5. Characterization of Biophysical and Socio-economic Aspects of Agewmariam Experimental Watershed, Northern Ethiopia

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Abstract

Watershed characterization is required to measure the changes due to intervention and it is important in the planning, monitoring, and utilization of resources in a sustainable way. This paper provides a detailed insight into the biophysical and socio-economic conditions of the Agewmariam watershed and the land capability and suitability maps including the management options. The study collected biophysical data such as land slope, soil properties, erosion severity, stoniness/ rockiness cover, and vegetation cover parameters from field surveys. Socio-economic data such as population demography, income, and expenditure were collected from individual interviews, complete census, and focus group discussions. The study found that there are 259 households inside and around the watershed, with an average family size of 4 people per household and a demographic dependency ratio of 96.6%. The major sources of income are crop production and livestock rearing, while working as casual labor and receiving food aid also contribute to their livelihood. The average farmland holding size in the watershed is 0.5 ha while sorghum, barley, tef, and wheat are the most dominantly grown crops. The study also revealed that the watershed is characterized by six land capability classes; which are classes II, III, IV, VI, VII, and VIII. The suitability analysis shows that the watershed is not currently suitable for wheat and tef crops unless it is managed and improved physically, chemically, and biologically. The major limiting factors were slope, erosion severity, and stoniness for the land capability and soil organic matter and soil texture for the suitability analysis in the watershed. The socioeconomic characterization increased awareness about the local socio-economic condition for appropriate planning and implementation of available management activities. The study suggests that an intensive soil and water conservation intervention, afforestation on hillsides, changing the land use system, and organic matter & fertilizer addition on farmlands could be considered the best alternative management options to improve the land capability and suitability.

Keywords: Land Capability, Land Suitability, Limiting Factor, Soil Properties.

Introduction

A watershed or catchment is commonly defined as an area in which all water drains to a common point (Desta *et al.,* 2005a; Kerr and Chung, 2005; Raghunath, 2006), On the other hand, watershed management is defined as the process of organizing land and resource use in a watershed to provide desired goods and services while preserving natural resources (DENR, 2015) It is recognized as the ideal approach for integrated natural resources management (Desta *et al.,* 2005a; Wani *et al.,* 2003) It is also a principal approach that fits community level planning and that can optimize the use of natural resources and untapped potential in degraded and potential areas (Desta *et al.,* 2005a). The hydrological perspective of a watershed makes it a useful unit of operation and analysis for a systems approach to land and water use in interconnected upstream and downstream areas (Kerr and Chung, 2005).

The Ethiopian Ministry of Agriculture and Rural Development employs a community-based participatory watershed development guideline to enhance productivity, generate income opportunities, and improve livelihood support systems while building resilience to shocks. It is designed to involve community members from the beginning of the idea up to its implementation and impact assessment (Desta 2005a). The partnership and participation of the local community, including farmers, state and local agencies, and community leaders, based on strong commitment, is essential for successful watershed management (Wani 2003).

The Ethiopian governmenthas been long implementing a watershed approach for soil conservation, water harvesting, afforestation, and land rehabilitation activities (Desta 2005a). Baseline assessments also have been conducted in Ethiopia to establish a reference point to monitor changes, and project impacts, and inform other stakeholders and restoration initiatives (Desta 2005a; Sacande 2018). Baseline data facilitates management tasks, research process policy, and planning decisions (Wani and Shiferaw, 2005).

Watershed Characterization is the process of describing the biophysical and socio-economic characteristics and features of a watershed to have an understanding of the various processes therein (DENR, 2015). It involves assessment, quantification, mapping, and understanding of the biophysical resources of a watershed. This process aids in land capability classification, targeting restoration interventions, and monitoring their effects on the environment and people (Desta 2005a; Sacande 2018; Sheng, 1990). Furthermore, Anantha (2009) suggested that characterizing economic variables before and after development can facilitate measuring the impact of watershed development programs on people's economic conditions.

Biophysical characterization involves identifying and characterizing various factors such as slope steepness, surface cover, vegetation type and coverage, soil texture, soil depth, and size of land holdings (Desta 2005a; Sheng, 1990; Ziadat 2006). General data should include agroecology, name and location, boundaries, size, elevation, streams, rivers, tributaries, and others (Desta 2005a).

According to the FAO (1976), the term "Land" encompasses the physical environment, including climate, relief, soils, hydrology, and vegetation, to the extent that they influence the potential for land use. On the other hand, "land evaluation" is the process of assessing land performance for specific purposes by analyzing the relationships between land use and resources, including physical and socio-economic resources(FAO, 1976; SYS C. 1991).

The approach and methods employed in land evaluation are based on fundamental principles such as assessing and classifying land suitability for specific uses, comparing the benefits obtained and inputs needed on different types of land, using a multidisciplinary approach, evaluating in terms relevant to the physical, economic, and social context of the area, evaluating for sustained use, and comparing more than one kind of use (FAO, 1976).

The two most commonly used methods for land evaluation are the USDA land capability classification developed by Klingebiel and Montgomery in 1961 and the FAO land suitability classification developed in 1976. Recently developed classification systems are more quantitative as there is an increased understanding of the relationships among the different factors that influence soil productivity and stability (Cruz, 1990).

The terms "capability" and "suitability" are sometimes viewed as interchangeable, while others consider capability as the inherent capacity of land to perform at a given level for general use and suitability as the adaptability of a given area for a specific kind of land use (FAO, 1976). Land capability classification involves describing and classifying lands based on their biophysical features and ability to sustain various kinds of uses (Cruz, 1990).

The USDA land capability classification system (Klingebiel and Montgomery, 1961) categorizes land into three major groups based on their capability to respond to management systems, conservation problems, and relative degree of hazard or limitation. These groups are capability units, capability subclasses, and capability classes. Accordingly, land suited for cultivation and other uses falls under Class I, Class II, Class III, and Class IV. Meanwhile, land limited in use and generally not suited for cultivation is categorized as grazing, woodland/wildlife, recreation/wildlife/water supply, or esthetic and falls under Class V, Class VI, and Class VII. Class VIII is considered the most limited in use.

The FAO, (1976), land suitability classification method for crops involves four levels: Land Suitability Orders, Land Suitability Classes, Land Suitability Subclasses, and Land Suitability Units. The method helps identify the types and degrees of suitability, as well as any limitations or improvement measures required for successful crop growth.

The FAO, (1976)Framework for Land Evaluation presents principles and procedures that can be applied worldwide. The watershed management guideline used in Ethiopia (Desta 2005a), is considered adaptable and practical for different types of areas. However, Hurni (2016) suggested that conservation technologies should be selected based on the area's characteristics where they will be implemented. Therefore, before implementing soil and water conservation measures, it is crucial to understand the characteristics of a specific region, given Ethiopia's diverse climatic conditions and altitudes (Hurni 2016). An assessment of the population, environment, agriculture, people's economic situation, their needs, characteristics, and professional bacKgrounds is necessary to plan any project or program (Wani and Shiferaw, 2005). The greatest weakness of the study area and the surrounding environment is the high variability in land characteristics inconsequence the difficulty to characterize and document the available data of justified accuracy. Hence, the research aimed to evaluate and describe the biophysical and socio-economic characteristics of the Agewmariam watershed, identify technological requirements, create land capability and suitability maps, and verify the local applicability of evaluation methods and techniques considering the variability in the biophysical and socioeconomic characteristics.

Material and Methods

Description of the Study Area

Location and Topography: The Agewmariam watershed was established in 2016 as an experimental area for soil and water conservation research on a watershed scale to represent the surrounding ecological, biophysical, and socioeconomic conditions accurately. The experimental area is situated in Sayda kebele, which is 23 km southwest of Sekota town in the Waghimra administrative zone of Amhara regional state, Ethiopia (figure 1). The area is part of the Tekeze River basin and covers 147 ha, with coordinates ranging from 12° 31' 40" to 12° 32'33" N Latitude and 38° 55' 14" to 38° 56' 15" E Longitude. The watershed's altitude varies from 2109 to 2381 meters above sea level, and the land slope ranges from nearly flat (<3%) to extremely steep slope (>50%).

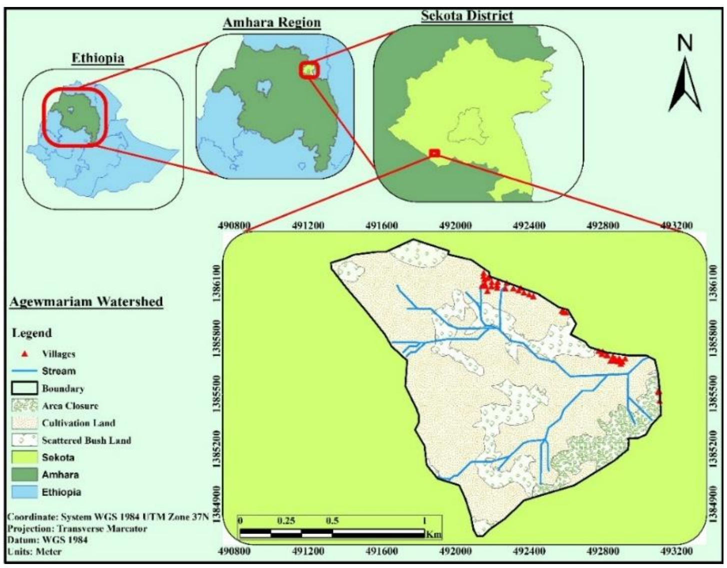


Figure 1 Location map of the watershed.

Climate: According to Hurni (2016), the experimental area is categorized as a Dry-Weyna-Dega agroecological zone. The region experiences a unimodal rainfall pattern, with low and inconsistent rainfall distribution. The rainy season lasts from late June to early September, and the average annual rainfall is 570.3 mm. The National Meteorology Agency (NMA) reported that the mean minimum and maximum annual temperatures in the area are 12.5 °C and 26.5 °C, respectively (NMA, 2019).

Methodological Procedures and Techniques: The study utilized a four-phase methodology which involved the selection and establishment of an experimental watershed, biophysical and socio-economic characterization, land capability mapping, and land suitability mapping for tef and wheat crops of the watershed.

The establishment process followed a Community Based Participatory Watershed Development Guideline approach (Desta 2005a) and included the selection of a representative watershed based on predefined criteria, the formation of a multi-disciplinary technical team, and the creation of a community watershed team from elected representatives of different social classes.

The watershed was selected based on various factors including geographical characteristics, agricultural productivity, natural resources degradation, socioeconomic factors, agroecological characters, land use type, and existing status of the watershed. The first activity conducted after the decision was made on the selection process was the delineation of the watershed using GPS tools and Arc GIS software.

Data collection

Socio-Economic Data Collection: The socioeconomic data were obtained through complete census and household surveys conducted on sample sets of households and villages. The questionnaire used in the survey focused on demographic data, economic profile, agricultural technology and experience, and access to extension service and training.

A representative sample of respondents were selected from the population using Systematic sampling. In such a system the selection process was started by picking some random point in the list of households and then every 4th household was selected aiming for more than 25% of the population and the probability of each household to be included in the sample was ensured (Babbie and Rubin, 2015; Kothari, 2004).

In addition to the household surveys, secondary socioeconomic data such as beneficiaries of governmental and non-governmental food aid programs were collected from documents in the Bureau of Agriculture. A focus group discussion was also held with selected farmers to identify the problems in the watershed and develop solutions for the identified issues.

Biophysical Data Collection: According to Sheng, (1990), it is important to gather and study all available reference material and aerial photographs before going out to the field. In addition, sometimes a general observation in the field is required. To study the land use, land cover, and land characteristics of the watershed, a transect walk was conducted across the watershed, and observations were made to create a rough map. Biophysical data such as slope, stoniness, past erosion severity, land use type, and soil depth were collected using a 100m*100m fixed grid, and some points were sampled based on the variability of land use, slope, and soil.

Soil depth was determined using a soil auger (Desta, 2005b) and by looking at stream banks and gullies for deep soils (Desta 2005b; Sheng, 1990). Soil depths were taken across the watershed to obtain an average soil depth, as cited in (Sheng, 1990)and the soil depth to a contrasting layer significant for soil conservation requirements was recorded as soil depth, as cited in (Desta 2005a).

The extent of stoniness cover and vegetation cover was assessed through visual estimates of cover in randomly established sample plot quadrants, as described in studies by (Blanco and Lal, 2008; Elzinga and Salzer, 1998). In order to assess the extent of erosion, (Lal, 2001) and his previous works suggested examining various indicators including gullies, rills, exposed roots, and rocks.

For the land suitability classification, further information on soil nutrients was collected (Sheng, 1990). In general, the data gathered from field surveys was complemented by data obtained from Google Earth Pro.

Data Analysis: Descriptive statistics, such as total count of the population, average land holding size, average household head age, average number of people per household, and percentage of students in the community, were used to summarize the collected socio-economic data. These statistics were used to describe the basic features of the dataset, including total count, average, and percentage. The total count provided an overview of the population size, while the average was calculated by adding up all the values and dividing by the number of observations. The percentage was calculated by dividing the number of observations in a particular category by the total number of observations and multiplying by 100 (Gravetter and Wallnau, 2014).

The collected soil samples were sent to the soil laboratory for the determination of texture and soil chemical properties. Soil samples were analyzed for soil pH, soil EC, soil organic matter, and organic carbon using standard laboratory procedures. Particle size distribution (texture) was determined using the hydrometer method, whereas organic carbon was determined by the wet combustion method.

The soil depth, soil texture, stoniness data, and erosion severity point data were mapped on ArcGIS into a raster form using the IDW interpolation technique. The elevation data was generated from Google Earth and DEM & slope maps were generated by using the elevation data on the topo to raster interpolation tool on ArcGIS environment. In line with Cruz, (1990); For the entire watershed, different data, such as slope, soil, Stoniness, past erosion severity, and land use maps, were used for overlay analysis to generate the land capability class map and land suitability class map. From the data overlays, the features and parameters needed in the capability classification, and land use suitability assessment for each cell were extracted. In overlaying several maps, format considerations, such as map resolution and projection, were appropriately defined to keep the joint probability of coincidence the same at all locations (Cruz, 1990).

For the suitability analysis tef and wheat were selected as major crops in the watershed. Land characteristics like slope, soil depth, soil texture, soil pH, and soil organic matter were used as a criterion for land suitability analysis. The limitation approach was employed as a procedure of land evaluation (Belayneh and Desta, 2014; Klingebiel and Montgomery, 1961; SYS C. *et al.*, 1991).

In summary, Determining the evaluation objectives and data requirements, a description of the types of land use to be considered and their requirements, a description of land mapping units and derivation of land qualities, a comparison of land use types with the types of land present, economic and social analysis, classification of land suitability (either qualitative or quantitative), and presentation of the results of the evaluation were the activities involved in land capability and suitability classification (FAO, 1976; Klingebiel and Montgomery, 1961).

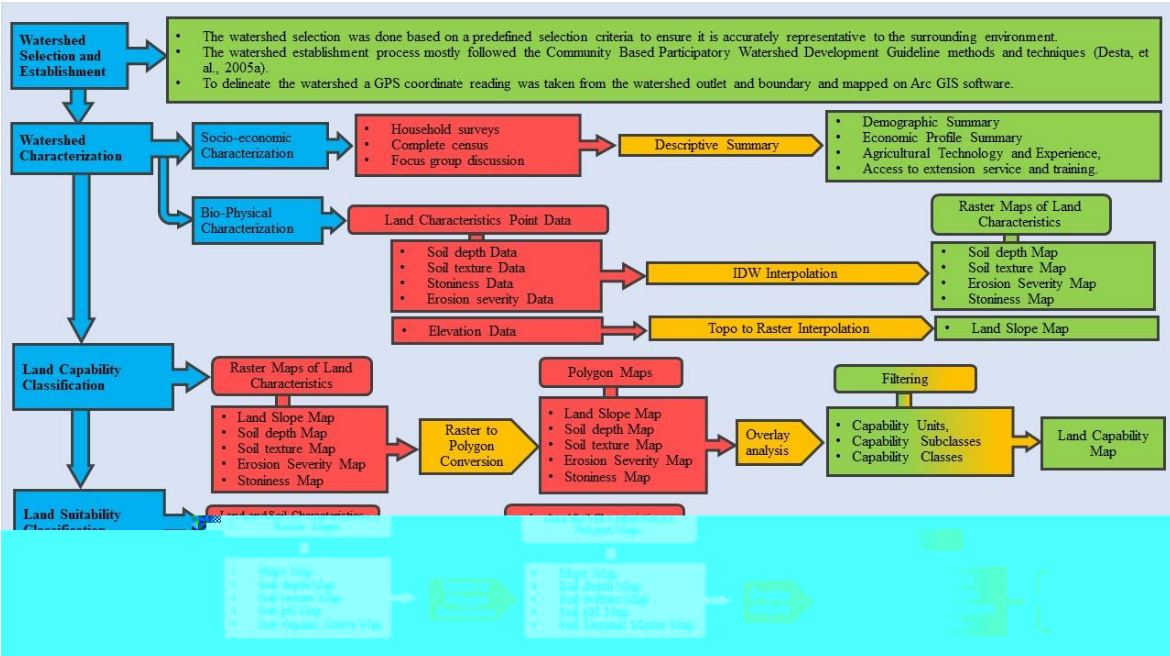


Figure 2: Research methodology flow chart.

Results and Discussion

Selection and Establishment of Model Watershed: The Agewmariam watershed was selected as the appropriate watershed based on several factors including its representativeness of the site, geographical characteristics, agricultural productivity, extent of natural resource degradation, socioeconomic factors, agroecological characters, land use type, and existing status of the watershed. The watershed was established on a 147-hectare area of land as an experimental watershed to represent the surrounding dry land areas of Waghimra which is characterized by a variable environmental condition.

The multi-disciplinary technical team consisting of 11 members organized from soil and water, crop, livestock, land use, and forestry experts was formed to oversee the project. Additionally, a community watershed team of 13 members was formed from elected representatives of the community who are from different social classes in the community to ensure community participation. An agreement on responsibility sharing was also reached between the partner sectors.

Socio-economic Characterization

Population: The watershed community consists of five villages with a total population of 1113 inhabitants and 259 households. The average family size in the community is 4.3 people per household, which is lower than the rural community average of 5 persons per household in Ethiopia (Sisha, 2020). The household heads in the watershed community have an average age of 49 years, and they are the most active participants in farming practices and decision-making (Mansoor, 2008).

The dependency ratio in the watershed community is 96.6%, which is lower than the national average of the rural population in Ethiopia as reported by Sisha, (2020). The demographic dependency ratio is the most commonly used measure of dependency, which shows that young ages (0-15 years) and old ages (more than 65 years) are dependent groups that rely on the workforce or Middle Ages (15-64 years) (Bekele and Lakew, 2014; Habtamu, 2011; Harasty and Ostermeier, 2020). A higher dependency ratio puts a burden on active members of the family to feed the household, leading to a higher probability of being food-insecure (Sisha, 2020).

Income Status and Occupation of the Watershed Community: According to the research, the majority of households in the watershed community rely on crop production, livestock rearing, labor, and food aid as their main sources of income. Food crop production and animal rearing are the dominant sources of economic income for all households. However, the average land holding size is only 0.5 ha, and only 8.4% of household heads own irrigable land which are very small in size (< 0.0625 ha). As a result, 36.7% of the respondents' resort to land tenancy to solve the shortage of land for landless youths and to get additional arable land for more food grain production.

The farmers in the community have no strong experience in recording their annual expenditures for health, shelter maintenance, children's clothing, books, and other expenses. They produce food grain for their family's consumption throughout the year and take some part of the grain to the market to substitute with other commodities. They also work as laborers for others and take animals to market to supplement their economic gap or in case of emergency. Additionally, they earn food aid from the government and non-governmental organizations.

Although Ethiopia has been successful in poverty reduction, the poorest segment of the population is mainly concentrated in remote rural areas, including the watershed community (Tom, 2020). However, more than 10.4% of members of the community in the watershed were food insecure and dependent on food aid programs of the government, which is a common issue in Ethiopia (Sisha, 2020).

Crop Production and Livestock Rearing in the Watershed: The farming system in the watershed is a mixed crop-livestock production system with a cereal-dominant cropping system. This practice is common in different parts of Ethiopia for example in the Bale highlands (Abate *et al.*, 2012), Adama and Arsi Negelle Districts (Addisu *et al.*, 2012). Sorghum, barley, tef, and wheat are the most dominantly grown crops. Even though cereals are dominant, farmers also grow pulse crops such as fabba bean, and field pea and all farmers allocate all of their farmland for food crop production for its high yield in grain and straw simultaneously.

The watershed is known for the production of common domestic farm animals like sheep, goats, cattle, donkeys, chickens, and honeybees. A large number of livestock populations exist in the watershed and follow a free grazing system. The livestock production system is extensive and completely local breeds. The main source of feed for animals is crop residue and some hey collected from farm boundaries. This is in line with (Abate *et al.*, 2012).

Draft cattle are the most important animals because of their use for cropland cultivation and crop threshing. In line with (Abate *et al.*, 2012)Animals are also kept for manure, meat, milk, and cash income.

Education and Capacity Building in the Community: Education and continuous training are crucial for ensuring the employability of all workers (Harasty and Ostermeier, 2020). In Ethiopia, there have been slight improvements in educational outcomes over time (Sisha, 2020). However, the high number of old-aged students in the watershed community indicates that children go to school too late or stop early due to social and economic limitations. About 27.2% of children between the ages of 6 and 15 still do nothave the chance to go to school. To address these issues, it is recommended to invest in education and capacity-building programs that cater to the needs of different age groups. Countries with young populations need to invest more in schools, while countries with older populations need to invest more in the health sector (EASD, 2018).

The Ethiopia Land Policy and Administration Assessment Final Report (ARD, 2004), has teachings of different management responsibilities to rural landholders to take care of their land. For example, if a person's holdings happen to border river banks and slopes, the landholder has the responsibility of cultivating his land at a distance away from the banks or slopes and taking care of them by planting trees and other plants, as shall be specified by the relevant body.

Since rural land cultivation is the major life support source of income in the watershed; they have a lifetime experience of traditional farming and taking care of their farmland. Almost all of the farmers have more than 10 years of experience in soil and water conservation. Moreover, awareness creation and capacity building of rural communities on integrating crops, livestock, and natural resource management technologies for effective soil and water conservation measures should be enhanced through a participatory integrated watershed management approach (Desta *et al.,* 2005a; Jilo *et al.,* 2020).

Biophysical Characterization

Land Characteristics: The Agewmariam watershed is composed of four major land use types: settlement, area closure, scattered bushland, and cultivation land, with an area coverage distribution of 1.1, 12, 29, and 104.9 hectares, respectively (Figure 3). The largest area is covered by cultivation land use type, which is the largest contributor to soil erosion.

Jilo *et al.,* (2020) suggest that knowledge of the distribution and slopes on which trees exist in the watershed can be useful in preparing an intervention plan for massive tree planting. The vegetation cover in the watershed is dominated by acacia tree species, shrubs, and grass species. The estimated vegetation cover percentage was 30% and 60% for the scattered bushland and area closure, respectively, during the dry period, while it was 70% and 85% during the rainy season.

According to Raghunath, (2006), the drainage system of a watershed can be characterized by stream density and drainage density. The Agewmariam watershed had two major streamlines and 25 tributaries, with a total length of 7.5 Km. The stream channels in this watershed had an irregular shape, and the stream density was 0.2 ha^{-1} while the drainage density was 0.0051 m/m^2.

A watershed's physical characteristics were assessed using several parameters, such as slope, soil depth, soil texture, stoniness, and erosion severity classes (Table 2). According to ratings in(Belayneh and Desta, 2014; Desta *et al.,* 2005b; Girmay *et al.,* 2018) the watershed is mainly characterized by a soil depth ranging from 0.5 to 1m (Figure 3c), sandy loam texture (Figure 3d), 15 to 30% stoniness (Figure 3f), and slight to moderate erosion severity (Figure 3e) and the watershed has an undulating topography that encompasses all land slope levels, ranging from flat to very steep slope (Figure 3b).

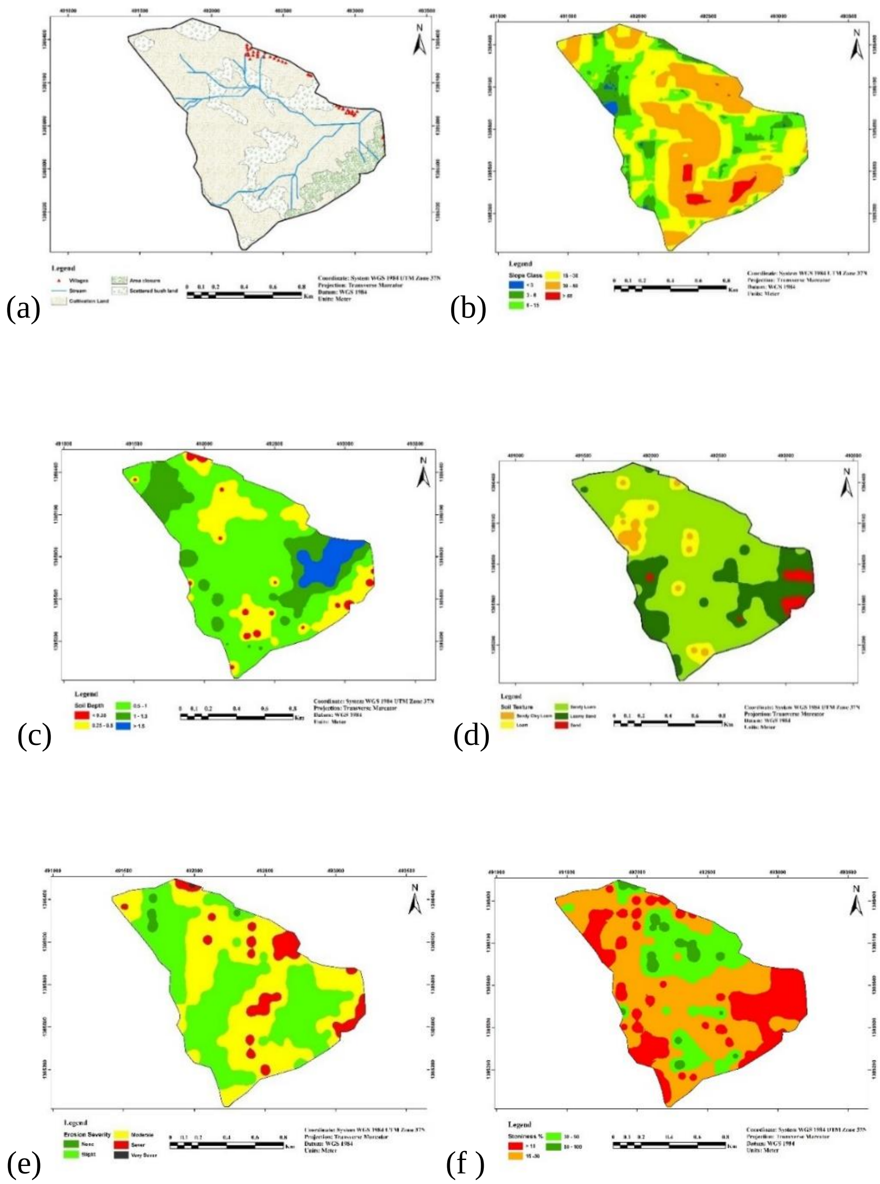


Figure 3: (a) Land use map, (b) Slopemap, (c) Soil depth map, (d) Soil texture map, (e) Erosion severity map, and (f) Stoniness map of the watershed.

In line with Ziadat *et al.*, (2006) the sampling procedure during the biophysical characterization was a compromise between free sampling and grid sampling. A 100*100 m grid sampling used in this study will be the highest resolution ever used in the study area and its surroundings. The accuracy of the results obtained from this method is largely dependent on the accuracy of the different input or source maps (Cruz, 1990). The greatest weakness of the surrounding environment is the high variability in land characteristics and the difficulty of having input data with these kind of resolutions to secure accuracy of input data. Since the watershed is established aiming to represent the surrounding environment the findings from this study watershed can be extrapolated by projects demanding threshold initial data for the use in the planning and management of the surrounding environment. The evaluation techniques used in this study also can be considered as they are verified to be used in the surrounding similar environments except the demanded flexibility of operation according to the variability in the local condition.

Table 1: Vegetation species identified in the Agewmariam watershed

Trees Spp.		Shrubs Spp.		Trees and Shrubs Spp.	
Local Name	Scientific Name	Local Name	Scientific Name	Local Name	Scientific Name
Sirwa	*Acacia sayal* Del.	Bubusha	Senna didymobotrya	Tikur Girar	*Acacia etbaica*Schweinf
Qulqual (Beles)	*Opuntia ficus-indica* (L.) Miller	Gorgoro	*Dichrostachys cinerea* (L.) Wight & Arn	Egula/Gemero	*Capparis tomentosa* Lam.
				Talo	*Rhus vulgaris*
Feteqa	*Combretum molle* R. Br. ex G. Don.	Anquwa	*Commiphoraafricana* (A. Rich) Engl	Kokoba	*Maytenus senegalensis* (Lam.) Exell
				Qulqwal	*Euphorbia abyssinica*Gmel.
Qulqwal	*Euphorbia abyssinica*	Duduna	*Cussoniaholsti*Harms ex Engl.	Gulo	*Ricinus communis* L.
Woyra	*Olea europaea* L. subsp.cuspidata (Wall.exG.Don) Cif.	Dediho	*Euclearacemosa subsp. schimperi*(A.Dc.) Dandy		
Wanza	*Cordia africana* lam.	Limurna	*Ormocarpumtrachycarpum* (Taub.) Harms		Grass Spp.
Bamba/Shola	*Ficus sycomorus* L.	Mentese	Becium grandiflorum (Lam.)		
Grfatsa	*Acacia albida* Del.	Eret	*Aloe vera* (L.) Burm.f.	Serdo	---
Giba	*Ziziphus spina*-christi L.	Qentafa	Pterolobiumstellatum (Forssk.)	Sembelet	Hyparrheniarufa
Qnchib	*Euphorbia tirucalli* L.	Damakase	*Ocimumlamiifolium*Hochst. ex. Benth.	Berbera	---
Bisana	*Croton macrostachyus* Del.	Qetetina	*Verbascum sinaiticum* Benth.	Chubasar	---

Land Capability Classes in Agewmariam Watershed: Land capability is a measure of the potential and limitations of agricultural land use, ranging from ample to limited uses. It serves as a nationwide indicator of land quality. The overlay analysis of soil depth, slope, soil texture, stoniness, and erosion severity maps of the watershed revealed six classes of land capability, namely Class II, Class III, Class IV, Class VI, Class VII, and Class VIII, covering an area of 2.5, 15.1, 61.6, 32.8, 29.9, and 5.1 hectares, respectively.

Class III, class IV, and Class VI are the dominant capability classes in the watershed. This could be caused by being the slope, soil depth, and erosion severity were the major capability limiting factors in the area. This is confirmed by(Girmay *et al.*, 2018) reported that slope and stoniness were the primary limiting factors for land capability classes VI and VII in a similar neighboring watershed, while erosion severity and slope were the primary limiting factors for land capability class VIII in the watershed.

Moreover, land capability classes II, III, and IV in the watershed are found suitable for crop cultivation with slight limitations due to slope, soil depth, erosion severity, and stoniness. This is in line with (Girmay *et al.*, 2018; Klingebiel and Montgomery, 1961).

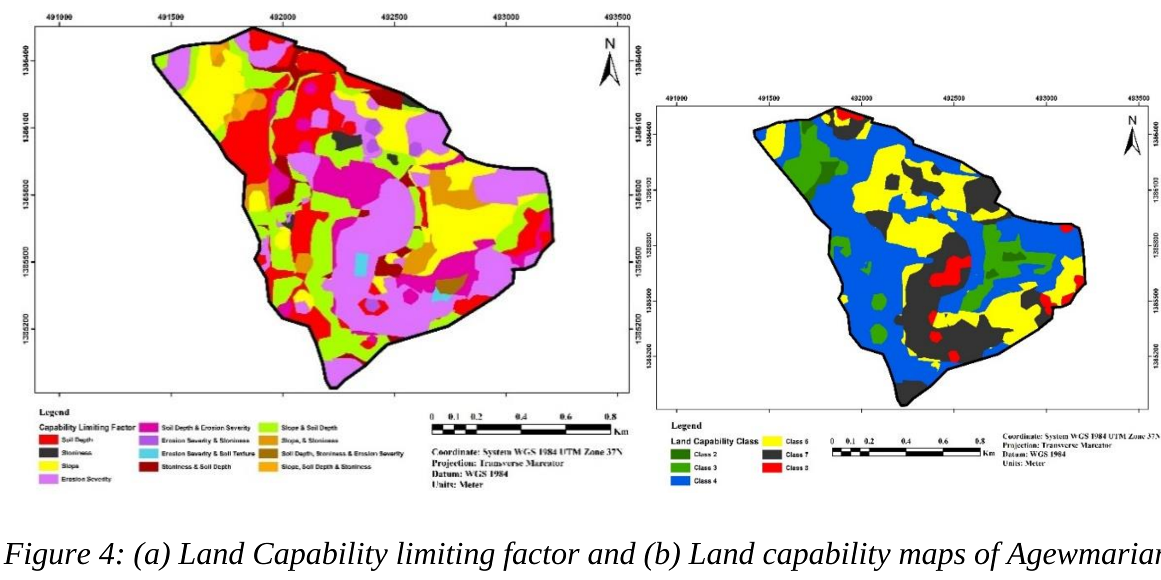


Figure 4: (a) Land Capability limiting factor and (b) Land capability maps of Agewmariam watershed.

The Federal Democratic Republic of Ethiopia Rural Land Administration and Land Use Proclamation (Federal NegaritGazcta, 2005), declares that rural lands, with a slope of more than 60 percent; shall not be used for farming and free grazing; they shall be used for the development of trees, perennial plants and forage production. It also states that rural land of any slope that is highly degraded shall be closed from human and animal interference for a given period to let it recover. In contrast a large area in the Agewmariam watershed with a slope, the major limiting factor is, unfortunately, under cultivation. This study is in line with (Jilo *et al.,* 2020) reported that the communities are not utilizing the resources potential wisely due to resource misuse and inadequate resource management.

However, Jilo *et al.,* (2020) concluded that land degradation was a serious concern, and watershed management programs could be enhanced. Girmay *et al.,* (2018); also recommended soil and water conservation interventions. Therefore, based on the land capability analysis in the watershed, soil and water conservation interventions, changes in land use patterns, and afforestation could be recommended as the best available management options to improve the capability of the land units in the watershed. The watershed also has to be closed from human and animal interference and be rehabilitated for a certain period.

Land Suitability for Wheat and Tef Crops in the Agewmariam Watershed: Land suitability refers to the fitness of a particular type of land for a defined use (FAO, 1976). The process of land suitability classification involves evaluating and grouping specific areas of land based on their suitability for defined uses. Suitability has been used to determine the degree of agroecological and socioeconomic adequacy of a specific use or land utilization type for each land unit (Comerma, 2010).

The limiting condition principle, in which the most unfavorable quality determines the suitability class (FAO, 1976), was used withLupia's, (2014) land characteristics and crop requirement rating for the specified tef and wheat crops (Table 3). Accordingly, 87.6% of the watershed area is permanently not suitable (N2) and 12.4% is currently not suitable (N1) for tef cultivation. Similarly, 47.1% is classified as N2 and 48.5% as N1 for wheat cultivation. Overall, the watershed is not suitable for wheat and tef cultivation, except for 4.5% which is marginally suitable (S3) for wheat. In line with Moshago *et al.,* (2022) there is no topographic position in the watershed that was classified as highly suitable (S1) for either crop.

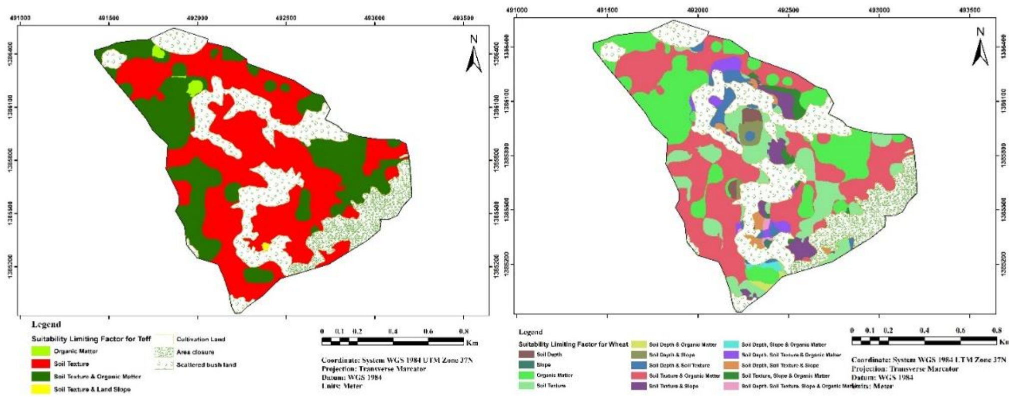
Table 3. Physiochemical land characteristics and land suitability in the Agewmariam watershed

Crop type	Suitability Class	Land characteristics & area coverage in the watershed										Overall suitability	
		Soil Depth		Slope		Soil Texture		pH		OM			
		Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Tef	S1	94.7	89.3	30.2	28.5	0.0	0.0	105.9	99.9	5.4	5.1	0.0	0.0
	S2	10.8	10.2	42.2	39.8	0.0	0.0	0.1	0.1	5.2	4.9	0.0	0.0
	S3	0.5	0.4	21.9	20.7	0.0	0.0	0.0	0.0	9.5	8.9	0.0	0.0
	N1	0.1	0.1	11.4	10.8	16.0	15.1	0.0	0.0	52.5	49.5	13.1	12.4
	N2	0.0	0.0	0.3	0.2	90.0	84.9	0.0	0.0	33.5	31.6	92.9	87.6
	Total	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*
Wheat	S1	32.4	30.6	30.2	28.5	0	0	101.8	96.1	5.4	5.1	0	0
	S2	29.3	27.7	42.2	39.8	12.1	8.6	4.2	3.9	5.2	4.9	0	0
	S3	32.9	31.0	21.9	20.7	3.9	2.7	0	0	9.5	8.9	4.8	4.5
	N1	11.1	10.5	11.4	10.8	66.1	65.9	0	0	52.5	49.5	51.4	48.5
	N2	0.2	0.2	0.3	0.2	23.9	22.8	0	0	33.5	31.6	49.9	47.1
	Total	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*	*106*	*100*

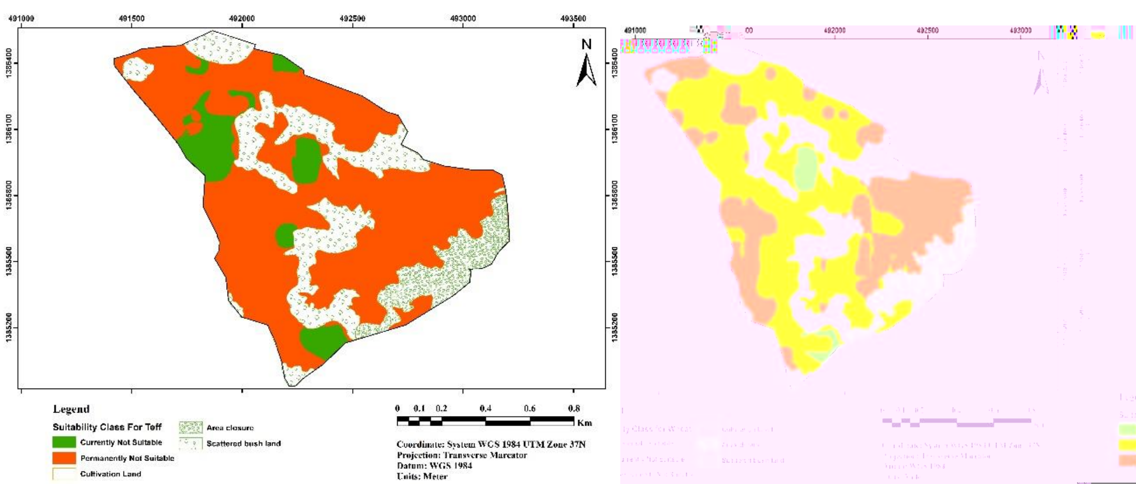
***Note:** *S1 = Highly Suitable, S2 = Moderately Suitable, S3 = Marginally Suitable, N1= Currently Not Suitable, andN2 = Permanently Not Suitable.*

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. A classification of current suitability refers to the suitability for a defined use of land in its present condition, without major improvements (FAO 1981).

In line with Girmay *et al.*, (2018) erosion, climate, and soil fertility are considered as common limiting factors for land suitability in general. The measured soil pH value in the watershed, ranging between 5.6 and 7.9, was not a limiting factor for wheat and tef cultivation. The major limiting factors were organic matter and soil texture for tef production, while organic matter, soil texture, and slope were the dominant limiting factors for wheat production. Girmay *et al.,* (2018) confirmed that soil organic matter was the major suitability limiting factor. Therefore, in line with Bahir *et al.,* (2015) integrated soil fertility management practices to increase soil organic matter levels and enhance soil fertility, such as increasing usage of readily available organic amendments and implementing fertilization programs based on published guidelines and correct diagnostics of soil nutrient status are recommended.



(a) *(b)*



(c) *(d)*

Figure 5: (a)Land suitability limiting factor for tef, (b) Land suitability limiting factor for wheat, (c) Land suitability map for tef, and (d) Land suitability map for wheat.

Conclusion and Recommendation

The study provides insights into the biophysical and socioeconomic aspects of the watershed. These insights can be used to propose appropriate policy directions and management plans to enhance productivity and sustainability. Additionally, the information generated from this research can serve as a baseline to evaluate future management intervention effectiveness.

The study reveals that the watershed is incapable of serving general and specific uses under the current biophysical and socioeconomic characteristics, leading to a reduction in overall production potential. To address this issue, it is recommended to plan and set a management option among different alternatives. Capacity building and enforcement bylaws are also recommended as a social aspect improvement to facilitate the implementation of rehabilitation and development plans.

The study identifies slope, stoniness, and erosion severity as the major land capability limiting factors in the watershed. To improve land capability and make it capable of multiple uses, intensive soil and water conservation intervention and re-vegetation, including changing the land use pattern, can be implemented.

For both tef and wheat, the major limiting factors were organic matter and soil texture. To improve organic matter and soil texture, management practices involving measures that increase soil organic matter levels and enhance soil fertility are recommended. Increasing usage of readily available organic amendments and implementing fertilization programs are also recommended.

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