subdivided into two as Fogera plain and Libo-Farta highlands. The study shows diversified agro-ecosystem with notable differences in terms of potentials, constraints and adaptation options. Disentangling with agro-ecosystem, the major challenges of agriculture in Fogera plain are excessive flood, siltation and hail, whereas in Farta-Libo highlands soil are erosion and land degradation. However, erratic rainfall, recurrent drought, lack of access to infrastructure and agricultural extension are common constraints of both agro-ecologies. The Fogera plain has high potential in irrigation, rice production, milk cow species and fish breeding. Libo-Farta highland agro-ecosystem is potentially rich in bee farming, cattle fattening, timber production and irrigation. Thus, the adaptation interventions should address these potentials and constraints as well as complementarities and differences. The government with the participation of the community should strengthen the natural resource conservation and plantation in the upper highlands for simultaneously addressing the siltation and sedimentation problem of Farta plain, and soil erosion and land degradation of Libo-Farta areas. The soil fertility can be further enhanced by applying organic substances such as manure, crop and plant residues. Soil pH is found to be normal in most of the areas. However, in some areas with pH of less than 5.5, it is important to reduce the toxic level and bring the pH to normal range through the application of lime. An appropriate drainage system should be constructed in Fogera plain for removing excessive surface water. These interventions will enhance rice production by maintaining an optimal level of water. The Fogera plain had excess sediment and the application of fertilizer in terms of type, quantity and time require special intervention from experts. Fogera plain wetland should have a properly defined property right and be a source of alternative income for the local community. There is a potential for breeding and harvesting various species of fish, but its success is conditioned on the presence of properly defined property rights.

Moreover, one of the causes of marginal contribution of the practices in reducing the vulnerability of farmers is blanket application of the same fertilizer irrespective of the type of soil and climate, the same species of plantations regardless of the difference in climate, construction of the same SWC structures regardless of land slope, and even the growing of low yield crops regardless of considering alternative high yielding crops.

Though the government has properly placed DAs in each *Kebele*, there are critical challenges in accessing extension services. Crop production is penalized due to frequent problems of accessing inputs like fertilizer, insecticide and improved seed. The *Woreda* administration should plan in advance and store the mandatory inputs such as fertilizer and pesticides. Otherwise, the use of traditional seeds, sowing without fertilizer and pest attack and weeds will further aggravate the food insecurity of the area. The absence of accessible transport to markets is also compromising the viability of growing perishable vegetables. This problem can be minimized through training farmers to use locally made traditional store. Moreover, the existing cooperative unions should be functional by linking rural villages to *Woreda* and zone level markets.

Declarations

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Availability of data and materials

Data sharing is not applicable to this article, data can only be directly accessed from the concerned institutions requesting through formal written letter. The authors have no right to dispose of the data as the climate data is owned by the Ethiopian meteorological agency and the crop yield by the Ethiopian central statistical agency.

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Figures

Figure 1

Conceptual framework for agroecosystem analysis and adaptation planning. Figure 1 explains the how the various factors of agro-climatic zoning, soil and train analysis, the farming system defines the agroecosytem. After defining the agroecosystems, pattern, productivity, and equity and sustainability analysis finally enables to design context specific adaptation strategies. Source: Adapted from [28]

Figure 2

shows the major soil type of Rib Watershed for both Fogera plain and Libo-Farta highland. Source: (Extracted from [32])

Figure 3

shows the elevation of Rib Watershed for both Fogera plain and Libo-Farta highlands, with the elevation range of 1772 to 2847 meters. Source : Extracted from [41]

Figure 4 Yield Per Hec of Major Crops in the Study Area

Figure 4

indicates the pattern of yield crops for five years. Source: (Compiled from [35])

Figure 5 Percapita Production of Major crops in the Study Area

Figure 5

presented the percapita production output/hectare/household) of crops from 2012 to 2016 Source: (Compiled from [35])

Figure 6

this Lorenz curve reflects the income distribution of the sampled households. The red line is the line of equality and the blue line is the actual income distribution. Source: (Researcher Survey, 2016)

Figure 7

shows the amount of damaged crop land in hectare and the respective causes from 2014 to 2016.
Source: (Compiled from [35])