

Full Length Research Paper

Utilizing Geographic Information Systems to Analyze Mountain Resource Degradation and Its Impact on Rural Livelihoods in the GUGE Mountain Range

Teshome Yirgu Bayu

Arba Minch University, P.O. Box, 20, Arba Minch, Ethiopia
E-mail: teshomeyirgu_bayu@yahoo.co.in

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The Guge mountain range of Gamo highland, which is the home of nearly three quarter of a million people, likely constitute one of the most affected part of the Ethiopian mountain system in terms of soil nutrient depletion, grassland and forest degradation and associated disruption in rural livelihood. Land-cover and use change detection analysis using GIS technique depicts that there is substantial alteration of cover dynamics in the area since 1976. In Guge area, agricultural activities is constrained by factors like frost/fog, low level of fertilizer application due to high cost, soil acidity, soil erosion and expansion of imported weed variety locally named as “Wosana”. In response to the constraints, currently some crop varieties were phasing-out of production (wheat and barley) and replaced by high yielding and crop varieties which are resistant to harsh climatic condition (Bashkala, Dana marke and potatoes). During surveyed period, in response to varying environmental and economic constraints household average food production was lower than annual food requirement, implying that food shortage is severe in the area

Keywords: Mountain system, Degradation, GIS, Environmental Management, Cropping Pattern.

INTRODUCTION

Background to the problem

The Guge mountain range of Gamo highland, which is the home of over 724,000 people (CSA 2007), likely constitute one of the most affected part of the Ethiopian mountain system in terms of soil nutrient depletion, grassland and forest degradation and associated disruption in rural livelihood. It is a vast mountain system covering partly four districts in Gamo Gofa zone including Bonke, Kemba, Chenchu and Dita. Thus Climatic variability, land resource depletion, loss of soil fertility and depletion of fuel-wood resulted from ever-increasing population are blamed as the main threat to sustainable environment and seasonal food shortage among the mountain people (Soul 1986 and Whitlow 1988). The negative effect of population pressure over natural environment was forwarded by scholars like, Kumer (1988) in Nepal, Bilsborrow (1991) in Guatemala. They

assumed that over-uses of natural resource and degradation are the consequences of population pressure. As a result of land degradation, soil organic matter has declined, soil nutrients are depleted, and soil depth has decreased, leading to a decline in crop yields and forage. Soil acidity, salinity, and drainage problems as well as the inherently low availability of soil phosphorus also cause yields to decline.

A number of other literatures have also critically documented the impact of population growth on environment and agricultural production. For instance, Roger Ngoufo (1992) in Bamboutos mountains, Western Cameroon; Zeng Yongnian, Feng Zhaodong and Gao Guangchao (2003) in the upper reaches of the yellow river, China, and Tor-Gunnar Vagen (2006) in the highlands of Madagascar. Furthermore, in the study of the relationship between environment, population and rural livelihood a number of views were forwarded by scholars. For instance dependency and regional political ecology theory (Murdoch, 1980), neo-classical economic perspective (Boserup, 1981) and neo-Malthusian approach (Bilsborrow, 1991) are some important theories. Thus, from the aforementioned reviews it is possible to suggest

*Corresponding Author E-mail: teshomeyirgu_bayu@yahoo.co.in

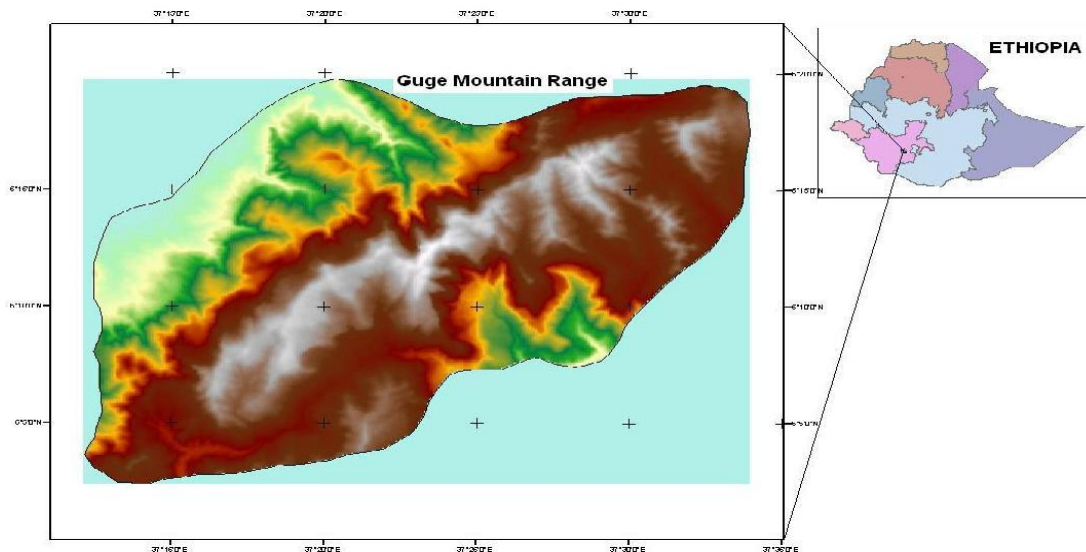


Figure 1. Location map of Guge Mountain Range, SW Ethiopia

that ecological degradation and the resultant resource dynamics can negatively constraint human habitation and food production in an area. In the Ethiopian context, several studies have reported that deforestation and expansion of cultivation into hill slopes and marginal areas were the principal causes of land degradation (Bewket 2003, Gete and Hans 2000).

Biophysical characteristics of study areas combined with inappropriate land use can lead to major and often irreversible environmental damage. In the study area, agriculture is a major land use, net sown area accounts for more than 80 % of total area of the mountain system. Traditional crop–livestock mixed farming is the basis of livelihood of local communities and backbone of rural economy. Extension of agricultural land use into grassland coupled with ecosystem degradation arising from traditional practices of fuel wood collection, grazing and cutting of alpine vegetation for sustaining livestock and maintaining soil fertility in cropland could be a threat to forest biodiversity and ecosystem services on one hand and sustainability of traditional farming on the other.

Given the lack of alternative sources of income, people in the study area remain essentially agricultural, and farming systems are the key determinant of household food security. Guge areas are usually characterized by relatively poor soil quality and often harsh climate conditions that slow vegetation growth and enlarged growing season. In addition, inaccessibility and remoteness of the mountain ranges are obstacles to supply and marketing of agricultural inputs and production, thereby further limiting opportunities for commercial agriculture. As a result, livelihood systems of the Guge households often combine a variety of activities like crop cultivation supported with limited livestock keeping, handicraft and small on-farm businesses. For many households, permanent or more commonly

seasonal migration of selected family members to low lying areas in search of supplementary means of income has become an integral part of the livelihood strategy. Access to food is therefore often a problem, both in terms of quantity (seasonal food shortages, as well as recurrent crisis) and quality (unbalanced diets). Thus the root cause of food insecurity of most households in the area is the inability of people to gain access to food probably due to poverty. Among the contributing factors agricultural dependency on climate, use of obsolete farm equipments, illiteracy and depleted environment holds the lions share. The objective of this study was to examine temporal and spatial land cover dynamics, assess resource degradation and thereby evaluate livelihood strategies used by the mountain people. In addition, it recommends various development options to be used by mountain community.

Data Base and Methods

The study area

Guge mountain range, the study area lies between 6° 05' N to 6° 15' N latitude and 37° 15' E to 37° 32' E longitude. Covering an area of 866 km² Guge mountain ranges are suited in northern Gamo Gofa at about 40 km north of Arba Minch. The location of the study area is depicted in Figure 1. The mountain range stretched from north eastern to south western direction and encompasses about 41 villages that are situated in four districts, namely Kemba, Bonke, Dita and Chencha.

Physically, it is rugged terrain with an altitude ranging between 2400 and 4207 m asl. The study area has cool highland climate with annual average temperature and rainfall of 12.5°C and 1232 mm, respectively. Over 67%

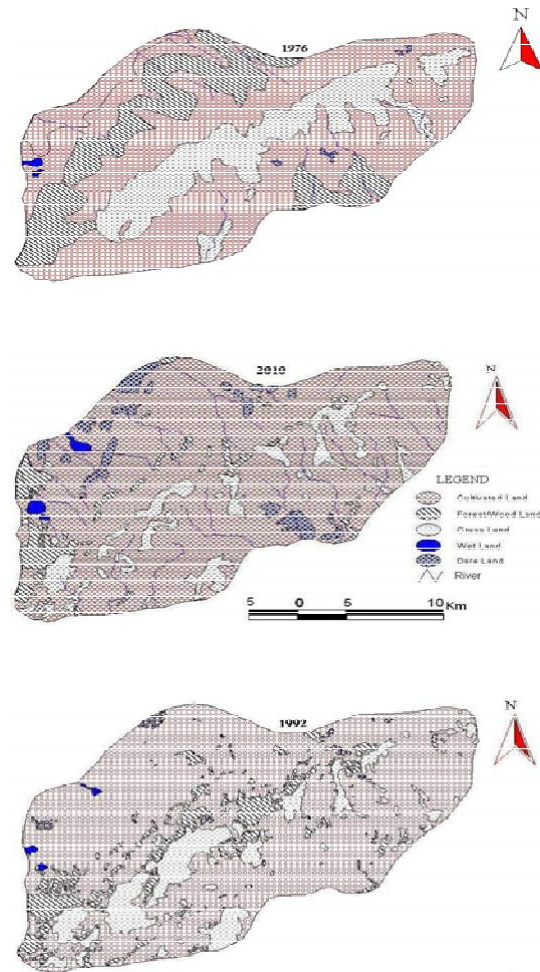


Figure 2. Land Use and Cover change in Guge Mountain Range (1976, 1992 and 2010)

of the total annual precipitation, i. e., 829mm is received during spring and summer seasons (April to September). The study area is among the earlier inhabited and populous part in the Ethiopian mountain system, where natural environment is severely depleted and farm sizes are extremely marginal.

Data acquisition and Analysis method

Various methods were used in the collection, analysis and presentation of land-use/cover and socioeconomic data. However, remote sensing and geographic information system (GIS) has been efficient and powerful tool in providing reliable information on natural resource classification and mapping of land-use/ cover change over space and time (Roy et al., 1991). Satellite images and aerial photographs are useful for both visual and digital assessment of natural resource dynamics occurring at particular time and space as well as quantitative evaluation of land cover changes over time

(Kibrom and Hedlund, 2000). Spatio-temporal changes of land-use/cover of Guge mountain range were monitored by analyzing multi-temporal remote sensing images, using aerial photographs, Landsat and Spot 5 image that are taken in 1976, 1992 and 2010 respectively. In addition, survey of Ethiopia Toposheet (1976) of the area was used for geo-referencing and field check.

The digital image processing of satellite data has been carried out using ArcGIS 9 version 9.2 software. The image elements were corrected based on the ground checks, land use/ cover units interpreted were verified and boundaries of different land-use/ cover finalized for the period 1976, 1992 and 2010. The boundaries of land-use/cover classes of the three periods have been identified and the differences were compared. In GIS environment, area under each category has been calculated. Hence, pattern and direction of changes in land use/ cover have been detected (Figure. 2).

In the collection of socioeconomic data four villages

Table 1. Land-Use/Cover Development for 1976, 1992, and 2010

Land-cover type	1976		1992		2010		Change/year	
	Area(km ²)	%	Area(km ²)	%	Area (km ²)	%	In (ha)	change/year (%)
Cultivated land	636.11	73.45	686.00	79.2	693.92	80.13	170	0.2
Forest land	97.23	11.23	70.00	8.08	46.78	5.4	-148	-0.17
Grass land	127.20	14.69	102.00	11.79	84.16	9.72	-127	-0.15
Bare land	4.06	0.47	5.00	0.58	35.83	4.14	93	0.12
Wet land	1.40	0.16	3.00	0.35	5.31	0.61	12	0.01
Total area (ha)	866.00	100	866.00	100	866.00	100	-----	-----

Source: Satellite imageries

Table 2. Matrix of land cover conversion from 1976 to 2010 (km²)

Land cover type	Cultivated land	Forest land	Grass land	Bare land	Wet land	Total area (2010)
Cultivated land	568.8	45.05	78.7	1.37	0	693.92
Forest land	12.20	31.7	3.08	0	0	46.78
Grass land	24.14	14.4	45.42	0	0.2	84.16
Bare land	27.06	6.08	0	2.69	0	35.83
Wet land	3.91	0	0	0	1.2	5.31
Total area (1976)	636.11	97.23	127.2	4.06	1.4	866.00

Source: Satellite imageries for 1976, 1992 and 2010

were randomly selected from 41 villages in four districts. In this case one sample village (10%) was selected from each district using systematic random sampling technique. Furthermore, 5% of the total household heads in each sample villages was chosen as sample size and used to fill the questionnaire. The household survey data was coded and entered into computer environment for analysis. Then using statistical package for social scientists (SPSS) data tabulation and computation of descriptive statistics techniques was used to examine the statistical relationship between food and farm variables. In addition, to quantify net food availability at household level and assess household food security, household food balance sheet (Negatu, 2005) was computed.

RESULTS AND DISCUSSION

Changes in land use and cover

In Guge mountain range, five major land-cover use types were identified in the 1976, 1992 and 2010 satellite images. Land-use in the area has undergone substantial changes since 1976. Our classification results showed that 3 land cover categories (farmland, bare land and wet lands) was significantly revealed positive change in the last 34 years. On the other hand, forest land and grassland have dropped to 5.83% and 4.97%, respectively in the same period (Table 1 and Figure. 3). To determine trends in land cover change and converted acreage from one category to another during 34-year

period in relation to degradation, we over laid a three period land cover maps. As can be seen in Table 2 that grasslands were reduced by 81.78 km², 78.7 km² of which was transformed into farmlands while the remaining 3.08 km² into forestland. Similarly, in the same period woodlands were reduced by 65.53 km², 45.05 km² of which was transformed into farmlands, and the rest 6.08 km² into bare lands. According to key informants view, over grazing has been widely blamed for grassland degradation. In the studied period, the size of livestock population in the area exceeded the normal carrying capacity by 24.5%, suggesting that overgrazing was critical environmental constraint.

Over the 34 years period, the expansion farm land was amounted to about 5781 hectares (6.68%), and the estimated annual increase was 170 hectares. This is primarily a result of cultivation for densely covered grassland and forestland. Thus, cultivation of grassland and forestland has destroyed soil structure, increased soil erosion, and triggered degradation and flooding of low-lying farms by sediments and gravels brought from the upstream areas. The increase in bare land (gullies, rock covers and sand cover areas) from 4.06 km² (1976) to 35.8 km² (2010) is the ultimate consequence of land degradation. Our analysis reveals that bare lands increased by 0.12% per annum, primarily as a result of over grazing, forest clearing and cultivation of sloppy hill slopes. The increase in bare land areas during the 34-year period indicates that over exploitation of natural resources in Guge mountain ranges have not been slowed when compared with the trend before 40 years

Table 3. Livestock Density in Guge mountain range, 2011

Variables	number	TLU	density/ha	livestock unit/ ha
Cattle	136,485	136,485	16.2	16.2
Sheep	160,799	24,119.9	19.12	2.87
Horse	11,200	11,200	1.33	1.33
Mule	1,169	1344.4	0.14	0.16
Total	309,653	173,149.3	36.79	20.6

Source: Survey data, 2011

(village elders' views). On the other hand, woodland and grasslands revealed a reverse pattern. The area occupied by woodland and grassland showed a drop of about 5.83% and 4.97%, respectively. Both positive and negative increase in the size of land cover was paramount in the latter period (1992-2010) probably due to the increasing pressure of human and livestock population on natural resource.

Environmental impacts of land cover change

Demographic and livestock density

Population of the study area has been increasing at an average rate of 2.5% per annum over the 1990s. Based on the 2010 population and 2010 satellite data, the average farm holdings is 10.4 person/ha; which is equivalent to 0.58 ha per household (average household size in the area is 6). This is far below the sustainable average farm size of 2.5 hectare per household in Ethiopian situation. In response to the newly added households into the farming community, additional grassland and forestlands were transferred into farmland at an increasing rate (0.2% per annum). If the present rate of population growth (2.5%) cannot be curtailed by positive measures all forest and grassland will be converted into farmland in less than five decades (district development agents view). Livestock plays an important role in supplementing the livelihood of rural community especially in those areas practicing sedentary agriculture. In the mountain community like the study area, the presence of livestock is important for the supply of manure or dung for enset/ cereal fields and supplement protein deficient staple food *kocho*, source of farm labor and for generating cash income in time of need.

Besides, livestock is considered as a means of security and coping method during crop failure and natural calamities. Livestock statistics except goats in all villages of Guge mountain range was 309,653 (district agriculture department, 2011), but due to increasing human population and shortage of grazing land, per capita livestock was below the optimal size to sustain a sedentary community. In the study area for most smallholders the price of inorganic fertilizer is unaffordable, thus farm production is progressively

declining in response to scarcity of animal manure that enriches enset and cereal fields. This situation aggravated condition of household food security and further shrunken available income among the households in the mountain community.

Based on the livestock census stated in Table 3, the aggregate stocking level (20.6 LSU per hectare) was more than the carrying capacity of the study area. According to Food and Agricultural Organization (FAO) 1986, the size of grazing land required per total live stock unit (TLU) is 1.5 hectares. If we consider FAO's estimate, the total grazing land required to the number of livestock unit in the study area should be 259,723.5 hectares. This is more than thirty folds from what is currently available in the study area (8416 hectares). Therefore, in order to support the present livestock population Guge mountain ranges need additional 164,733 hectares grazing land.

From the ongoing analysis it was evident that the grass lands are over-stocked and deteriorated beyond the carrying capacity and it became the major cause for severe environmental deterioration in the mountain system. This condition further aggravates condition of over grazing and soil erosion on the rangelands. The condition was clearly seen in the analysis of satellite images that barren land has increased by 7.3 percent (0.2 percent per annum) during the studied period (1976-2010). In response to decreasing grazing lands, the size of sheep and cattle per household was sharply diminished, which negatively threaten the status of food security in the area. Field observation in Haringa, Gugula, Wusamo, Bonke Kashaso and Gana kare villages revealed that due to the scarcity of grazing lands people in the neighboring villages are continually clashing over the scarce resource and such conflict became a serious security and ecological threat for the mountain community.

Mountain Resource Degradation

The dominant vegetation covers in the area are: (i) remnants of woody vegetation such as *Hagenia abyssinica*, *Bamoo* (*Arundinaria alpuria*) *Erythrina bruce*, and *Eucalyptus tree* are found in remote well drained hill sides; but among which purely bamboo and *Eucalyptus*

Table 4. Locally perceived cause for declining vegetation covers

Causes	Number of response (consider only top rank)	Percentage
Farmland expansion	56	74.7
Demand for fuel & construction material	7	9.3
Inappropriate forest management overgrazing	2	2.7
	10	13.3

Source: Author's notes, Feb. 2011

Table 5. Locally perceived cause for declining soil fertility

Causes	Number of response (consider only top rank)	Percentage
Repeated plough	48	64
Soil erosion	19	25.3
Inappropriate land use	2	2.7
Low use of fertilizer	6	8

Source: Author's notes, Feb. 2011

tree forests are found in few selected localities like Lasho, Mitsa, Galga, Tsida, Sura and Maze hills (ii) in hill slopes above 3000m asl short grasses and thickets of alpine type are dominant. Currently these covers were highly disturbed and encroached by cultivators from low-lying villages. Along the hill slopes group discussion with village elders revealed that the increasing need for fuel wood and farmland forest covers were badly damaged beyond natural regeneration rate. Thus alpine woody covers subsequently gave way to short mountain grass covers. Discussion result further confirmed that before 35 years, current cover types (short grasses and remnant bamboo forest) was occupied by highland forests, bush of herbs, thickets that sheltered numerous wild lives; suggesting that the rate of forest degradation in the area was paramount. As to the current situation of forest resource, respondents were asked to rate the cause of vegetation deterioration in their locality. Accordingly, over 74% of the respondents have the opinion that farmland encroachment resulted from newly added households into farming community would be blamed as the major constraint. Overgrazing by livestock could be rated as the second major cause of grassland degradation in the mountain system, which was chosen by 13.3 % of the total respondents.

As stated in Table 4, 9.3 % replied that clearing forest for fuel and construction materials could be the third environmental problem in the area that need further attention from concerned stakeholders. The analysis was further confirmed by the satellite data that natural woody vegetation cover was receding at alarming rate, indicating the rate of degradation was 148 ha per annum. It became clear from the group discussions that farmers are able to identify soil degradation (loss of soil nutrients and erosion) by reduced yields and followed by poor crop

performance. In addition, Farmers also listed rocky outcrops and crop wilting at the end of the rainy season as indicators of low soil fertility. Discussion about the status of soil on their farm further revealed that it was moderate to severely eroded. Respondents were asked to explain the main cause of fertility decline of soil on their farm. Majority of farmers argued that repeated plough (64%) is the main reason. Due to population pressure most farmlands including marginal lands were cultivated and fallow period was neglected as more lands were brought under cultivation, resulting in decreased soil fertility and increased erosion.

Furthermore, 25.3% believe that soil erosion, especially washing soil nutrient during the rainy season as the main agent; another 8 % believe low manure or inorganic fertilizer use to be the problem (Table 5). This is related to the limited size of livestock population that dwindle the amount of manure applied on the farm and the increase in market price of inorganic fertilizer in the area. 2 % of the farmers perceive inappropriate land use to be the other cause, arguing that it is up to the farmers to arrest human induced soil degradation.

As outlined during group discussion with village elders and Development agents that soil erosion, variability of rainfall (early or late on-set of rainfall), scarcity of grazing ground, farmland encroachment to steep slope alpine grass lands, soil acidity and expansion weeds locally named as "*wosana*" are the outstanding environmental problem that badly affect farm production in the mountain system.

Livelihood system and change in crop diversity

The Guge mountain range is characterized by relatively

Table 6. Household asset endowments and technology use in sample villages.

Attribute	Yoyera	Gana kare	Koche	Kacha kashaso	total
1. Education of household head					
Illiterate (%)	40	60	40	60	50
Literate (%)	60	40	60	40	50
2. Family size (%)					
< 5 members	13.3	5	15	8.3
5-10 members	80	80	95	85	85
> 10 members	6.7	15	5	6.7
3. Livestock holding (%)					
1-5 LSU	69	52	66	62	62.3
6-10 LSU	31	48	34	38	37.8
4. Land holding (%)					
<0.25 ha	26.7	20	25	10	20.5
0.25-0.75 ha	46.7	35	55	45	45.5
>0.75 ha	26.6	45	20	45	34
5. Use of modern input (%)					
Improved seed	32	38	17	22	27.3
Chemical fertilizer	76	84	72	68	75

Source: survey data, 2011

poor soil quality and often harsh climate conditions which slow down the growth of crops. Inaccessibility and remoteness of the area is obstacle to supply and marketing of agricultural inputs, thereby further limiting agricultural production. As a result, livelihood systems of mountain households often combine a variety of activities such as crop cultivation, keeping of animals, handicrafts and seasonal labor. For many households, seasonal migration of selected members of the households (mainly male household heads and girls) in search of supplementary income has become an integral part of the livelihood system. Most young house holds are migrating to maize and cotton farms located in low-lying areas and stayed there for not less than eight months in a year. Usually labor migration made after sowing season (July) and returned back to their home villages in the harvest season (January).

In the previous days growing of Barley (*hordium vulgare*), and enset (*enset ventricosum*) in mid elevation and potatoes and Dana marke at the alpine zone is the dominant cropping pattern in the area. But currently in response to the changing climatic condition, declining soil fertility and shrinking farm size pease, beans and wheat are phasing out of the cropping pattern at the expense of potato, Bashkala and Dana marke. The driving forces for the expansion of “Bashkala” would be its resistance to frost/fog, its high market value, and promising yield in less fertile soil, and its large potential to cover household food supply compared to other cereals. On the other side, *Dana Marke* has also the ability to stand against harsh alpine climatic condition and gave high yield in acidic and less fertile soil condition irrespective of its long growing season, usually eleven months. Due to cold

temperature, farmers in Guge mountain range often harvest one time a year and the harvest is vulnerable to early and late frosts. Thus, seasonality of agriculture production and low yield affects local food availability and consumption. In the area, productivity in agricultural activities are constrained by factors such as low level of fertilizer application, lack of knowledge in improved farming practices, climatic variability and low soil fertility. In response to constraints most of the households in the area must endure several food-insecure months every year.

Socio-economic characteristics

As stated in Table 6 that assets such as educational attainment of household head, size of land and labor, size of livestock and technology uses are the critical factors that affect farm economic performance and influences food production. For instance, an educated farmer can better understand and apply modern farm inputs and other recently introduced farm innovations, so that she/he can increase farm output as compared to non-educated households and thereby easily secures any food shortfall. In the study villages, educational attainment of the household heads was varies at village level, though it was 50% for literate and illiterate at an aggregate level. The average family size in the area was 7, which is higher than national average (5.4) and majority of households (85%) have 5-10 members in the family, though there exist disparity throughout the studied villages (Table 6). In traditional society under which the farm economy and consumption tends to be mainly Family-centered; the per

capita food availability declines when the number of consumer increases. This is, in fact, one of the reasons for blaming rapid population growth and the resultant large family size. Therefore, under condition of degraded soil, diminished holdings and obsolete production techniques coupled with large family size, especially dependent family members can do nothing for increasing agricultural production. However, according to the perception of village elders, large family size is considered to be an asset for the households; since children at the early ages engaged in looking after cattle, fetching water and fuel wood.

Sufficient land appears a critical input both for crop production and livestock rearing. Hence, it is assumed that households' food security and size of landholding have a strong positive relation. In the study area, the mean holding size per households was 0.5 hectare, which is almost equal to the national average, while 20.5% households are small holders (0.25ha), and 34% are large size holders (> 0.75ha). The Guge community also raises sheep, cow, oxen and horses. The average live stock holding size was 4.6 LSU and 62.3% households own 1-5 LSU. An increase in livestock population enables the people to be food secure either through income or through direct consumption. Livestock possession particularly the ownership of farm oxen forms the cornerstone of farm economy in the traditional agriculture. However, the number of oxen per person, which is an important traction power in the Ethiopian farming system, is very low and its ratio is 1: 0.6. The condition was even worse in the studied villages (0.3 ox per household), suggesting that in this part of the study area hoe is the most dominant farm implement used for cultivation. Hoe is labor intensive and time-consuming farm implement.

The increasing use of modern farm inputs, such as chemical fertilizer, improved seeds and pesticides has a positive effect on food supply, because they have the capacity to raise agricultural production. However, the application of those inputs was constrained by its increasing price and inability of smallholder farmers to purchase those items. But due to government involvement in payment facilitation and awareness creation, in the studied year about 75% and 27% of the total respondents in the study area used chemical fertilizer and improved seeds, respectively. Therefore, the availability of labor, land and livestock and other production factors play an important role in raising agricultural productivity in the study area.

CONCLUSION

It can be concluded that Guge mountain ranges are susceptible to varying categories of land degradation such as soil erosion, overgrazing, landslides and deforestation, which finally resulted in disruption of the

rural livelihood. In the mountain system scarcity of crop land and grazing land, soil nutrient depletion especially soil acidity, rainfall variability, extreme cold temperature, occurrence of frosts, expansion of environmentally hazardous weeds and food shortage are among the pressing problem. When recommending changes in environmental management and farming practices, a new approach to the farmers needed in many cases: Such as biological and mechanical conservation structures should be followed by inputs such as lime application on acidic soil, fertilizer and other farming factors are effective strategies for mountain resource rehabilitation and sustainable livelihood development. To reduce the situation of household food shortage, farmers should be encouraged to cultivate acidic soil and bad climate resistant crops in addition to recently emerging practices such as cultivating value added crops (Dana marke, highland apple and bamboo trees). The long-term remedy for rural food shortage however, rests on ensuring small-scale credit facilities and diversifying livelihood strategies by pushing out the smallholders from unproductive and marginal farms into more viable income sources such as ecologically sound livestock husbandry and small scale businesses.

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