Vol. 9(10), pp. 164-179, October 2018
DOI: 10.5897/JSSEM2018.0695
Articles Number: E99077F58847
ISSN: 2141-2391

http://www.academicjournals.org/JSSEM

ACADEMIC JOURNALS
expand your knowledge

Journal of Soil Science and Environmental Management

Full Length Research Paper

Mapping soil terrain resources and descriptions of agro-ecological zone in Dawuro and Gamo Gofa zones in south-western Ethiopia

Asrat Guja Amejo

Department of Animal Science, Agricultural Sciences College, Arba Minch University, Arba Minch, 21, Ethiopia.

Received 26 June, 2018, Accepted 17 July, 2018

This study aims to identify and delineate land resources including soil, water and terrain resources, and major river basins, with demographic data and agro-ecological zone classification of general climatic conditions and vegetation characteristics of Gamo Gofa and Dawuro zones in South-western Ethiopia. Metadata source and visual assessment were used for this purpose. Agroecology zone classification is based on elevation, reference length of growing period, temperature, soil type, major river basins at district level alongside their relationship and specificity in land use system. Agroecology approach is particularly useful for agrarian systems, because it provides information about their physical functioning and their spatial/temporal differences. It shows the differences that exist clearly in the structure and physical/biological functioning in agriculture- either natural resources and consumer market link or a new transition toward a more sustainable agrarian development. This work is designed to ascertain the state of natural resources to aid coherent decision making regarding resource use efficiency in rural development process.

Key words: Agroecology class, Dawuro, Gamo Gofa, river basin, spatial soil distribution.

INTRODUCTION

Landscapes that have many different uses and in a way that meet the multiple objectives supporting livelihoods, food production, and ecosystem conservation of land users have received a wider attention. Managing food, water and energy at the landscape level is key to achieving sustainable farming systems, and that has received increasing recognition over the last 10 years (Braslow et al., 2016). Changes in land, water, and other natural resources will either impact users' access to resources or require individuals or communities to adopt certain natural resource management, both of which are likely to affect users' livelihoods. For example, mountain small-scale farms are usually not the centres of national production in terms of quantity, yet small-scale farms in mountains help shape mountain landscapes, providing ecosystem services (such as provision of freshwater, disaster risk reduction, preservation of biodiversity including agro- biodiversity, and space for recreation and tourism) that

Email: gujasrat@gmail.com Tel: +251911071200.

are vital for development far beyond mountain areas (Wymann von Dach et al., 2013).

According to the United Nations Sustainable Development Solutions Network (UNSDSN, 2013), soil erosion, drought, salinization, waterlogging, desertification and other forms of land degradation have spread widely in the past 30 years, particularly threatening ecosystems and agriculture in smallholder environments. Recent land degradation associated with economic losses was estimated at 5% of total agricultural gross domestic product (UNCCD, 2013).

In the coming decades as the report indicates, less water may be available, and more droughts are expected to occur (Dai, 2013). Over 40% of the world's population may be living in river basins experiencing severe water stress by 2050 (OECD, 2012). The world food production coming from irrigated systems is 40%; only about 20% comes from the arable land area. A much higher level of food security and sovereignty without more irrigated agriculture can be unlikely achieved in Sub-Saharan Africa (UNSDSN, 2013). More investments in improving water productivity in existing schemes and safely expanding irrigated agriculture will be needed for long-term food security that should ensure maximum efficiency and protect critical freshwater resources with a strong emphasis on policies and new technologies (Rosegrant et al., 2009). The use of surface water and groundwater resources by different sectors will be a balance of integrated solution (Gleick, 2003).

Without clear metrics and well-designed research using institutional approach to make the metrics operational, efforts to evaluate the cross-sectoral performance, systems that take full advantage of new technologies, and reaching the targets for sustainable development will remain an amorphous goal.

Reversing land degradation in most cases will require investments by either outside investors or by communities and individuals. Following recently agreed voluntary guidelines for responsible governance of tenure of land, fisheries and forests (FAO, 2012), countries should craft their own policies to ensure equitable, inclusive access by the rural poor to these critical resources. The acting together now for pro-poor strategies against soil and land degradation (AGORA) seeks to facilitate a process by which farmers are empowered to work together with other stakeholders to design and implement equitable solutions to land degradation and associated development problems, for instance, in many Africa countries.

Mapping characteristic feature of spatial information will identify areas that could be targeted for natural resource management and land restoration. Any proposed changes through these management practices can have positive impacts on their livelihood and could be equitable to all potential users. The maps that result from this process can also validate previous or future suitability analysis or assumptions about land use and land cover change trajectories. The maps can also be used to target detailed biophysical data collection on current stocks of ecosystem services, which will provide an indication of whether current levels of use are sustainable that could provide the benefits on improved natural resource management. An inventory of available resources, often summarized in database formats and expert systems are the two complementary components for a system-based research strategy. With its greater emphasis on the capability of land resources to support specific types of agricultural development, the agro-ecology approach can improve the efficiency of research and the potential impact of technologies generated by research (FAO, 1994).

This approach initiated the idea to identify topography, soil type, watershed, river and to classify agro-ecological zones on general climatic condition and vegetation characteristic using metadata source together with visual assessment to map Gamo Gofa and Dawuro zones in south-western Ethiopia.

MATERIALS AND METHODS

Description of the study area and data

The areas addressed in this study are Gamo Gofa and Dawuro administration zones in South Nations, Nationalities Peoples' (SNNP) regional state in south-western Ethiopia. Gamo Gofa and Dawuro administration zones are those of the fourteen zones in SNNP region in Ethiopia suited in the south-western part of the country. It lies between 5° 34′ 16.31″ N to 7° 20′ 57.61″ N of latitude and 36° 22′ 13.04″ E to 37° 51′ 25.91″ E of longitude. The total area of the zones is about 16,530.49 km^2. The zones' location with boundary are presented in Figure 1A and B. The zones in SNNP region capture a multitude of AEZ and various diverse form of heterogeneous farming system demonstrated in the entire regions of the country. The traditional management and conservation roles of indigenous knowledge associated with biodiversity expanded biomass base are used for different purposes such as human and animal disease treatment (Andarge et al., 2015).

Taken together with obvious attractions of lakes, hydroelectric dams, and national parks would ensure long-term prospects for tourism. The scene is superb around Gibe III hydroelectric Dam over River Omo, lakes Abaya, Chamo and other small lakes, parks of Neschsar, Maze and Chabara-Churchura which rise toward the hills to over 3560 m behind villages and towns. As Makin et al. (1975) indicated the 1972 World Bank report on aviation and tourism selecting Arba Minch as a center maintains rift valley merits special tourist development.

Data

The dataset includes digital elevation model (DEM), shape, contour line and point data features of Dawuro and Gamo Gofa zones on 10 m x 10 m resolutions projected with global coordinate (GC) system derived from global mapper 8 (USGS) in area extent of 812,529 m north, 616,449 m south, 209, 664 m west and 373, 424 m east. The soil data were obtained from harmonized world soil database (HWSD) version1.2 (FAO/ IIASA/ ISRIC/ ISS-CAS/JRC, 2012). Actual decadal rainfall and Normalized Difference Vegetation Index (NDVI)are processed data for livelihood early assessment and protection (LEAP ver. 2.7) in Ethiopia (WFP/FAO, 2012; Hoefsloot and Calmanti, 2012); reference length of growing period (RLGP)

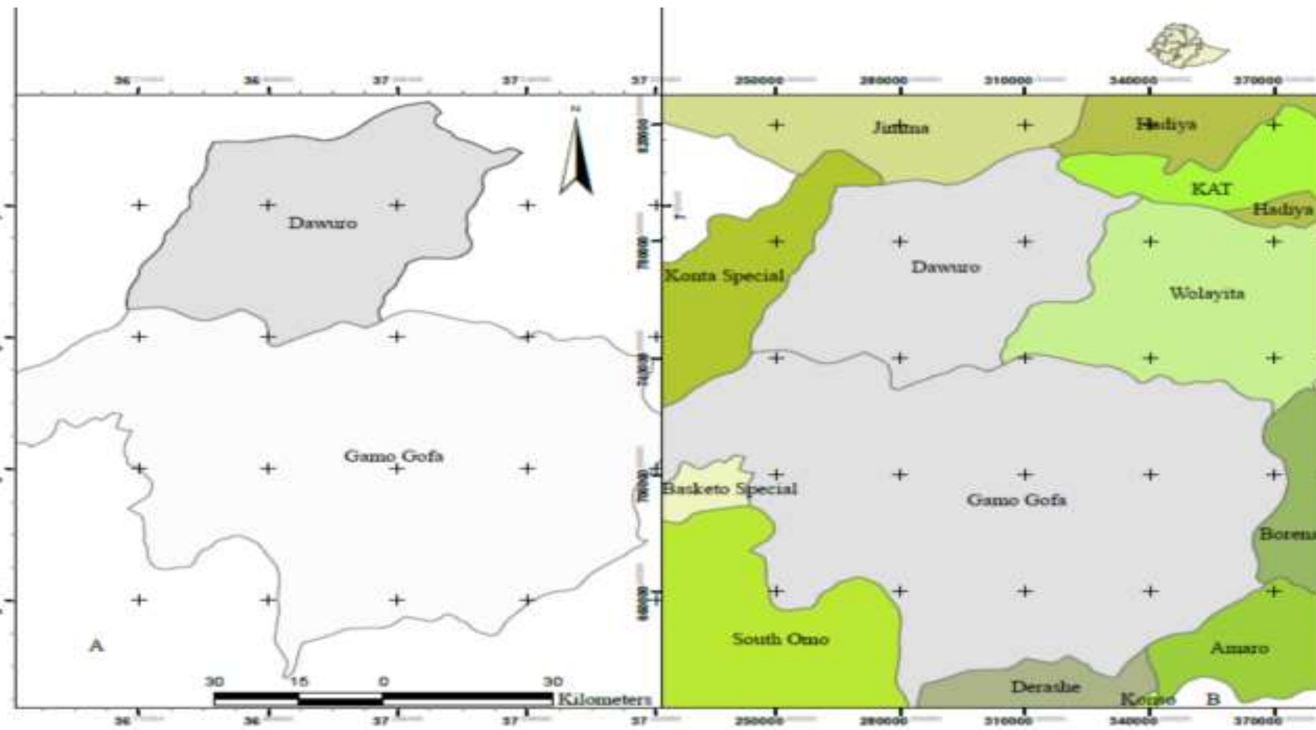

Figure 1. Location map of (A) administration zones, and (B) boundary in the direction in Gamo Gofa and Dawuro zones.

and average annual temperature data from FAO Global Agro-ecology database were obtained. Moreover, field condition observation was purposively made for 2014 to 2017 in different parts of the zones (Amejo et al., 2017; Amejo et al., 2018; Amejo et al., 2018a).

Terrain model data

The DEM of the zones was built in Arc GIS 10.2 to generate terrain dataset in different file formats. The DEM by 10 m x 10 m resolution was derived from global mapper 8. The terrain data include slope, slope direction (aspects), flow direction; and slope of flow directions was derived in the study zones by defining parameters in Arc GIS 10.2. The flow direction was used to derive watershed dataset in the zones, and water resources potential in the zones were assessed zones. The slope (%) of the topography and its area coverage were described from the output dataset in the zone. The slope direction (aspect) and hillside areas were highlighted in the zones.

Soil data

According to FAO report, HWSD is composed of a GIS raster image file linked to an attribute database and can be extracted to excel format. It is a digitized and online accessible soil information system, which aims to allow policy makers, planners and experts to overcome some of the shortfalls of data available to address the old challenges of food production and food security and plan for new challenges of climate change and accelerate natural resources degradation. Thus, the soil dataset from HWSD software was assembled to Arc GIS 10.2 with its projection in GC. The data were re-projected and extracted to point values in area extents of the zones and processed on spatial interpolation in 10 m x 10 m resolutions. The major soils were identified from the analysis, and corresponding soil properties were extracted to excel from HWSD version 1.2 before processing the original dataset and after reprocessing in Arc GIS 10.2 for the purpose of comparison. The spatial distributions of major soil (soil unit) interpolated in inverse distance weight (IDW), were mapped for the zones. The top and subsoils properties of major soils were described.

Rainfall and NDVI data

The long-term, decadal values of actual rainfall and NDVI (RF1, RF2, and ARC2), based on the range of availability were used to describe the trends and patterns of environmental responses in the zones (Amejo et al., 2018a). The actual rainfall available from 1983-1994 ARC2, 1995-2000 RF1 and 2000-2014 RF2 was used. The actual NDVI value available from 2008-2015 in FAO MODIS was used. The data value from LEAP software version 2.7 (WFP/FAO, 2012; Hoefsloot and Calmanti, 2012) was extracted to excel, and averaged to monthly scale at each district level to describe trends of vegetation growth and intra-seasonal environment response in the zones. Intra-seasonal variability on vegetation growing season was described using independent samples Kruskal Wallis test on long-term seasonal average rainfall and NDVI value in the twenty districts of the study zones.

Reference length of growing period (RLGP)

The RLGP from 1961-1990 online available on FAO global agro-ecological database (Tóth et al., 2012) was projected in the project coordination of the country; it was extracted to point values in zonal statistics in GIS 10.2 in area extents of the administrative zones. The values were used for AEZ classification and delineation in the zones.

Figure 2. Terrain map of districts in Dawuro and Gamo Gofa Zones.

Socio-demographic characteristic and water resource

Data record of population census report of 2007 (CSA, 2007) in each district *i* of the zones was used to estimate population density per km^2 as follows.

$$Population\ density = \frac{Total\ population\ in\ district\ i}{\text{Shape area of district } i} * 1{,}000{,}000$$

The river dataset with its attribute obtained from zonal agriculture and rural development office was also mapped in different forms.

Agro-ecological zone (AEZ) classification

The watershed dataset derived in terrain model from flow direction was used as a base for AEZ classification. Using elevation, river basin, resemblance to natural break and boundary share between the districts, soil type, RLGP and temperature together with visual aiding processing in Arc GIS 10.2, AEZs were classified in the zones. For the classification of AEZ an earlier classification made by Ministry of Agriculture (MoA, 2000) in Ethiopia was adopted.

RESULTS AND DISCUSSION

Terrain surface feature

An earlier study showed that Ethiopia has extremely varied topography (FAO, 1984). The complex geological history that began long ago and continues to accentuate the unevenness of the surface; a highland complex of mountains and bisected plateaux characterizes the landscape. Similarly, the terrain surface of Dawuro and Gamo Gofa is patchy mountainous fold across the AEZ (Figure 2), which may be the result of recent earth surfaces transgression. Mirab Abaya, Arba Minch, Bonke Kemba, Ubadebretsh and Ayida districts in Gamo Gofa zone are also laid in East Africa rift valley towards Lake Rudolf. In this striking landscape, the zones area covers about 8.08% above 2400 m.a.s.l. which was classified as the highland AEZs; about 10.79% within ranges of 1800-2400 m.a.s.l. was the midland AEZs and about 81.13% below 1800 m.a.s.l. was the lowland AEZs.

In northern Ethiopia, Dove (1890) described major agricultural zones more precisely as: 'Kolla' with altitudes below 1800 m.a.s.l., 'Weyna Dega' with altitudes between 1800 – 2400 m, and 'Dega' with areas above 2400 m. These are based on broad traditional classification; however, other sub-agroecological classifications have been done in Ethiopia. In the highlands includes the Weyna Dega, Dega, High Dega and Wurch zones; coverage of the observed landscape considerably amounts to 26% of these zones (Hurni, 1998). Assuming that the inverted cone-shaped landscape with narrow side ends in the highlands zones could probably be acceptable to the area coverage amount observed in the present analysis.

The altitude in Dawuro and Gamo Gofa zones varies from about 500 m.a.s.l. at lower valley of Omo River basin in Issara, Loma and Melekoza districts to about 3600 m.a.s.l. on highlands in Dita (Figure 3A). Issara, Loma, Gena, Mareka, and Tocha are districts in Dawuro zone presented in Figure 2 with another fifteen districts in Gamo Gofa zone. The boundary of the two zones lies at Omo River at the center to Gibe III dam between Kuch and Loma districts, and at the lower valley of the Omo River between Melekoza and Issara districts.

A varied complex setup of the land surface topography was observed in the zones through vertical gradients of the slope (%) surface measured from DEM (Figure 3B). In

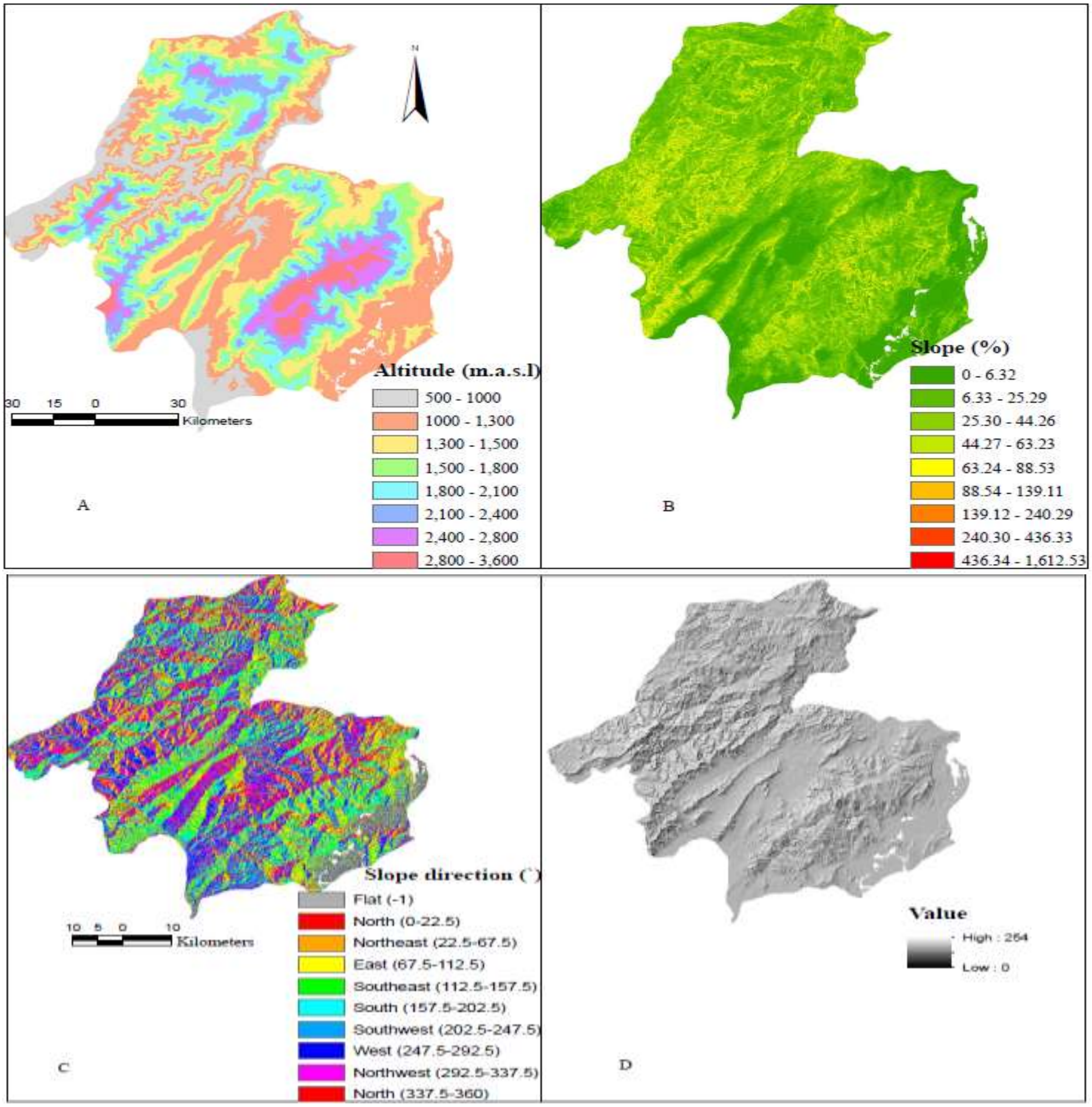

Figure 3. Terrain surface of (A) Elevation (m.a.s.l)l; (B) Slope (%); (C) Slope direction (aspect, ^{0}); and (D) Hillshade (%) in Dawuro and Gamo Gofa zones.

its natural break, the coverage area of the slope surface ranging from 0.0-6.32% is about 17.12% in the zones. This landscape is mainly situated in lowland AEZ of Mirab Abaya, Arba Minch Zuri, Zala and Boreda districts in Gamo Gofa zone. This slope ranges in the central lowlands regions, where Buka, Alee, Tone and Mansa rivers intercept Zea, Gesa, Wogayow, Yidedia, Chawa, Dibina, and the tributaries of Gojeb River from the north to northwest in Dawuro Zone (Figure 9).

Large percentage, about 40.20% area in the zones lies within 6.33-25.29% slope rise, which includes the mound (uplifted) surface scattered across the lowland and the upper highland AEZ. The slope between 25.30-44.26% accounts for about 26.22% area in the zones, marking a uniform break in the gradient upward at an altitude of about 1400 m.a.s.l. The topography lies between 44.27-63.23% slope; its coverage is about 12.14% of the area in the zones. This ranges at an altitude above about 1800 m.a.s.l. by-passing some deflated surfaces in the highland. The remaining 3.94% and 0.38% land surface lie between 63.24-90% and above 90% slope rises, respectively in the zones. The first is a long, vertical

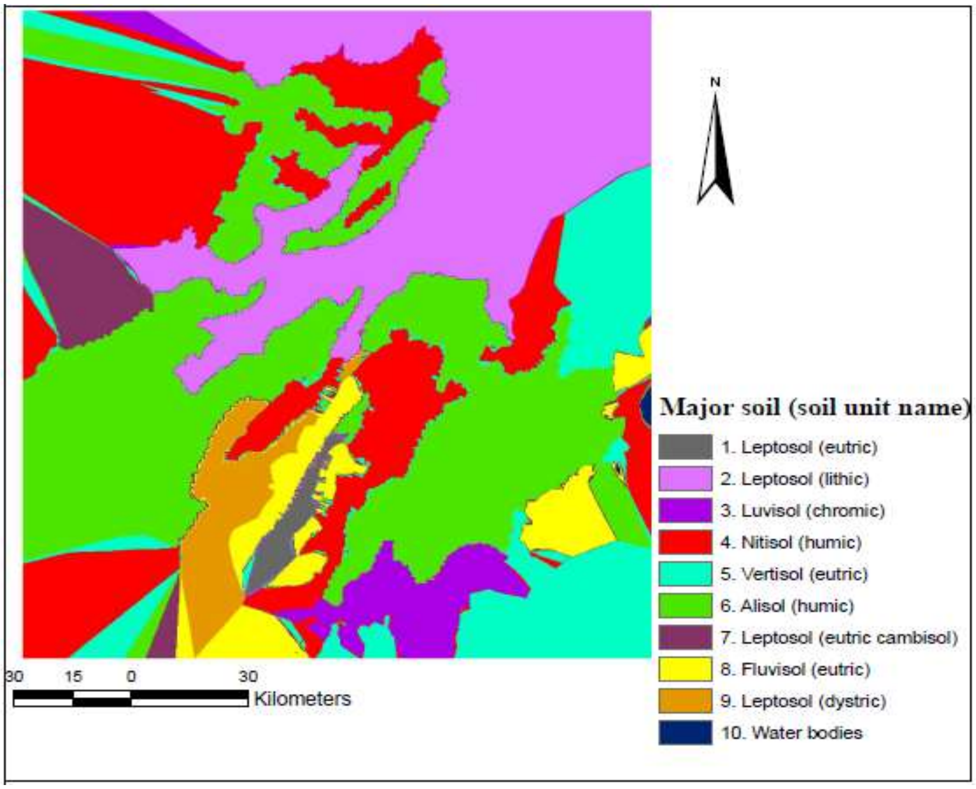

Figure 4. Spatial distribution of major soils (soil unit) from inverse distance weight interpolation on 10 m × 10 m in Arc GIS 10.2 in Gamo Gofa and Dawuro zones.

narrow ridge instituted all over the AEZs whereas the latter is the uplift of the mountainous surface in the highland regions commonly in Dita, Geze Gofa and Tocha districts (Figure 3B).

The degree measures of slope direction (aspect) in the zones are generally inclined towards south-west angle (Figure 3C) having mainly less sun illumination or are darken regions (Figure 3D).

Most of the terrain surface coverage in the zones remarkably reflects typical silvopasture agricultural system despite the varied, complex heterogeneous mixture of the crop-livestock system. The landscape below 25.29% slope could still be important for mixed farming system with its constituent assortment of multi-river channels from upstream, grasslands with diverse browsing species and a wide variety of crop types with favourable performance in wide ranges of soil properties. The existence of an expert agreement and certain characteristics of flexibility in land use system in Ethiopia were addressed by Hurni (1998).

Soil general termed as land is the only basic building blocks of livelihoods of an agrarian society.

Soil mapping

Soil general termed as land is the only basic building blocks of livelihoods of an agrarian society. From farm plot family produces crops and raises livestock; the community gathers food, feed and fiber from forests; water bodies are used for irrigation and catch fish; fibers are used to make clothes and create tools for artesian and fundamentally useful in family incomes to pay taxes, educate children and for medication in free market economy; all these are derived from soil. On top of that, about 42.68% area coverage of the zones landscape lies above 25.29% slope rise which can significantly affects agricultural production and productivity in a marginalized society. Some old church buildings and prolonged historic trends, and dense settlement pieces evidence that some highland regions have been cultivated for longer periods of time in Ethiopia. A frequent phenomenon of frost was also reported (Hurni, 1998). Within the altitudinal range of 1214-2723 m.a.s.l. in some of the present areas, a severe wet stress was also observed (Amejo et al., 2018a).

Leptosols, alisols, nitisols, vertisols, fluvisols, and luvisols are major soils in zones (Figure 4). The first four soils comprise about 91.11% area coverage of the zones. The leptosols are also include about four soil units and cover about 29.06% of zones area, which about 21.72% the lithic leptosols, 3.38% the eutric combisols, 3.15% the dystric leptosols and 0.81% the eutric leptosols unit in the zones area coverage.

The lithic leptosols soil largely occupies the stony bushland to the savannah grassland; it is dominant in lowland regions along riversides mainly where maize, sorghum, teff, groundnut, bean, zinger, taro and sweet potato grow (Figure 4).

The second most abundant soil in the zones, alisols (humic) covers about 28.60% area in the zones. Alisol soil is generally distributed all over the districts with dominant coverage in highland AEZ like Chencha, Dita, Daramalo, Melekoza, Geze Gofa in Gamo Gofa zone and one uppermost escarpment in all districts in Dawuro zone (Figure 4 and Figure 5). Nitisols (humic) soil in the zones occupies 21.23% area of soil distribution mainly in forest belt in Issara, Tocha and Ayida and savannah grasslands of Kucha, Zala, Denibu Gofa, Ubadbretshey and along the plain area in Boreda district.

Eutric vertisols covers 12.22% area of the zones, significantly the lower plains of Arba Minch Zuri, Mirab Abaya, Boreda and Kucha districts in flood running bays to Omo River direct towards the dam point at Gibe III. The eutric fluvilsols covers about 4.74% of the area, basically distributed in Mirab Abaya, Arba Minch Zuri, Boreda and at the center to the south in Zala, Denibu Gofa, Ubadbretshey and Kemba districts.

The chromic luvisols soils which are mainly distributed in Arba Minch, Bonke, Kemba and Tocha districts cover about 4.05% of the zones' area. The soils unit of eutric cambisols (leptosols) are mainly found at lower valley of Omo River basin at about 500 to 600 m.a.s.l. altitude in Melekoza and Issara districts and 600 to 1000 m.a.s.l. in Ubadeberetshey, Ayida, Geze Gofa and Denibu Gofa districts. The eutric leptosols unit occupies the floodplain areas in Zala, Kemba, and Ubadbretshey districts.

The diversity of the major soils is relatively high in plain areas of lowland AEZ. The diversity mainly mechanical results in soils and soils layers due to drainage, erosion and flooding events on upper high slope surface and high weather processes in some rift valley regions in Arba Minch Zuri, Mirab Abaya and Bonke districts. Apart from the limited information on soil, a field experiment by Mengestu (2009) demonstrated about four types of soils in 182 km^2 area of hare watershed between Chencha, Boreda, Mirab Abaya and Arba Minch Zuri districts in Gamo Gofa zones. These soils were cambisol, ferrasol, fluvisol, and regosol.

The topsoil (0-30 cm depth) properties of major soils in the zones are described in Table 1. The topsoil textural classes of major soils in its spatial distribution are mainly dominated by clay loam, light clay, loam, and sand clay loam based on USDA classification.

The topsoils organic matter content, in general, better describe the soils in the zones and particularly high for the humic alisol and humic nitisol soils unit which are the highest distribution in highland to midland AEZ in the zones (Table 1). Soil management and manure utilization condition can enrich this situation in the zones. The topsoil in the zones has traces of mainly acidic to neutral properties which are often described as the best pH for nutrient availability and suitable situations for most crops type in the essence of agronomic management, except the lithic leptosols which are low in pH.

The pedogenetic characteristics of topsoil which relates with clay fraction are mainly kaolinite to illite mixes whereas lithic leptosols are dominated by kaolinite. The total nutrient fixing capacity of topsoil of major soils in the zones is mainly above 10 cmol/kg; it indicates they have high resilience and can build up stores of nutrients. The topsoil properties of major soils identified in the zones mainly reflected saturated conditions for base saturation (Table 1).

Subsoil properties of major soils in the zones are presented in Table 2. The dominant textural classes of subsoil properties described on major soils in the zones are clay loam, heavy clay, light clay and loam-based on USDA classification. The top and subsoil properties of major soils described in Dawuro and Gamo Gofa zones are generally low in cation and salt contents. The situation there indicates that soils in the zones need activation and treatment with cation.

Climatic condition and seasonal response in vegetation

The livelihood system of the community is organized based on the environment and depends on the land size holdings, the scale of food and feed products available from the plots and socio-cultural means to sustain life across seasons in the year. Farm operation and labour productivity are further hindered by the acute seasonality of many climates, in which wide differences exist between the wet and dry seasons, or seasons with and without irrigation water (Ruthenberg, 1971) in tropics. Thus, the series of the seasons are remarkably important for production and allocations of livelihood systems.

Gamo Gofa and Dawuro zones experience dry season during winter period with short rainfall and wet season in summer and rainy period. However, often in the society the year is subdivided into four different seasons locally, namely from Sept-Nov as 'adile'; from Dec-Feb as 'boneya'; from Mar-May as 'assura' and from June-Aug as 'balegua' with respect to differences in rain and sunny condition, environment and access to and availability for livelihood options in a period of season.

The seasonal average of long-term rainfall and NDVI in the districts in Dawuro and Gamo Gofa zones is indicated in Table 3. The seasonal overall average rainfall and NDVI in drier winter season during December to February was 11% (98.79 mm) and 21% (0.23), respectively in the districts in Dawuro and Gamo Gofa zones. In wet (monsoon) winter season during March to May seasonal average land surface rainfall was 44% (410.61 mm) and NDVI was 23% (0.25) in the districts of the zones. This marginal amount of rainfall is the highest in peak bimodal rainfall distribution and more than the main rainy seasons of the year.

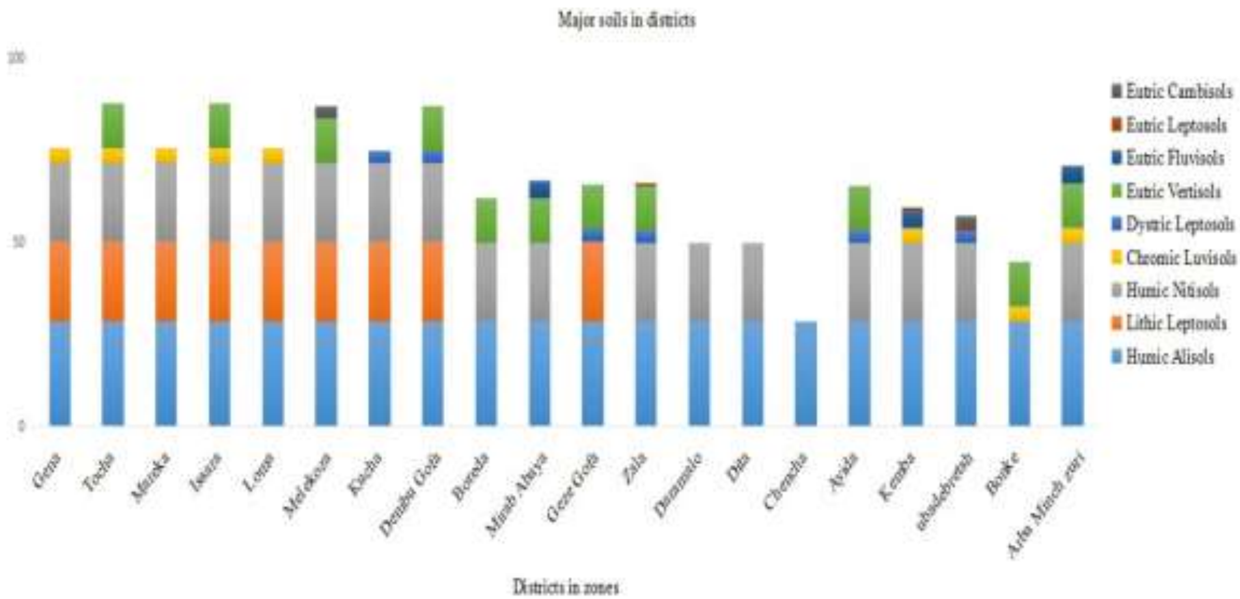

Figure 5. Major soil units extracted to point values from inverse distance weight interpolation on 10 m x 10 m in Arc GIS 10.2 in Gamo Gofa and Dawuro zones.

Table 1. Topsoil (0-30 cm depth) properties of major soils extracted from spatial interpolation on 10 m x 10 m in ArcGIS 10.2 in Dawuro and Gamo Gofa zones.

Property	ALu	NTu	LPq	CMe	LPd	LPe	VRe	FLe	LVx
Texture	M	F	M	M	M	M	F	M	M
Depth (cm)	100	100	10	100	30	30	100	100	100
Drainage (0-0.5 slope %)	MW	MW	IMF	MW	IMF	IMF	P	MW	MW
AWC (mm)[1]	150	150	15	150	50	50	125	150	150
Sand fraction (%)	39	24	43	45	53	50	21	44	51
Silt fraction (%)	29	27	29	31	26	30	25	33	22
Clay fraction (%)	32	49	28	24	21	20	54	23	27
Class	CL	LC	CL	L	SCL	L	LC	L	SCL
Bulk density (kg/dm^3)	1.19	1.18	1.31	1.38	1.45	1.35	1.51	1.33	1.45
Gravel content (%)	1	1	32	1	31	31	1	1	1
Organic carbon (% weight)	2.28	2.45	0.39	0.87	0.75	0.72	1.07	0.73	0.63
pH in water solution	5.5	5.3	7.5	6.6	5.1	6.5	6.9	7	6.4
Clay CEC (cmol/kg)[2]	33	21	51	50	15	49	68	50	31
Soil CEC (cmol/kg)[3]	19	20	16	15	6	12	40	14	10
Base saturation (%)	45	27	100	91	38	87	100	91	85
TEB (cmol/kg)[4]	8.6	5.4	16	13.7	2.3	10.4	40	12.7	8.5
Calcium carbonate (% weight)	0	0	3.1	0.3	0	0.2	0.4	0.8	0
Calcium sulfate (% weight)	0	0	0.1	0.1	0	0.1	0.1	0.1	0
Sodacity (%)	1	1	1	2	2	2	1	2	2
Salinity (dS m^{-1})	0	0	0.4	0.1	0	0.1	0.3	0.1	0

[1]Available water storage capacity (AWC), [2]Cation exchange capacity of the clay fraction (CEC), [3]Cation exchange capacity of the soil (CEC), [4]Total exchangeable bases (TEB); Medium (M), fine (F), Moderately well (MW), imperfectly (IMF), poor (P), clay loam (CL), light clay (LC), loam (L), sandy clay loam (SCL), Humic Alisols (ALu), Humic Nitisols (NTu), Lithic Leptosols (LPq), Eutric Combisols (CMe), Dystric Leptosols (LPd), Eutric Leptosols (LPe), Eutric Vertisols (VRe), Eutric Fluvisols (FLe), Chromic Luvisols (LVx).

The highest annual average (30%) in vegetation growth was achieved during September to November in the districts in zones (Table 3). The period was also the second peak for bi-modal rainfall with 24% of the annual

Table 2. Subsoils (30-100 cm depth) properties of major soils extracted from spatial interpolation on 10 m x 10 m in ArcGIS 10.2 in Dawuro and Gamo Gofa zones.

Property	Humic Alisols	Humic Nitisols	Eutric Vertisols	Eutric Fluvisols	Chromic Luvisols
Class	Clay loam	Clay (heavy)	Clay (light)	Loam	Clay loam
Sand fraction (%)	36	18	20	46	45
Silt fraction (%)	30	21	24	31	21
Clay fraction (%)	34	61	56	23	34
Bulk density (kg/dm^3)	1.35	1.25	1.58	1.4	1.5
Gravel content (%)	1	1	1	1	1
Organic carbon (% weight)	0.82	0.96	0.56	0.32	0.35
pH in water solution	5.6	5.4	7.5	7.3	6.5
Clay CEC (cmol/kg)[1]	37	16	70	49	31
Soil CEC (cmol/kg)[2]	16	20	41	13	12
Base saturation (%)	31	29	100	94	84
Total exchangeable base (cmol/kg)	5	5.8	41	12.2	10.1
Calcium carbonate (% weight)	0	0	1.4	1.8	0.1
Calcium sulfate (% weight)	0	0	0.1	0.1	0
Sodacity (%)	1	1	2	2	1
Salinity (dS/m)	0	0	0.3	0.1	0

[1]Cation exchange capacity of the clay fraction (CEC), [2]Cation exchange capacity of the soil (CEC).

Table 3. Seasonal average of long-term rainfall and NDVI in districts in Dawuro and Gamo Gofa administration zones.

District	Long-term rainfall (1983-2015) mm					NDVI (2008-2015)			
	Dec-Feb	Mar-May	June-Aug	Sept-Nov	Yearly	Dec-Feb	Mar-May	June-Aug	Sept-Nov
Issara	126.68	495.55	303.97	291.9	1218.1	0.28	0.36	0.4	0.42
Gena	106.4	437.89	313.67	291.62	1149.58	0.19	0.24	0.33	0.36
Loma	113.64	489.11	285.38	304.05	1192.18	0.21	0.28	0.35	0.37
Mareka	110.1	483.65	312.84	308.5	1215.09	0.26	0.3	0.34	0.39
Tocha	109.87	476.87	324.59	316.19	1227.51	0.31	0.35	0.37	0.42
Arba Minch Z.	71.49	333.19	112.75	167.29	684.73	0.1	0.11	0.13	0.15
Ayida	108.1	396.98	144.69	182.88	832.64	0.26	0.27	0.23	0.32
Bonke	82.61	354.62	107.38	161.43	706.03	0.25	0.25	0.25	0.32
Boreda	79.12	377.58	195.99	191.53	844.21	0.19	0.19	0.26	0.29
Chencha	75.11	340.86	155.4	185.68	757.05	0.26	0.23	0.26	0.34
Daramalo	84.27	380.85	168.28	190.16	823.57	0.21	0.22	0.29	0.32
Denibu Gofa	111.99	458.98	225.44	246.09	1042.49	0.22	0.26	0.32	0.35
Dita	75.3	353.62	159.67	180.18	768.77	0.24	0.21	0.2	0.31
Geze Gofa	118.76	446.43	202.39	228.66	996.24	0.26	0.3	0.33	0.38
Kemba	94.11	360.51	113.2	166.78	734.6	0.23	0.26	0.27	0.31
Kucha	89.52	421.44	207.81	221.08	939.85	0.19	0.22	0.29	0.32
Melekoza	122.64	462.88	250.27	252.68	1088.46	0.28	0.33	0.34	0.39
Mirab Abaya	82.01	353.57	170.45	192.1	798.13	0.11	0.11	0.14	0.17
Ubadebretsh	110.34	374.16	124.58	174.23	783.3	0.28	0.3	0.29	0.35
Zala	103.74	413.57	178.57	205.19	901.07	0.2	0.23	0.3	0.32
Total average (%)	**98.79 (11)**	**410.61 (44)**	**202.86 (22)**	**222.91 (24)**	**935.18**	**0.23 (21)**	**0.25 (23)**	**0.28 (26)**	**0.33 (30)**

amount. Vegetation was fairly accomplished and normal growth, which started in the second decade of September and reached maximum level in the first decade of November (Figure 6). This could probably be the period vegetation (crops) matures with maximum potential in zones. However, vegetation growth might end in the

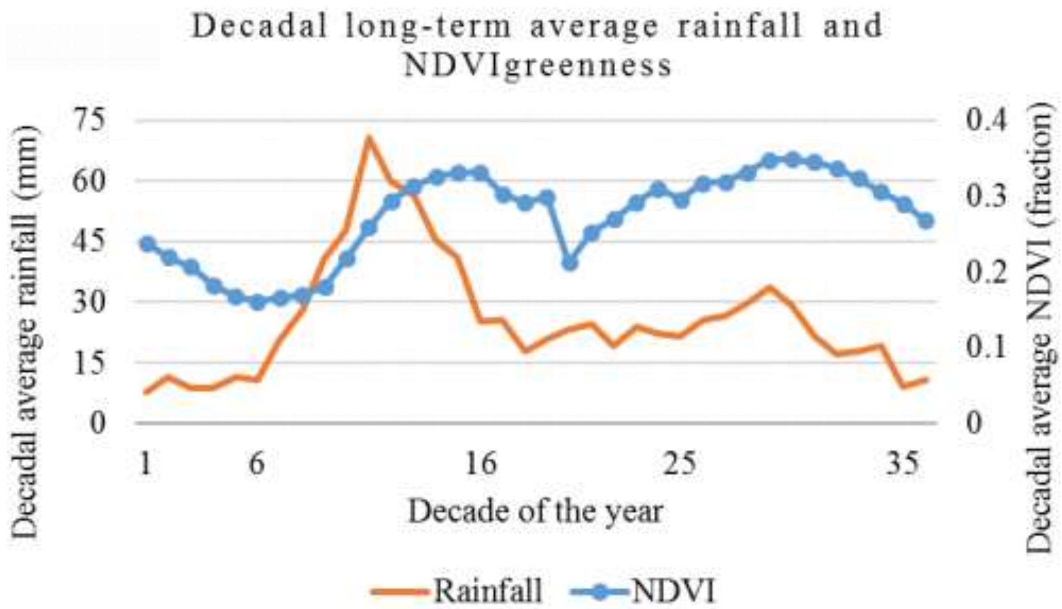

Figure 6. Yearly onset and cessation in vegetation growing season based on overall decadal average long-term rainfall and NDVI in Dawuro and Gamo Gofa zones (decade 1 start on January).

second decade of December in which overall decadal rainfall enters into lagging phase, below 10 mm in the zones.

Vegetation growth is defined in the third decade of March when the overall decadal average rainfall surpasses 33 mm (Figure 6). This persistently continued to peak in the first decade of June after 80 days during the onset of growth. The average amount of NDVI is also high in this period compared to the other seasons of the year which was accompanied by stable rainfall distribution since the onset of growth in the districts.

As Figure 6 shows the main rainy season, during June to August, the decadal overall average rainfall in the second decade of June highly fluctuated till the second decade of July; this might have a negative impact on vegetation growth in the zones. Eventually, vegetation growth retakes from third decade of July to third decade of August with a steady increase in growth curve for about 40 days (Figure 6). The optimum level of vegetation growth was observed in this season in the zones exceptional to some abrupt sunk in growth curve from fluctuation in rainfall amount in July.

A stable decade to decade rainfall amount with averages above 33 mm in each season could largely influence a maximum potential in vegetation growth in the zones. Rainfall occurs back to back period with a decadal average above 26 mm; this could maintain a sub-optimum level of vegetation growth in the regions. This should remind experts of irrigation, hydrology, etc to at least maintain the given level of soil water moisture content in some river available in AEZs in the zones.

The independent samples Kruskal Wallis test showed a significant difference (χ^2=25.55, p=0.00) on a seasonal average NDVI; similar significance difference (χ^2=65.21, p=0.00) was observed on a long-term average of seasonal rainfall in the zones. Pairwise compression of an intra-seasonal pattern of rainfall and NDVI also showed a significant difference in response to yearly periods of growing season. The response of NDVI variability significantly differred between drier winter (December-February) season and summer (June-August) season (χ^2= -20.53, p=0.01), between drier winter and spring (September-November) season (χ^2 =35.03, p=0.00), between wet dry (March-May) and spring (χ^2 =26.08, p=0.00), and between summer and spring season (χ^2 =14.50, p=0.048). Significant difference between drier winter and summer (χ^2 =-26.05, p=0.00), between drier winter and spring (χ^2 =31.25, p=0.00), between drier winter and wet dry (χ^2 =-59.10, p=0.00), between summer and wet dry (χ^2 =33.05, p=0.00) and between spring and wet dry (χ^2 =-27.85, p=0.00) were observed in intra-seasonal variability of the rainfall that induced the variability in environmental condition and growing season in the regions. The trends in the length of the growing season are the results of the differences between the trends in the onset and end of the growing season (Linderholm 2006; Høgda et al., 2013).

The reference LGP between 1961 to 1990 in Dawuro and Gamo Gofa zones isindicated in Figure 7. The reference LGP in the zone ranges from 236 to 279 days. The mean LGP is highest in Chencha 274 days with 15 days range and in Dita 272 days with 20 days range within districts. The different maximum range was in reference LGP in Kemba (43 days) and Bonke (40 days).

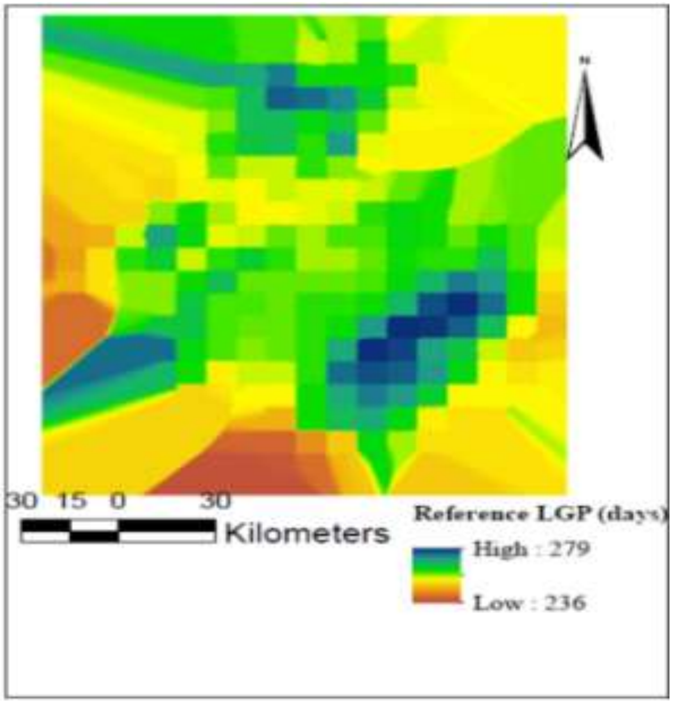

Figure 7. Average long-term (1961-1990) reference LGP (days) from IDW interpolation in Arc GIS 10.2 Gamo Gofa and Dawuro zones.

Socio-demographic and water resource

The highland districts of the zones have high population density. The districts, Mareka in Dawuro zone and Daramalo, Dita, Chencha, and Bonke in Gamo Gofa zone have highest population density, which ranges from 187 to 302 person/km^2 (Figure 8). Whereas the lowest, 62 to 107 person/km^2 is found in lowland AEZ of Gena, Loma, and Issara districts of Dawuro and in Mirab Abaya, Zala, Ubadebretsh, Ayida and Melekoza in the Gamo Gofa zone.

The indicated highest population density in the highland region is probably associated with early period trends of population settlement due to environmental condition suitability to agriculture production and health. Whereas, currently population displacement and resettlement increasingly continued from highlands to lowland due to agricultural land scarcity, less produce and decreasing productivity. In the zones, the rural highland population density is nearly equal to the urban settlement in Ethiopia town. This is in eastern Ethiopia; in Dire Dawa city administration was done by 328 person per km^2 (CSA, 2007).

The zones have about 2286 counts of surface water bodies consisting of 930 intermittent and permanent 1356 rivers (Figure 8 and 9). Among the twelve major river basins in Ethiopia, Gojeb and Omo are the two found in the zones.

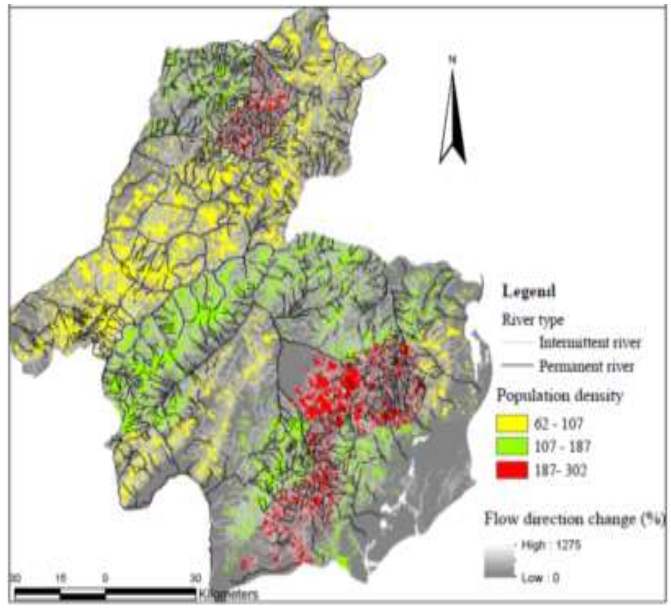

Figure 8. Population density and river types in Dawuro and Gamo Gofa zones.

Agro-ecological zone (AEZ) class

The lower wet lowland AEZ mainly located below 600 m.a.s.l. in the lower valley of Omo River could probably be unique in its elevation range in Melekeza, Issara and Loma districts in the zones (Table 4). An earlier study mentioned that a wide altitudinal range within this range of AEZ (associated variation in climate), from 500 m at Chew Bahir (Makin et al., 1972) which lines in gradients up to Lake Chamo and Lake Abaya was parallel in the eastern side to the Omo River. In fact, Omo River is an upland water contributor to Lake Turkana.

The vegetation is tall grass cover of savannah type grassland. Whereas metadata analysis indicated soils are characterized by riparian type such as Eutric Combisols CMe and Lithic Leptosols LPq. The reference LGP ranged from 242-255 days and long-term average annual temperature between 22.42-25.01 C^0. This AEZ could probably be less anticipated for human settlement and cropping activity. An altitudinal range between 600-1000 m.a.s.l. is almost similar in AEZ, land use system, reference LGP and previous soil type, and exceptional to wider area coverage across districts along the lower valley from Omo to Gojeb river basins. AEZ within a similar altitudinal range around Chamo and Limo-Danigilo lakes differ in soil type, RLGP;the land use system consists of human settlement and livelihood activities alongside Bonke, Kemba, Ubadebretsh districts (Table 4). The AEZ classes could also bear difference given as lower moist lowland adopted from previous AEZ classification of MoA (2000) in Ethiopia.

The AEZ classification of MoA demonstrates that

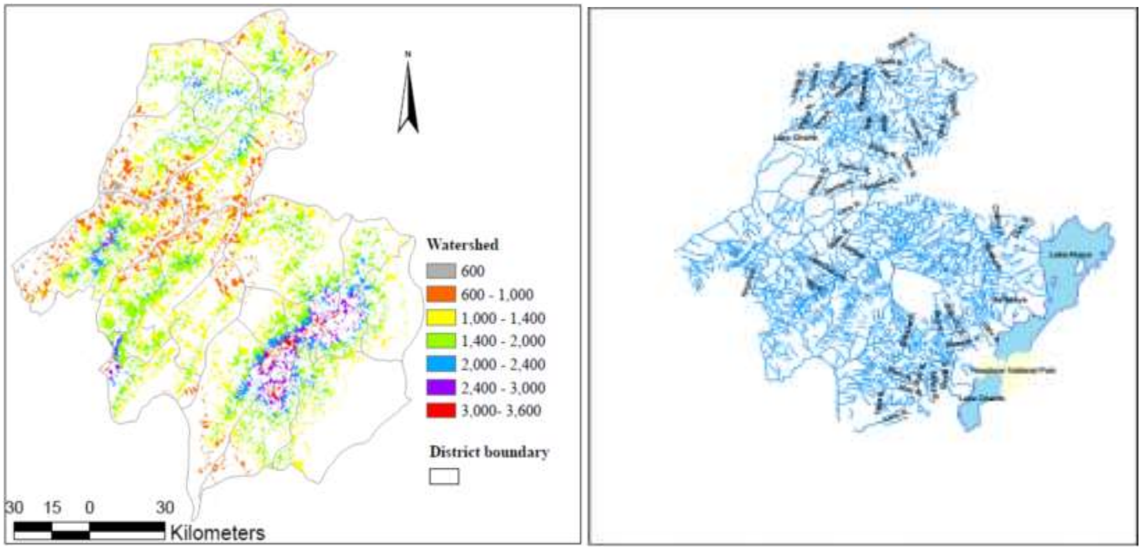

Figure 9. Major watershed within elevation range (left) and rivers, lakes and parks (right) in Gamo Gofa and Dawuro zones.

altitude ranges between 500-1500 m.a.s.l. and average annual rainfall amount is below 900 mm as dry lowland. Based on this Abaya-chamo basins from 1000-1400 m.a.s.l. alongside Arba Minch zuri, Mirab Abaya, Boreda, Chencha disticts are classified into dry lowland AEZ (Table 4). An earlier study by Makin et al. (1975), as well as current station measurement in this AEZ evidence average annual rainfall of about 800 mm. Maize in important food and cash-crop cultivated with cotton, beans and banana with or without intercropping, whereas banana growing towards specialized type farming system is the most promising cash-crop in this AEZ. The woodland opens out and decreases in height, until only well-spaced tall specimens of *Balanites aegyptiaca* and *Acacia tortilis* occur, as well as include common genera in riparian forest such as Ficus, Manilkara, Trichilia, Garcinia and Bridelia along the Culfo River between the lakes (Makin et al., 1975).

At this point, between lakes Abaya and Chamo several of the larger mammals have survived in favoured localities, and especially at Neschsar National Park. At Neschsar, Burchell's zebra, Swayne's hartebeest, Grant's gazelle, greater kudu and waterbuck all occur commonly (Makin et al., 1975). By the same authors, soil fertility, structure and drainage are generally favourable for arable use, the major constraint being low and unreliable rainfall.

The wet lowland AEZ within same altitude range often consists of areas of sparse human settlement with major livelihood activities such as maize, teff, sorghum, beans, groundnut, taro, sweet potato, cassava, sugar cane, coffee, tree fruits, etc. The common livestock are cattle and goats. This AEZ occupies substantial area of savannah grassland with sparsely distributed woody coverage; high prevalent rate of tse tse fly is also common in the dry lowland regions. The wet lowland AEZ includes all the districts in Dawuro zone. At Chabara-Chuchura National Park, mammals such as elephant, buffalo, lion, leopard, wild cat, hyaena and jackal are typical in wet lowland AEZ between districts of Issara, Tocha and Konta special. On the other hand, Swayne's hartebeest is unique feature at Maze Park, between Kucha, Zala, Dermalo districts. Likewise, the AEZ consists of several river basins (Table 4); the upland streams and rivers provide maximum potential for irrigation technology.

Mengistu (2009) highlighted the long tradition of farmers on water management in small scale agricultural use. The author mentioned that hare watershed downstream farmers extensively irrigate a command area of 2224 hectares with three different features. That was a modern diversion from traditional delivery system; a fully tradition and a modern diversion weir at water delivery structure. However, there is no substantial irrigation scheme in Dawuro zone except the failed attempt made by Derg regime during its final phase in Wini-Mawula river basins.

Upper wet lowland AEZ (1400-2000 m.a.s.l) generally lines up region in highland bamboo plantation zones. Teff is an important cash-crop at lower gradient where maize cropped twice yearly either with fresh harvest grows above the boundary of this AEZ. Ruminant livestock density probably high and family diet consists of widely milk and milk products in the advent of extensive grazing. Another AEZ with similar altitude range is upper moist AEZ (Table 4).

The typical characteristic of upper moist zone is usually the short cycle, horticulture farming practice. There is also relative variation within or between soil units (Table 4) that could reflect land use system, mainly in wet upper lowland grassland with increasing tree cover, while in moist upper

Table 4. Classification of agro-ecology zone (AEZ) in Gamo Gofa and Dawuro zones.

AEZ	Characteristics					
	Altitude (m)	Temperature (°C)	RLGP (days)	Major soil	Major river basin	Districts in AEZ belt
Lower lowland wet	< 600	22.42-25.01	242-255	CMe, LPq	Lower Omo valley	Issara, Loma, Melekoza
	600-1000	18.03-23.94	247-264	CMe, LPq	Omo-GojebValley	Issara, Melekoza, Geze Gofa, Denibu Gofa, Zala, Kucha, Loma, Gena, Mareka, Tocha
Lower lowland moist	600-1000	22.72-25.07	236-255	FLe, LVx, Ve, LPe, Nu	Chamo, Limo-Sile-Danigilo	Bonke, Kemba, Ubadebretsh
Wet lowland	1000-1400	20.50-23.43	252-260	LPq, VRe, LVx, NTu	Mansa-Wini/Shata-Wogaye	Issara, Loma, Gena, Mareka, Tocha
	1000-1400	20.03-23.28	247-260	LPq, CMe, LPe, FLe, LPd, VRe, NTu, ALu	-	Melekoza, Geze Gofa, Denibu Gofa, Kucha, Zala, Daramlo Kemba, Bonke, Ubadebretsh, Ayida
Dry lowland	1000-1400	22.06-22.52	251-254	LVx, FLe, VRe, CMe, NTu, ALu	Lake Abaya-Chamo, Sile-Culfo-Hare	Arba Minch, Mirab Abaya, Boreda, Chencha
Upper lowland wet	1400-2000	16.12-22.78	253-272	LPq, LVx, VRe, NTu, ALu	Gindera-Zea, Yideda-Wari, Chewa-Dibisa	Issara, Loma, Gena, Mareka, Tocha
	1400-2000	15.46-21.96	257-268	LPd, VRe, ALu		Melekoza, Geze Gofa, Denibu Gofa, Zala, Ubadebretsh, Ayida
	1400-2000	13.35-21.65	259-274	LVx, VRe, ALu	Sero-Kola-Beshe, Anitale-Bonge, Yamero-Chichla	Bonke, Kemba, Daramlo, Dita, Chencha, Kucha, Boreda, Mirab Abaya, Arba Minch
Sub-humid wet	2000-2400	17.60-18.31	265	ALu, NTu, VRe	Bera	Issara
	2000-2400	16.04-18.69	260-274	ALu, NTu, VRe	Koranto-Gabeno-ton-Aukma	Loma, Gena, Mareka, Tocha
	2000-2400	17.95-18.63	262	ALu	Zea	Gena
	2000-2400	18.52-21.69	255-262	ALu		Denibu Gofa,
	2000-2400	14.25-17.04	261-266	ALu		Geze Gofa, Zala, Ubadebretsh, Ayida
	2000-2400	12.16-21.59	261-278	ALu,VRe	Aniziya Hare	Arba Minch, Bonke, Kemba, Daramlo, Dita, Chencha, Kucha, Boreda, Mirab Abaya
	2000-2400			ALu		Kucha
	2000-2400	15.46	268	ALu		Melekoza
	2000-2400			ALu		Mirab Abaya
Wet highland	2400-3000	16.04-18.69	265-273	ALu, NTu, VRe	Yechi-Wata-Geda-Shepa	Tocha, Mareka, Loma, Gena,
	2400-3000	18.41-19.81	260-263	ALu		Denibu Gofa,
	2400-3000	1654-17.12	262-273	ALu		Geze Gofa, Ayida, Ubadebretsh,
	2400-3000	11.99-18.31	266-279	ALu, VRe	Baba-Beg, Fala-Hayie-Subeno, Alila-Lama	Arba Minch, Bonke, Kemba, Daramlo, Dita, Chencha, Kucha, Boreda, Mirab Abaya
	2400-3000	15.46	268	ALu		Melekoza
Wet upper highland	3000-3600	15.46	268	ALu		Melekoza
	3000-3600	11.83	273	ALu		Ayida, Ubadebretsh,
	3000-3600	12.70-13.54	275-279	ALu		Chencha, Dita

Table 4. Contd.

	3000-3600	13.54	275	ALu		Dita
	3000-3600	11.99-17.64	269-278	ALu	Beg-Kosa-Sheisha	Dita, Kemba, Daramlo, Bonke
	3000-3600	12.97-13.32	275	ALu	Chilo-Hanich	Bonke, Kemba

lowland bush/woodland there is visible bare surface. The common characteristic of upper lowland is the long mountains belt, with high slope rise in the mid-altitude of each zone.

Sub-humid wet within altitude ranges between 2000-2004 m.a.s.l. and is characterized by annual crops such as pulses, wheat, barley, etc. Typical, this AEZs are the origins of many long distance travel rivers downward the lowland AEZs. Most of the districts at this point occur independently by detaching or losing the link along the neighbouring region (Table 4). That could also differ in time and space during planning or by influencing the livelihood of the farm household themselves.

Wet highland within altitude range of 2400-3000 m.a.s.l. is characterized as having dense human population, as well as regions dense in enset, bamboo, eucalyptus/juniper tree plantation farming system. In livestock system, they are specialize in sheep and mare production. Introduction of apple fruit is a foundation stock throughout the country. Soil wet stress is considered as a common problem. Irish potato, garlic and some traditional cabbages are usually rare household income source particularly for women. In the AEZ, enset is supplemented by cabbage and mostly staple food in the household. Farm holdings are increasingly declining and there is shortage of infrastructure for marketing opportunity.

Wet upper highland with altitude range within 3000-3600 m.a.s.l. is characterized as having crops such as barley and pea. Its common vegetation includes broad leaved, short height forbs and shrubs. The supply-side challenge could be considered as high.

SCOPE FOR FUTURE OPPORTUNITY AND POSSIBILITY

Agroecology is deeply enriched by interaction and communication between disciplines and different systems of knowledge in a manner called transdisciplinarity interactive enrichment (Casado and de Molina, 2017). By the same authors, agroecosystems are ecosystems with a "purpose," and that purpose is socially constructed and changes over time, so agroecosystems are much more than systems that produce food. All ecosystems provide environmental services for our planet (such as biodiversity conservation, soil and water protection, carbon sequestration, etc.); they must all be maintained with a high priority for their economic viability, affordability, and accessibility to all. Most importantly, the social sustainability of the food system must become a primary focus of food system change, with what we now call food justice, food security, and food sovereignty being the key goals (Casado and de Molina, 2017).

Nix (1983) asks a question, 'how do we prescribe a technology that is appropriate to the land, labour, capital and management of resources of individual farmers? One of the first steps in classifying land utilization needs to be agroecosystems in which the strong social dynamic system is explained by the way societies interact with their agrarian environment. It can provide a conceptual framework for the integrative analysis of natural (ecological or biophysical) and social processes based on different perspectives to aid coherent decision making regarding energy use efficiency. One of the most relevant is the perspective of the agroecosystem itself, trying to measure both its efficient management and the state of health of its different components falls squarely within the realm of agroecology (Casado and de Molina, 2017). Agroecological indicators have been designed to ascertain the state of the natural resource elements of agroecosystems and, therefore, provide a very useful tool to evaluate the sustainability of agroecosystem management.

Two particular noteworthy characteristics have natural resources and assets; they process energy, materials, and information at a rate determined by their own structure; and they require periodic renewal or reproduction (Scheidel and Sorman, 2012). Given this (Giampietro et al., 2009) a part of the input flows needs to be devoted to constructing, maintaining, and reproducing the spread out energies. The boundaries of the agrarian sector signify the optimization of its possibilities by raising biomass production, otherwise limits growth rate of a given society.

The main elements of natural resource and asset the agrarian development process encompasses are agroecosystems (land in the broad sense: soil, water, biodiversity, etc.) and domesticated livestock, which, when managed by humans, process external energy, materials, and information to produce biomass that, in turn, provides a flow that feeds other dissipative structures of social metabolism (Casado and de Molina, 2017). According to Giampietro et al. (2009), capital is the set of artifacts (a preparative procedure made by an agrarian society) capable of processing energy and materials that are created by humans. The fund elements (productive resources and assets) could even be improved over time, allocating increasing amounts of energy and materials for this purpose (Casado and de Molina, 2017).

The qualitative leap in human transformation power first had impressive effects on the forms of appropriation of nature—agriculture, livestock breeding, fishing, management of water, forestry, and mining, among other sectors—that, in turn, potentiated the accelerated growth of human population, cities, and industry (Casado and de Molina, 2017). The human population living within the territorial limits of a given society should, therefore, consider the processor of the energy, materials, and information required to produce work and assets.

This current agroecology based approach provides land resources including soil resources, terrain resources, major river basin, water resources and demography. Agroecology zone classification is based on elevation, reference length of growing period, temperature, soil type, major river basins at district level with their relationship and specificity in land use system alongside. The potential of land use and farming system is derived through field experience since mid-2014. The database on soil type, terrain feature, water and river basin and the agroecology classes could have importance for various future applications such as:

i) Land use allocation;
ii) Agricultural performance and land suitability assessment;
iii) Rangeland biomass potential assessment;
iv) Hydrologic and irrigation potential analysis; and
v) Land protection status, infrastructure availability, and market access conditions by administration unit in the district level.

A new study can be established on a variety of uses, for instance, ensuring the accuracy of spatial information on soil data obtained from the most recent version of SoilGrids and comparing and estimating probability distribution on soil information by point sampling and laboratory analysis. Regarding the quality of information, further scaling up can be done at regional as well as country level. Agroecology approach is particularly useful to agrarian systems, because it provides information about their physical functioning and their spatial/temporal differences (Casado and de Molina, 2017). It enables differences to be shown with greater clarity, in terms of their structure and physical/biological functioning, between agriculture—either natural resources and consumer market link or a new transition toward a more sustainable agrarian development process.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

Amejo AG, Gebere YM, Dickoefer U, Kassa H, Tana T, Lawrence P (2017). Evaluation of livestock contribution to household income through descriptive analysis and modeling livestock performance in crop-livestock systems in Southwestern Ethiopia. Omo International Journal of Sciences 1(2):1-26.

Amejo AG, Gebere YM, Dickoefer U, Kassa H, Tana T, Lawrence P (2018). Herd dynamics and productivity performance modeling of livestock in smallholder crop-livestock systems in Southwestern Ethiopia. Journal of Veterinary Science and Animal Husbandry. 3(1):17-24.

Amejo AG, Gebere YM, Kassa H, Tana T (2018a). Comparative analysis of climate change impact on livestock in relation to biomass base feed availability using standardized precipitation index in south-western Ethiopia. International Journal of Livestock Production 9(7):184-191.

Andarge E, Shonga A, Agize M, Tora A (2015). Utilization and conservation of medicinal plants and their associated indigenous knowledge (IK) in Dawuro Zone: An ethnobotanical approach. Journal of Medicinal Plants Research *4*:330-7.

Braslow J, Cordingley J, Snyder K (2016). A guide for participatory mapping of ecosystem services in multiuse agricultural landscapes – How to conduct a rapid spatial assessment of ecosystem services. International Center for Tropical Agriculture (CIAT). Cali, Colombia. 86 p.

Casado GIG, de Molina MG (2017). Energy in Agroecosystems: A Tool for Assessing Sustainability. (Eds.), CRC Press.

CSA (2007). Population and Housing census. A. A., Ethiopia.

Dai A (2013). Increasing drought under global warming in observations and models. Nature Climate Change, 3(1):52.

Food and Agriculture Organization (FAO) (1984). Provisional Soil Map of Ethiopia. Land use Planning Project, Addis Abeba.

Food and Agriculture Organization (FAO) (1994). AEZ in Asia. Proceedings of the Regional Workshop on Agro- ecological Zones and Applications, Bangkok, Thailand, 17-23 November 1991. FAO, Rome, Italy.

Food and Agriculture Organization (FAO) (2012*).* Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security*.* FAO, Rome, Italy. http://www.fao.org/nr/tenure/voluntary-guidelines/en

FAO/IIASA/ISRIC/ISSCAS/JRC (2012). Harmonized world soil database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Giampietro M, Mayumi K, Ramos-Martin J (2009). Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. Energy 34(3):313-322.

Gleick PH (2003). Water use. Annual review of environment and resources, 28(1):275-314.

Hoefsloot P, Calmanti S (2012). LEAP version 2.61 for Ethiopia.hoefsloot.com

Høgda KA, Tømmervik H, Karlsen SR (2013). Trends in the start of the growing season in Fennoscandia 1982–2011. Remote Sensing, 5(9):4304-4318.

Hurni H (1998). Agroecological belts of Ethiopia. Explanatory notes on three maps at a scale of, 1(1,000,000).

Linderholm HW (2006). Growing season changes in the last century. Agricultural and Forest Meteorology, 137(1-2):1-14.

Makin MJ, Kingham TJ, Waddams AE, Birchall CJ, Teferra T (1975). Development prospects in the Southern Rift Valley, Ethiopia. Development prospects in the Southern Rift Valley, Ethiopia (21).

Mengistu KT (2009). Watershed hydrological responses to changes in land use and land cover, and management practices at Hare Watershed, Ethiopia.

Ministry of Agriculture (MoA) (2000). Agroecological Zonations of Ethiopia. Addis Ababa, Ethiopia.

Nix HA (1983). Minimum data sets for agrotechnology transfer. In Proceedings of the International Symposium on Minimum Data Sets for Agrotechnology Transfer pp. 181-188.

Organisation for Economic Co-operation and Development (OECD) (2012). Publishing, and Organisation for Economic Co-operation and Development Staff.. Rosegrant environmental outlook to 2050: the consequences of inaction. OECD publishing.

Rosegrant MW, Ringler C, Zhu T (2009). Water for agriculture: maintaining food security under growing scarcity. Annual review of Environment and resources, 34.

Ruthenberg H (1971). Farming systems in the tropics. Oxford University: Clarendon Press.

Scheidel A, Sorman AH (2012). Energy transitions and the global land rush: Ultimate drivers and persistent consequences. Global Environmental Change, 22(3):588-595.

Tóth G, Koslowski B, Prieler S, Wiberg D (2012). Global Agro-Ecological Zones (GAEZ v3. 0). GAEZ Data Portal, User guide, Laxenburg, Austria.

United Nations Convention to Combat Desertification (UNCCD) (2013). The economics of desertification, land degradation and drought: methodologies and analysis for decision-making. Background document. UNCCD 2nd Scientific Conference. (UNCCD, Bonn). http://2sc.unccd.int

UNSDSN (2013). Solutions for Sustainable Agriculture and Food Systems. Technical report for the post-2015 development agenda (www.unsdsn.org).

WFP/FAO (2012). LEAP version 2.61 for Ethiopia. Retrieved from/Available from http://hoefsloot.com/download/leap_install.exe

Wymann von Dach S, Romeo R, Vita A, Wurzinger M, Kohler T (2013). Mountain farming is family farming: a contribution from mountain areas to the International Year of Family Farming 2014. FAO.