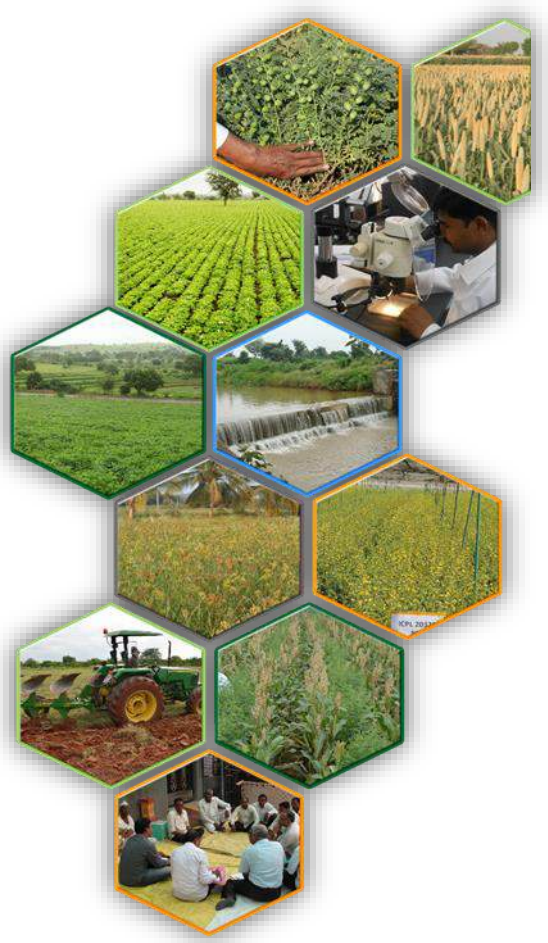
Hydrological Modelling, Validation Mapping and Flood-based Productivity of Afar Region, Ethiopia



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Acronyms and Abbreviations

AV.P	Available Phosphorous
AWC	Available Water Holding Capacity
Bd	Bulk Density
CEC	Cation Exchange Capacity
Cm	Centimeters
DEM	Digital Elevation Model
ds/m	Deci-Siemens per meter
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
FAO	Food and Agricultural Organization
FC	Field Capaicty
Ha	Hectare
K	Potassium
KM	Kilometer
LPG	Length of Growing Period
LUT	Land Utilization Types
M	Meter
Mg	Magnesium
Mm	Millimeter
MoARD	Ministry of Agriculture and Rural Development
N	North
Na	Sodium
OC	Degree Celsius
OC	Organic Carbon
OM	Organic Matter
PBS	Present Base Saturation
PET	Potential Evapotranspiration
pH	Soil Reaction (log10H+ions concentration)

ppm	Parts per Million
PWP	Permanent Wilting Point
SMU	Soil Mapping Unit
TN	Total Nitrogen Percentage
UTM	Universal Transverse Mercator
WRB	World Reference Base for Soil Resources
WWDSE	Water Works Design and Supervision Enterprise

Executive Summary

The Afar region is one of the driest areas in Ethiopia. The dominant part of the region is characterized as arid- and semi-arid with rainfall of not more than 144 mm per year at the desert in Asiata and Dedal to a little above 800 mm per year in Chifra and Dulecha . On the average the region has rainfall of less than 300 mm (53% of the region) and average temperature exceeding 27.5 0C. There is little to no water resources available from rainfall for most of the year that can be used beneficially.

The people of Afar practice pastoral and agro-pastoral modes of life. Crop production in the region is practiced through irrigation; spate and river water abstraction[1]. Thus, the major farming system in the region is pastoralism with intermittent crop farming practices in some areas. With changing climates and more frequent extreme events expected in the Ethiopian highlands, flooding in the region may lead to catastrophic results if it coincides with the existing vulnerable systems. Every year in the months of July to September these floods inundate the lowlands of the region. If not controlled, the floods can cause land degradation that will have a negative impact on the livelihood of the local population especially the pastoralists. However, if floods are well managed, they can serve as a source of livelihood by recharging groundwater levels, improving soil fertility, and water availability for livestock drinking, agriculture and household uses. They can be also very important sources of much needed water for growing crops.

The ability to provide alternative source of water and implement efficient rainwater management systems in such a moisture stressed area are key to building a resilient production system, for sustainable growth of agriculture, rural development and overall economic progress. It is also important for effective use of available land resources in the region.

Recently, GIZ in close collaboration with the regional government of AFAR and ICRISAT explored the potential benefits of 'Flood harvesting' through the construction of water spreading weirs. ICRISAT then took an initiative to test the 'feasibility' of landscape intensification, particularly food and fodder production-using moisture available from flood. Tremendous achievement was made in terms of both crop and forage gain and biomass yield.

In order to better understand the overall potential and identify potential target locations for scaling-up, ICRISAT team also has mapped the area covered by flood over time using high-

[1] Daniel Teka , Tesfa-alemGebreegziabherAyeleAlmawGoitomTukue and AbityGetaneh. 2014. Assessment of the Potential of Flood-Based Farming in Ethiopia (Afar, Amhara, BenshagulGumuz, Oromia, The Southern Nations, Nationalists and People Region).

resolution satellite images and hydrological tools. Based on this, it was possible to see that about 900,000 ha of land have been flooded with potential (adequate) soil moisture for crop and forage production. In order to develop detailed land use planning and develop guideline for 'exploitation', it is necessary to physically validate the flood area during the cropping season.

With this study results as a background this project was undertaken to determine and identify the flood based productive areas with the potential to grow crops that will help reduce the food insecurity of the Afar region and validate the previous study results. The process taken to accomplish this were determining the extent of flood areas, estimating the amount of water that is available for productive purposes through hydrologic analysis, and developing land suitability map for key crops (maize, sorghum and forage) in three major agriculturally potential flood areas of Afar.

The validation for runoff and soil moisture included samples from seven districts and eighteen *kebeles* of Afar Regional State guided with the geo-spatial maps produced by ICRISAT. The five selected districts (Afdera, Erebti, Awra, Golina & Teru) were found in Danakil basin in the Northwestern part of Afar National Regional State while Dubti and Mille falls under Awash River basins. Hence, the selection of the districts and the *kebeles* were solely contingent up on the areas mapped by ICRISAT for validation.

Assessment of the socioeconomic and biophysical circumstances was the first step in this process. Concurrently, in field assessment and collection of soil samples and subsequently making analysis of the samples was done in the laboratory. The hydrological data were extracted from available databases and other secondary sources. The field observations and others set of activities had shown that most of the non-intervention districts identified by ICRISAT were found to be districts where there was flood water that adds soil moisture that could allow spate irrigation development as long as resources are mobilized for investments.

Hydrologic analysis resulted availability of an estimated 796 million m^3/year that could be available for growing crops typical of the region, i.e., (Sorghum, maize, forage, and vegetables) using spate irrigation.

Physical land suitability evaluation for irrigation was carried out for the region, following FAO methodology for general irrigation farming. Land suitability analysis resulted 877,000 ha that can be used to grow crops provided there is enough water that would be available continuously available during the growing season.

Overall, the results of this study show that there is enough water and land to practice spate irrigation during the rainy seasons. It also proved scaling up of spate irrigation is possible across the region and other parts of the country with similar conditions such as Somali, and Gambela regions. Hence, flooding can turn to be an irrigation development opportunity with the

appropriate infrastructure and resources. This in turn helps to overcome the incidents of food insecurity that affects the majority of the inhabitants residing in the region.

Key-Terms: Afar Regional State, Flood Mapping, Soil Moisture, Spate Irrigation Development, Physical and Socio-economic parameters, Ethiopia

1. INTRODUCTION

1.1. General Background

The Afar region is one of the driest areas in Ethiopia. It is located in the North Easter part of Ethiopia (Figure -1), bordered by Amhara and Oromia regions, and Eritrea and Djibouti. The region has a total area of 95,242 km^2. The dominant part of the region is characterized by low rainfall of less than 300 mm (53% of the region) and average temperature exceeding 27.5 0C. Most of the area is considered as arid- and semi-arid with rainfall of not more than 144 mm per year at the desert in Asiata and Dedal to a little above 800 mm per year in Chifra and Dulecha. For practical purpose there is little to no water resources available in the region from rainfall for most of the year that can be used beneficially. Most of the people of Afar practice pastoral and agro-pastoral modes of life. Crop production is practiced through irrigation; spate and river water abstraction[2].

Most of the arid lowlands of Ethiopia including those in Afar Region are currently inhabited by dispersed population with a rough estimation of 12 million. These lowlands are arguably the most vulnerable to food insecurity. On a positive note, however, the arid lowlands are endowed with abundant land resources and numerous seasonal rivers and, if these resources are utilized effectively through the development of sustainable flood-based farming systems, they have the potential to contribute to the development of these regions[3].

The major farming system in the region like Afar is pastoralism with intermittent crop farming practices in some areas. With changing climates and more frequent extreme events expected in the Ethiopian highlands, flooding in the region may lead to catastrophic results if it coincides with the existing vulnerable systems. Every year in the months of July to September these floods inundate the lowlands of the region. If not controlled, the floods can cause land degradation that will have a negative impact on the livelihood of the local population especially the pastoralists. However, if floods are well managed, they can serve as a source of livelihood by recharging groundwater levels, improving soil fertility, and water availability for livestock drinking, household uses and for using irrigation for food production. That is they can be very important sources of much needed water for growing crops.

[2] Daniel Teka , Tesfa-alemGebreegziabherAyeleAlmawGoitomTukue and AbityGetaneh. 2014. Assessment of the Potential of Flood-Based Farming in Ethiopia (Afar, Amhara, BenshagulGumuz, Oromia, The Southern Nations, Nationalists and People Region).

[3]Mehari Haile, A., Demissie, A., Embaye, T. G., Getaneh, A., 2013. Flood-Based Farming for Livelihoods in Ethiopia Lowlands. Status, Potential and Investment Guide

The ability to provide alternative source of water and implement efficient rainwater management systems in such a moisture stressed area are key to building a resilient production system, for sustainable growth of agriculture, rural development and overall economic progress. It is also important for effective use of available land resources in the region.

Flash flood irrigation has been practiced since 70 centuries ago as a main means of survival and income source for the poor in dry-lands[4]. Flood-based farming systems (spate irrigation, flood recession and inundation, flood-spreading weirs) account for over 30 million hectares across the world. They represent a unique option for the management of scarce water resources in support of agricultural production and livelihoods of marginalized populations in many arid regions[5].

Flood-based farming is among the potential options in ensuring access to water for crop and livestock production for small-scale farmers in the arid and semiarid lowlands of sub-Saharan Africa, and Ethiopia in particular. Flood-based irrigation wile inexpensive is rooted in tradition in many rural communities including Afar areas[6]. Although its extent is relatively minor compared to other types of irrigation, it represents a unique option for the management of scarce water resources in support of agricultural production and rural livelihoods in many arid regions (Daneil, et al 2014)[7].

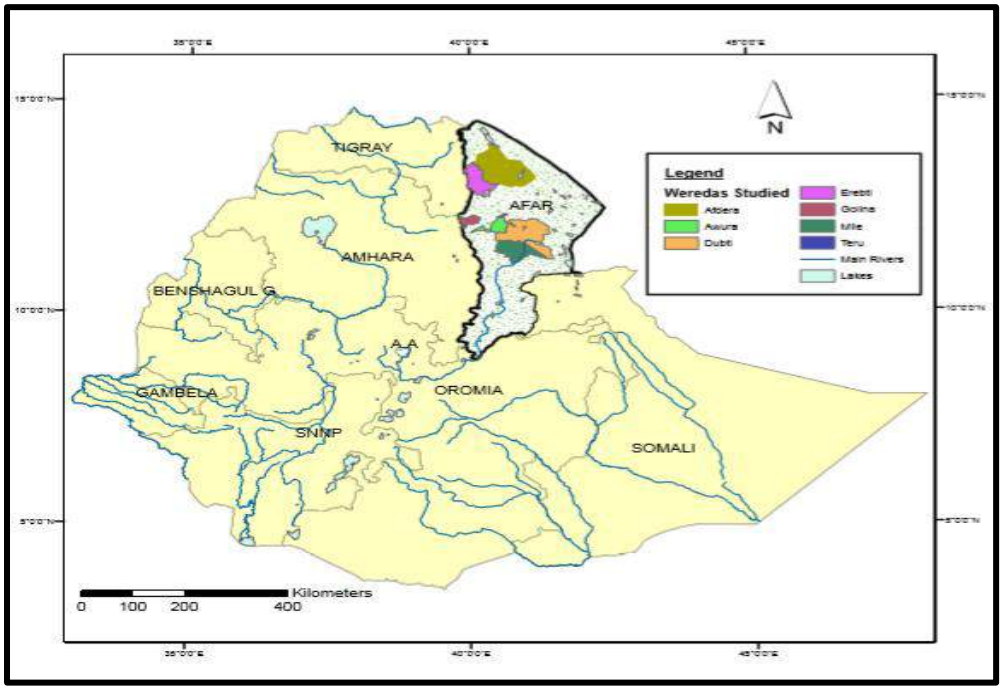
Recently, GIZ in close collaboration with the regional government of AFAR and ICRISAT explored the potential benefits of 'Flood harvesting' through the construction of water spreading weirs. ICRISAT then took an initiative to test the 'feasibility' of landscape intensification, particularly food and fodder production-using moisture available from flood. Tremendous achievement was made in terms of both crop and forage gain and biomass yield.

In order to better understand the overall potential and identify potential target locations for scaling-up, ICRISAT team also has mapped the area covered by flood over time using high-resolution satellite images and hydrological tools. Based on this, it was possible to see that about 900,000 ha of land have been flooded with potential (adequate) soil moisture for crop and forage production. In order to develop detailed land use planning and develop guideline for 'exploitation', it is necessary to physically validate the flood area during the cropping season.

[4]KassahunBirhanuTadesse and MegersaOlumanaDinka.2019. "Improving Traditional Spate Irrigation Systems: A Review," in Landscape Architecture - The Sense of Places, Models and Application.
[5]Mehari Haile, A., Demissie, A., Embaye, T. G., Getaneh, A., 2013. Flood-Based Farming for Livelihoods in Ethiopia Lowlands. Status, Potential and Investment Guide.
[6]Erkossa, T.; Hugos, F.: Lcfore. N. (Eds.). 2014. Proceedings of the Workshop on Flood-based Farming for Food Security and Adaption to Climate Change in Ethiopia: Potential and Challenges. Adama. Ethiopia, 30-31 October 2013. Colombo, Sri Lanka: International Water Management Institute (IWMI). I78p. doi: 10.5337/2014.233
[7] Daniel Teka , Tesfa-alemGebreegziabherAyeleAlmawGoitomTukue and AbityGetaneh. 2014. Assessment of the Potential of Flood-Based Farming in Ethiopia (Afar, Amhara, BenshagulGumuz, Oromia, The Southern Nations, Nationalists and People Region).

It is imperative that there is a need for an accurate determination of the areal extent of this potentially productive area for the effective use of this scarce water resource with the abundantly available land. Thus, this project was undertaken to determine and identify the flood based productive areas with the potential to grow crops that will help reduce the food insecurity of the Afar region. Specifically, steps were taken to validate the extent of flood areas mapped by ICRISAT as part of the upscaling possibilities, to estimate the amount of water that is available for productive purposes using a volume balance approach, and to develop land suitability map for key crops (maize, sorghum and forage) in the major agriculturally potential flood areas of Afar.

Figure 1: Map of Afar National Regional State



Source: GIS,

The flood hazards in Afar are the combined result of its topography, land cover, runoff from highland and intensive torrential rainfall conditions. Generally, the increase in the destructive nature of floods in the Afar Region can be partly attributed to climate change/variability and unsustainable practices from increased population (livestock and human) pressures on the environment[8].

Recognizing the achievements made by ICRISAT and other stakeholders to harness the runoff from the highlands to the lowlands districts of Afar for spate irrigation, this project was intended

[8]Mehari Haile, A., Demissie, A., Embaye, T. G., Getaneh, A., 2013. Flood-Based Farming for Livelihoods in Ethiopia Lowlands. Status, Potential and Investment Guide.

to validate the results of previous projects and thus to prove the possibility of upscaling to other areas of the country with similar condition.

1.2. Objectives

The overall objective of this project was to determine and identify the flood based productive areas of Afar region with the potential to grow crops to help reduce the food insecurity of people and also minimize the hazardous damages caused by floods over years.

The specific objectives were to validate the extent of flood areas mapped by ICRISAT as part of the scaling up activity, to estimate the amount of water that is available for productive purposes, and to present land suitability map for the region.

1.3. Scope and Major Task Undertaken

To validate the flooding (flooded area) with plausible potential for productive use the following major activities were done:

- Design sampling strategies with representative study areas in the region corresponding to those studied by ICRISAT. Accessibility and security issues in the sampled districts were considered in this step.
- Conduct field survey to observe whether the area of interest (sampling point) has been flooded recently (after weir construction), and for how long;
- Conduct focus group discussions and consult key informants to gather information about the incidence of flood since weir construction and the benefits that the local communities have enjoyed since then;
- Evaluate the potentials, constraints and risks associated with flooding for the local community and ecological conditions; and
- Provide a practical guidance on the size, risks and opportunities of selected major flood potential areas

To produce land suitability map and analysis multi-layer information was used. This was achieved through undertaking the following major activities:

- Review literature to understand the major biophysical (environmental – soil, topography, climate, etc.) requirements of the major crops (considering specific varieties planned for potential scaling);
- Determine the potential soil moisture (due to flooding) that would be available to the respective crops (considering specific varieties and length of growing period);
- Assess the economic benefits and social acceptability of the varieties of crops.
- Use multi-criteria approach (or any other relevant option) to generate suitability maps

2. Methodology

The field investigation has been carried out by integrating the activities described in the ToR with due consideration of achieving the above objectives. It was undertaken as to ensure maximum coherence and synergy between the different elements. The first step in the validation process was to determine the magnitude of the runoff that is flowing to the lowlands from the surrounding highland areas flowing through different streams. This involves hydrologic analysis using appropriate methods. The flood area maps that were done by ICRISAT using higher resolution satellite images were used for identification of selected districts.

Laboratory analysis of the collected soil samples was done and the result used to compare to the results identified using high-resolution satellite images.

In order to generate credible and reliable information, the team has adopted Participatory Rural Appraisal (PRA) techniques. Consultation with stakeholders, Key Informant's Interview (KII), direct observation and composite soil sampling were the main tools employed for data collection. Furthermore, employing distinct methods for data collection has enabled to triangulate consistency of data that is found on different sources. Data collection tools (checklists) have been initially prepared before undertaking the fieldwork. In the study process, the team has given due focus on collecting data at grass root level. Thus, stakeholders at district and *kebele* levels and the potential beneficiaries have been approached and consulted.

2.1. Key Informants' Interviews (KII)

This activity was made with key responsible individuals, mainly officials, area specialist experts from stakeholder offices, and *Kebele* level administrations. The Key Informant Interview was carried out to get comprehensive and detailed information on specific issues related to spate irrigation and other relevant socio-economic features of the selected *kebeles* and districts. Such consultations, in fact, sought high level skills and experiences. The explanations provided by the consulted groups also were very essential for constructing narrations about their respective localities. Overall all, closer to 15 Key Informants were consulted on the both flooding areas, frequency and the nature of irrigation developments that had been practiced in the localities. The figure below depicts when the interviews was made with the key informants at Mille.

Figure 2: Key Informant Interview with experts and *Kebele* administrations at Millie

2.2. Key-Stakeholders Consultations

Successful deliberations were held with decision making bodies, key stakeholders, sector institutions and experts on the very concepts and nature of the flooding work and the importance of weir constructions, role of the public participation, role of key stakeholders and joint contributions of these actors to the success of the intended scaling up of flood based irrigations. In addition, the scope of the proposed development and possible means of maximizing local communities' social, economic and environmental benefits from the project implementation were raised and thoroughly captured.

In this respect, consultations were held with stakeholders and authorities such as the district administrators and cabinet members. From the discussions made with the decision makers and stakeholders, it was realized that the decision makers were very enthusiastic and holds favorable views towards the effective implementation of the proposed flood based irrigation developments. They have pointed out that food security is one of the major priority areas at districts level. One of them possible strategies to reverses such food deficiency in the areas could be through the mobilizations of investments towards these business.

Hence, there was a general presumption that the realization of flood-based irrigation developments or project possess enormous contributions to improve the food security of the project beneficiaries and the district, in general. They have, thus, agreed to support in resolving any issues with provision of land allocations, water distribution and management of communal

areas throughout project implementation period. Yet, such community promises and engagements require further decisions and consensus by all concerned bodies at various levels where there must be also some agreements to be effected in place. Moreover, the consulted community groups also corroborated that, the such irrigation projects often become the center for promoting the social welfare by increasing crop productivity and enhancing income level of the households, which in turn creates the opportunity for parents to send their children to school by fulfilling their necessities and covering their expenses. Therefore, the districts' officials have spelled out their full commitments to mobilize all district level stakeholders and the community members for the success of the envisaged flood harvesting and spate irrigation project. The figure below shows when the community members were having hold heated discussions with the team members from the Ministry of Water Resources, Irrigation and Energy.

Figure 3: Stallholder consultation conducted at Awura

2.3. Observation and Transect Walk

Another chief method deployed for the validation of runoff mapping and soil moisture analysis was transect walk. The transect walk involved trips in some of the selected villages together with few community leaders across the selected districts and *kebele*. The primary target of the trip was visual identification of the flooded areas starting from the upper catchments and grazing land, and then paying attention to the existing biophysical and socio-economic features of the *kebeles* and districts. In the process of conducting the transect walks, very vivid and succinct discussions were held with individual pastoralists to explore their opinion and attitudes towards soil moistures, earlier trends of crop productivity, flooding frequency and history and so on. The figure below depicts while transect walk had been being conducted with the pastoral households at Golina.

Figure 4: Transect walk and harnessing the opinion of individual pastoralist at Golina

2.4. Soil sample collection

One of the most important work for the project was the soil analysis that involved detail review of previous studies and prefeasibility soil survey that intended to map the soils of the study areas falling under different types of land utilization.

The review processes dealt with knowledge accumulation from some similarly produced basic materials and review of previous studies. Previously conducted and reported documents relevant to the study districts including information on topography, agricultural, land use and land cover, natural resource studies as well as other general bio-physical features and soils of the area in particular were thoroughly reviewed. The review gave general background information of the study areas and some of the review results at different levels have been used as secondary sources for the soil report.

For the prefeasibility study, systematic survey was planned for the areas previously surveyed and mapped at different scales instead of repeating the conventional survey. Hence, the survey followed collecting samples using free auger whole and observation to ensure that reference soil group and mapping units were inspected.

Soil sampling and observations were conducted within the flooded area, to check and delineate soil types. Furthermore, simple observations while driving in all accessible parts of the sample sites were made to mainly identify very shallow and stony areas. At each observation and description point, the important site characteristics such as location, soils, landform, slope and land use/cover were recorded.

Composite soil samples (altogether 19 samples) were collected from representative sites of flooded areas in the region. These flooded sites were located in seven districts and 18 *kebeles.* Composite samples analysis (physical and chemical properties of the soils) were made in the laboratory adhering to internationally recognized method and procedure of analysis. The physicochemical property of the soils, soil fertility evaluation, potentials, limitations, management requirement and land suitability evaluation of the flooded area were done, based on the field morphological and laboratory physicochemical analysis of the soils. The figure below shows when the teams were taking soil samples from distinct districts and *kebeles.*

Figure 5: Auger observation and description

2.5. Hydrologic Analysis

2.5.1 Method for Flood Analysis Using Rainfall-Runoff Relationship

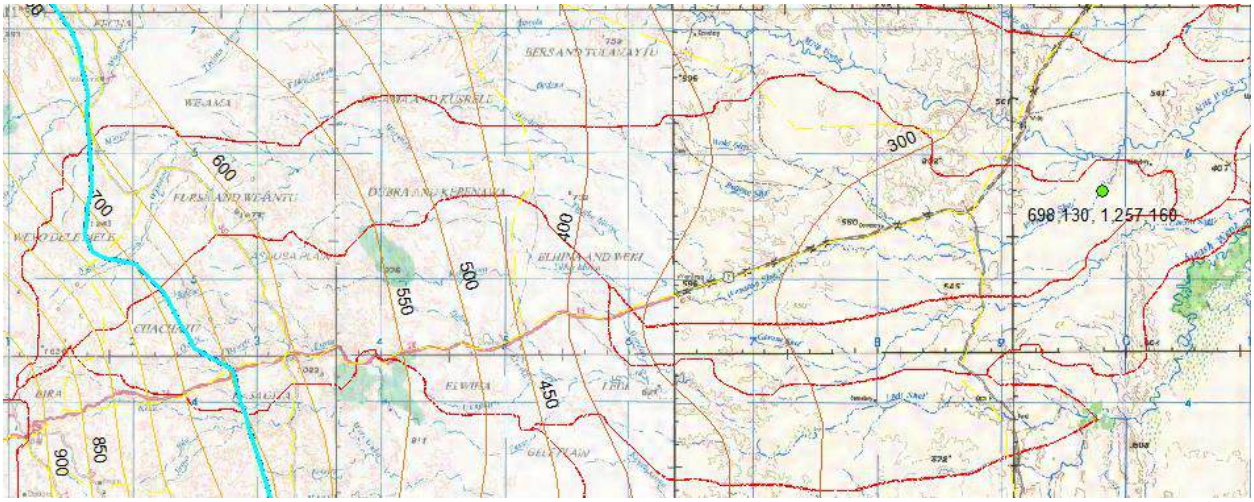
Runoff estimation resulting from precipitation is one of the most important factors that have been the basis for many studies in water resources management. When the rainfall intensity is greater than soil infiltration the result is surface runoff. Forecasting and determining this factor is very important in designing structures that controls or distribute it for use in irrigated agriculture. This is particularly significant if runoff is going to be used to meet water demand for agricultural use.

Floods resulting from surface runoff in arid and semi-arid regions such as Afar are in general short-term with low base flow as the streams or rivers are temporary. The challenge has been using empirical models for estimating annual runoff in these types of flows as there are no hydrometric stations in most of the areas of interest.

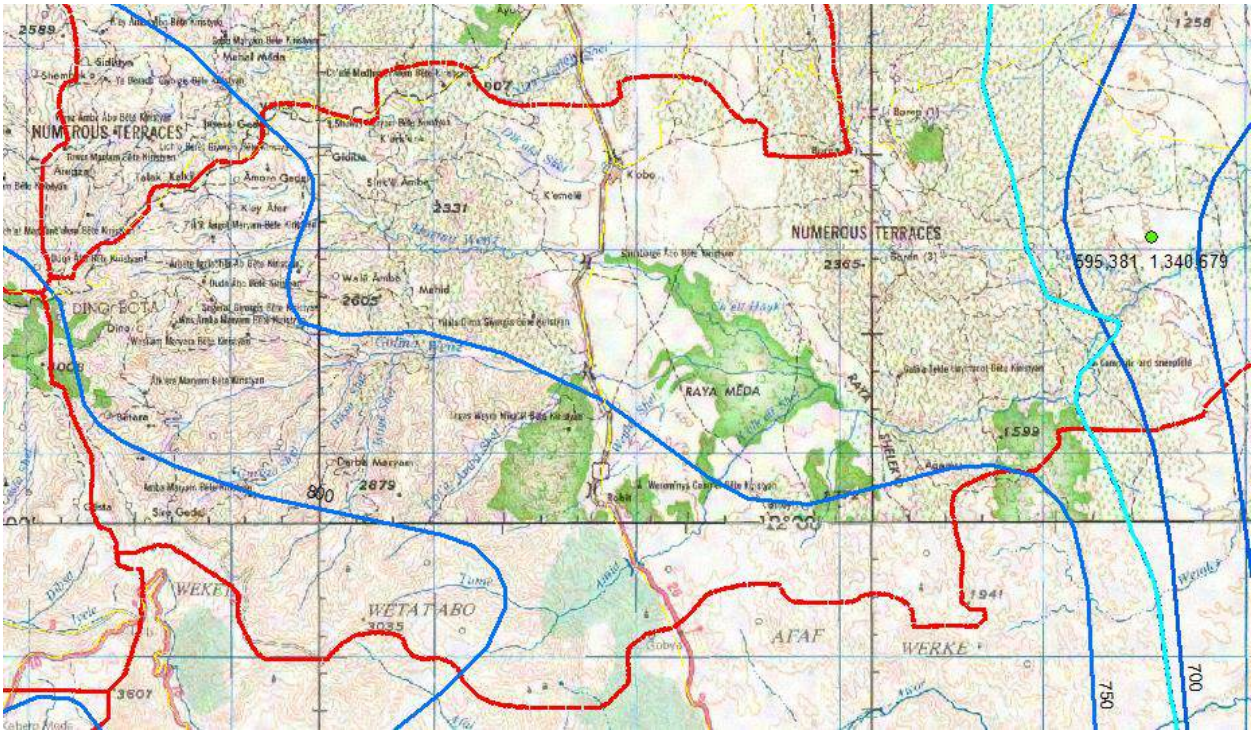
Due to lack of sufficient and reliable hydrological information in most of the Afar region, here in we applied the simplest approach using the surface runoff coefficient method. In this method

the surface runoff is a percentage of precipitation considering all the factors that affect runoff. We also used the rational formula to estimate the peak runoff for the watersheds contributing to floods that are potentially to be used for spate irrigation.

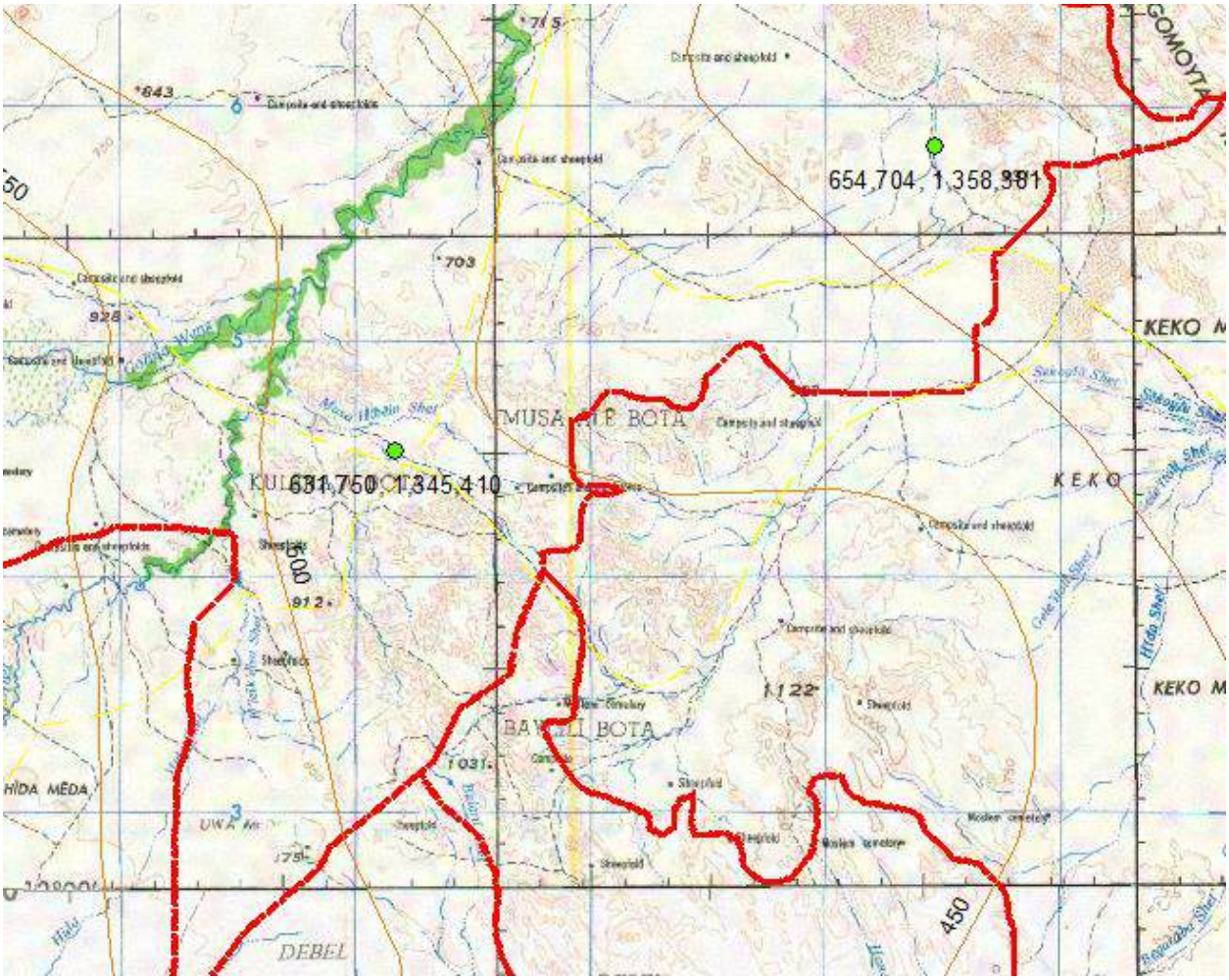
Isohyetal method was applied to get the areal average of rainfall over the selected sites using the maps as shown below..



Giraro	Mille

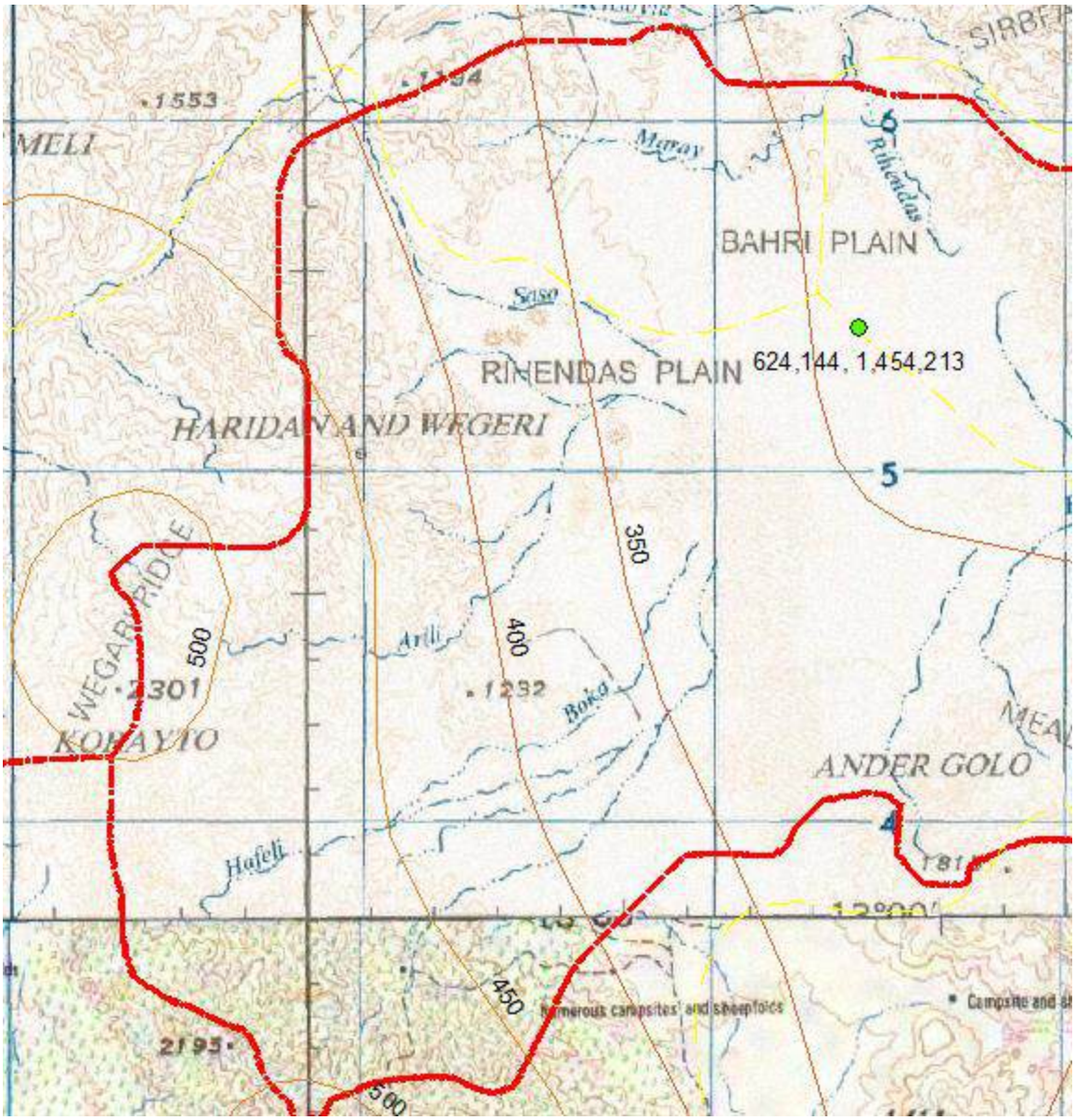


Adumdello	Gulina

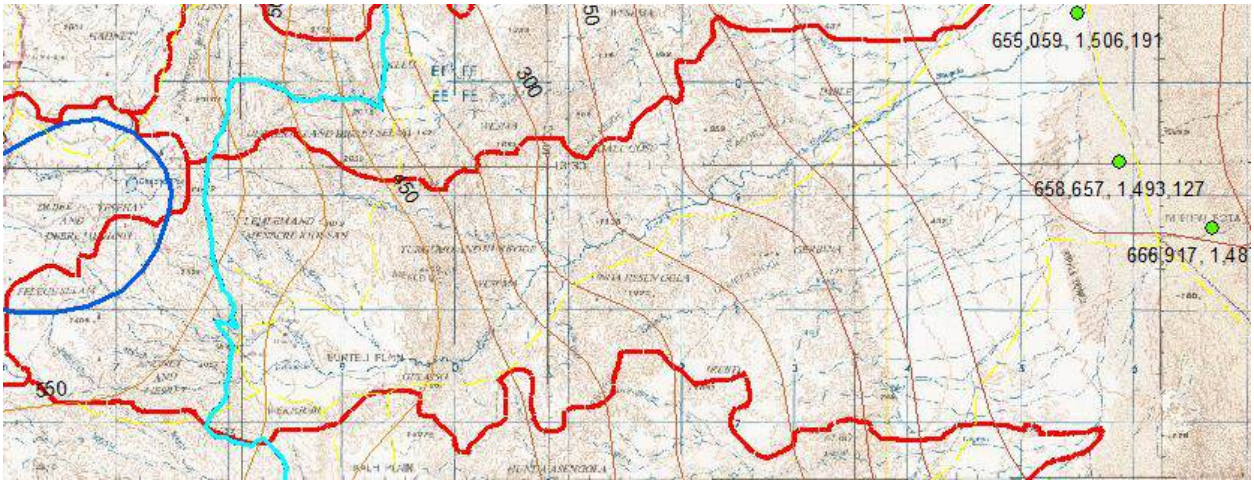


Germille	Terru

Mokole	Awra



Ereti	Afdera



Ereti	Afdera
Kesuwad	Afdera
Yalebhe	Afdera

The flood analysis had involved considering the rainfall patterns in the sites specified in the table below:

Table 1: Location of Field Validation Woredas for Flood Estimation

No	Site name	woreda	Location Coordinate			Remark
			Long UTM	Lat (UTM)	Altitude(m)	
1	Ereti	Afdera	1454213	624144	695	Danakil basin
2	Kesuwad	Afdera	1487287	666917	-60.2	Danakil basin
3	Yalebhe	Afdera	1493127	658657	-65.1	Danakil basin
4	Aetu ra	Afdera	1506191	655059	-78	Danakil basin
5	Giraro	Mille	1257160	698130	459	Awash basin
6	Mokole	Awra	1345410	631750	759	Danakil basin
7	adumdello	Gulina	1340679	595381	975	Danakil basin
8	Germille	Terru	1358381	654704	646.1	Danakil basin

9	Lemaarakobel	Terru	135327	635524	707	Danakil basin

As a result, the flood frequency distribution of a Danakil and Awash basins were somehow determined by physical & meteorological factors that vary in space and depend much on such catchment characteristics. The analysis took into account catchment area coverage, average annual rainfall, soil type, land cover/land use.

2.5.3. The Rational Formula Approach

The second flood estimation analysis applied the rational formula to estimate the peak flows in the catchment of the selected *kebeles*. The main purpose of applying the formula was to estimate the peak flow and use it with the surface runoff coefficient approach. The essential components of the formula used for peak flow estimation was:

- Q_p = CIA
- Q_P = peak runoff (m^3/sec)
- C is a dimensionless coefficient, C=f(land use, land cover, slope)
- I = rainfall intensity [mm/hr]
- A = drainage area [Km^2]
- where- C = 0.25 (moderately steep, grass-covered clayey soils, some development) C (0.25----0.50)

It was found that in Danakil basin most of the river networks were ungauged catchments. This has caused lack of hydrological and catchment information. Had those hydrological responses from each catchment were able to be captured, it would have helped in flood routing vis-à-vis in flood modeling and flood forecasting.

3. DESCRIPTION OF THE SELECTED PROJECT AREAS

3.1. Location and Extent

The Afar Region is located in the Northeast parts of Ethiopia. The region has five zones and 32 districts. The regional capital, Semera is situated about 591 km away from Addis Ababa, on the way leading to Djibuti. The study areas found in three zones, seven district and eighteen Kebeles and comprised 136, 245 ha of land. Of all seven districts, the five selected districts (Afdera, Erebti, Awra, Golina & Teru) found in Danakil basin in the Northwestern part of Afar National Regional State. While Dubti and Mille lies in Awash River sub-basin.

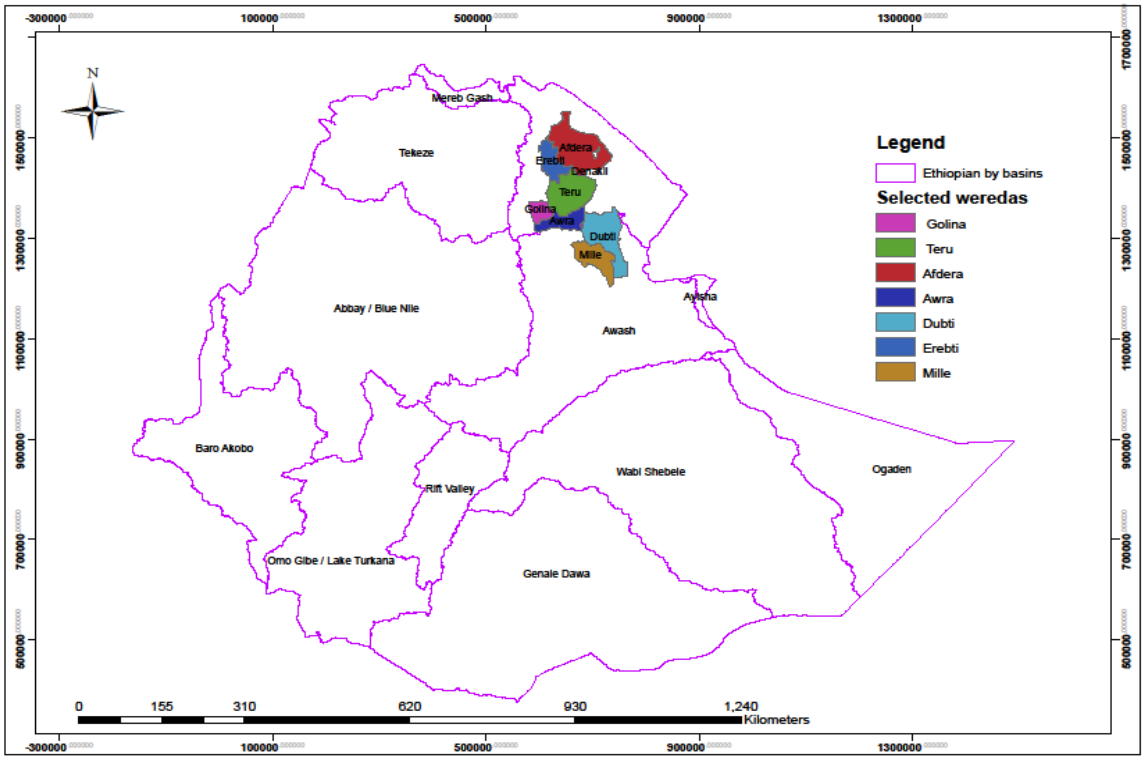


Figure 6: Location map of selected districts

3.2. Topography

The rate and volume of runoff and sediment yield from the upper catchment have much to do with slope and other parameters of the landscape. There are four aspects of topography on which information is required when assessing its impact on soils namely, slope, macro and micro relief and position in relation to survey area. The altitudinal ranges of the selected flooded areas are -96 meter below sea level to 1031 meters above sea level.

The slope classes of the study area were generated from 20 meter resolution digital elevation model (DEM). The area coverage showed that about 88,955 ha of the main land form of the study area is flat land and followed by slightly undulating plain, such as gently sloping (44,543 ha) and gently undulating to sloping (2,323 ha) topography with slope ranging between 2-4% and 4-6% respectively. The sloping topography having a slope value above 6-8 and >6% is located within the different part (scattered place) of the study area and covered 424 ha (0.31%) of the land. This results shows that the flooded areas have flat terrain. The flooded areas presented in the following figure and summary table.

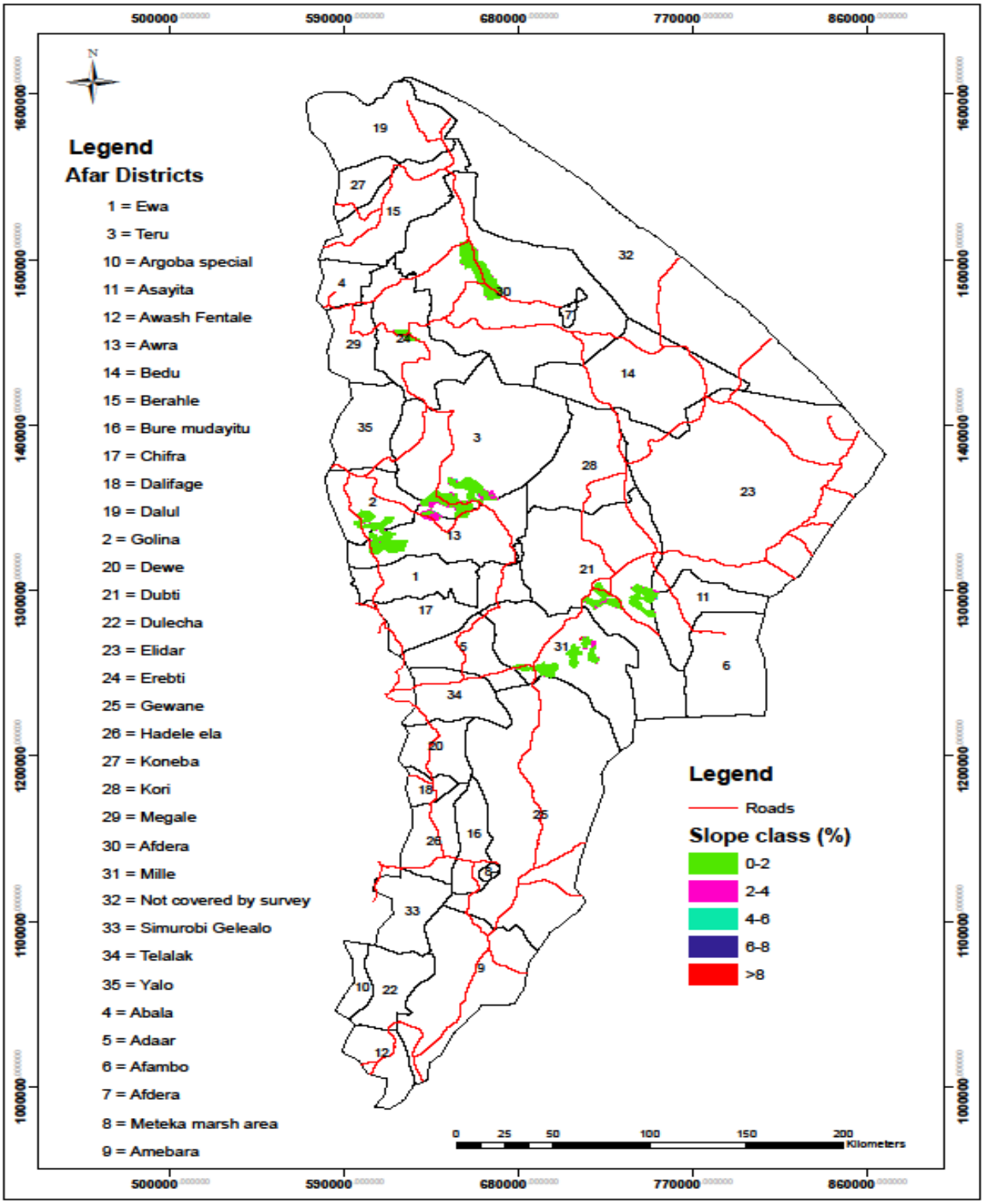


Figure 7: Map of the flooded areas from the sampled *kebeles* of seven districts

Table 2: Synopsis of slope class and coverage of flooded areas

Slope (%)	Descriptions/topography	Area	
		Ha	%
0-2	Flat	88,955	65.29
2-4	Gently sloping	44,543	32.69
4-6	Gently sloping to sloping	2,323	1.71
6-8	Sloping	354	0.26
>8	Sloping	70	0.05
Total area		136,245	100

Per the terms of reference provided for this task, the areas to be included under this validation study is those flooded *kebeles* and districts with a slope range of 0 to 2. Hence, closer to 65.29 % the areas selected for this validation falls within the required range covering a total areas of 88,955 hectares of land in all the seven districts.

3.3. Length of Growing Period and major agro-ecology

Moisture availability for plant growth is assessed by giving attention to the concept of the length of growing period (LPG), which considers the mean monthly rainfall and mean monthly evapo-transpiration relationships. The growing period defines the period of the year when both moisture and temperature conditions are suitable for crop production (FAO, 1996). The length of growing period of crops is determined by the amount of distribution of rainfall and evapotranspiration. These climatic parameters indicate the soil moisture either in a surplus or in a deficit manner. When the moisture content of the soil is surplus, the length of growing period is greater and vice versa. Within the tropics, areas having heavy rainfall and low temperature have a greater length of growing period, whereas areas having inadequate rainfall and high temperate have less LGP. The estimation of growing period is based on a simple water balance model which compares rainfall with potential evapotranspiration (PET) that determines the start, end and type of growing period. The periods in which the rainfall is greater than half PET and full PET are known as moist and humid periods respectively (FAO, 1996).

Agro-climatic zone is a land resource mapping unit defined in terms of climate, and having a specific range of potential and constraint for land use. One of the main factors in differentiating an agro-climatic zone from the other is the existence of uniform characteristics of the growing period zone of an area. In fact, agro-climatic zones are produced using the map of the growing period zones is superimposed over the thermal zones.

Table 3: Major agro-ecology and length of growing period in days

No	Selected kebeles in Districts	Major agro-ecology	Length of growing period (days)
1	kebeles in Afdera	Hot arid lowlands (A1)	0-45
2	kebeles in Dubti	Hot arid lowlands (A1)	0-45
3	kebeles in Mille	Hot arid lowlands and Warm arid lowlands plain	0-45
4	kebeles in Awra	Warm arid lowlands plain and Warm sub-moist lowlands	0-45 and 61-120
5	kebeles in Golina	Warm arid lowlands plain and Warm sub-moist lowlands	0-45 and 61-120
6	kebeles Teru	Warm arid lowlands plain	0-45
7	kebele Erebti	Warm arid lowlands plain	0-45

In synopsis, as shown in the above figure the three agro-econolgical zones of the selected study areas are:

- Hot arid lowlands (A1): The mean annual temperature is greater than 27^0C and the mean annual rainfall ranges from 100-400 mm with high evaporation. Growing period is less than forty five days (<45 days). This zone has potential for livestock rearing, irrigated agriculture, salt mining, tourism and wildlife. However, malaria, poor infrastructures, and high temperature are the constraints.
- Warm arid lowlands plain (A2): The mean annual temperature varies from 21 to 27.5^0C and the mean annual rainfall ranges from 100 to 600 mm. The growing period is less than 45 days.
- Warm sub-moist lowlands (SM2): The annual temperature falls between 21^0C and 27.5^0C. The growing period ranges between 61 and 120 days (MoARD, 2005).

3.4. Climate

Climate is a controlling physical factor in irrigated agricultural land use. It is the main agent determining the water balance in geo-hydrology and hydrology. Finally, climate largely determines the nature of the natural vegetation, and interactions of climate, relief, and soils are particularly important for land use. Any irrigation project has to consider the existing climatic and hydrologic parameters prevalent in its surrounding area. In this case temperature, rainfall and other climatic features has to be studied for selection and determination that fit to the purpose of agronomic practices.

The mean annual rainfall of the study area ranged from 100-600 mm. The average mean temperature falls between 21 and 27.5^0C. Air temperature regulates the growth and development of many plants by regulating the rate of biochemical processes. The growth of many

crops ceases below a critical temperature of 5^0C or above 35^0C, adversely affecting the yield (MoARD, 2005).

4. FINDINGS AND ANALYSIS

4.1. HYDROLOGIC ANALYSIS

4.1.1. Surface Runoff Coefficient Approach

Hydrologic assessment was made in two sub-basins of Afar: Dankil and Awash sub-basins. The selected districts and respective *kebeles,* however, fall under the Dankil depression. The flood analysis had involved considering the rainfall patterns in the sites specified. Initial estimate of annual runoff is estimated by multiplying annual rainfall by annual runoff coefficient.

A rough estimation of the mean areal catchment rainfall by Isohyetal method and data extracted through various sources. The tables below are results of the hydrologic analysis using the surface runoff coefficient and the rational formula approaches respectively.

Table 4: Location of Field Validation Woredas for Flood Estimation

No	Site name	woreda	Location Coordinate			Watershed Area Km^2	Average annual rainfall value (mm)	Annual runoff coefficient	Annual Flood Volume (10^6m^3)	Basin
			Long UTM m	Lat UTM m	Altitude (masl)					
1	Ereti	Afdera	1454213	624144	695	524	300	0.02	3.14	Dankil basin
2	Kesuwad	Afdera	1487287	666917	-60.2	260	120	0.01	0.31	Dankil basin
3	Yalebhe	Afdera	1493127	658657	-65.1	584	150	0.01	0.88	Dankil basin

4	Aetu ra	Afder a	150619 1	655059	-78	1560	250	0.02	7.80	Danakil basin
5	Giraro	Mille	125716 0	698130	459	1071	450	0.06	28.92	Awash basin
6	Mokole	Awra	134541 0	631750	759	133	450	0.06	3.59	Danakil basin
7	adumdello	Gulina	134067 9	595381	975	1175	700	0.15	123.38	Danakil basin
8	Germille	Terru	135838 1	654704	646.1	4300	400	0.05	86.00	Danakil basin, Awira and Golina rivers
9	Lemaarakobel	Terru	135327 0	635524	707	4300				Use Awira and Golina river

As arid area rainfall is highly variable, the above estimate of annual runoff should be confirmed by discharge measurements for at least 2-3 years before implementing any work.

Table 2: Estimated mean areal catchment for flood runoff in different sub-basin of Afar Regional State

Area coverage classified in attitude	Area KM^2	Average rainfall value (mm)	Annual runoff coefficient	Estimated volume of flood ($10^6 m^{3/}$ year)

High land (Mountainous) 2500 masl (eastern tributaries of Awash river)	670	600	0.2	80
Between 1500----2500 m asl Golina, Awra (part eastern tributaries of Awash river and Danakil depression)	6270	500	0.08	250

Table 6: Estimated mean areal catchment for flood runoffs in different sub-basin of Afar Regional State

Area coverage classified in attitude	Area KM^2	Average rainfall value (mm)	Volume (10^6m^3)
High land (Mountainous) 2500masl	670 km^2	1000mm	670.0
Between 15000----2500 m asl Golina, Awra	6270 km^2	800mm	5016.0
Flat region (Erbeti & Teru, Dubti	23620 km^2	600mm	14171.0
Arid region (Afdera) , Millie	43440 km^2	50mm	2172.0
Total	74,000 km^2		22029.0

Based on the above estimation, the average catchment rainfall was found to be 300.0 mm as we divide the total runoff for the catchment areas to be covered 22029.0/ 74000.0. Although it dependent on the crop and vegetables types, there are indications for having relatively adequate runoff to expand spate irrigation. The most important key fact in this regard tend to be the amount investments to be mobilized on water storage structures and ensure irrigation developments. Thus, from the rainfall analysis, one can deduce the presence of adequate water for spate irrigation in those kebeles and districts selected for validation except Afdera. However, there was a robust argument that there are probabilities of developing spate irrigation if there would be properly constructed diversions even at Afdera.

4.2. SOCIOECONOMIC ISSUES

4.2.1. Population

According to CSA 2007, the total populations of selected seven districts were 429,036, where 56% are male and 44% are female population. From the total population 28,492 (8%) are urban and 316,773 (92%) rural residents. When we say urban residents, it is only those living in these emerging towns of the Woreda headquarters. The size of population of the region is one of the essential factors in the development efforts. The balance between economic and population growth is among the concerns of the regional and federal governments. Today the growth of population of the region as well as the country is shows rapid growth.

When compared each Districts population; Mille and Dubti district are with large population size and Afdera with a small residents. The rest districts with moderate population size with underdeveloped and poor social interactions. In the table, the male population exceeds the female population by considerable amount 11.7% which indicates imbalance between male female and the ratio is 1.27:1 (One and 27 male to one female ratio).

Table 7: Population, Density and average household in the selected Districts

Zones	Districtss	Districts Population (CSA 2007)			Density per km^2	Average house hold (number of families per)
		Male	Female	Total		
04	Golina	31619	24118	55,737	70	7
04	Teru	43841	30915	74,756	12	7
02	Afdera	20609	15784	36,393	6	6
04	Awra	21095	17306	38,401	17	7
01	Dubti	43588	38147	81,735	14	6
02	Erebti	21558	16779	38,337	15	5
01	Mille	56734	46943	103,677	36	7
Total population		239,044	189,992	429,036	25.14	6.43

Source: CSA, 2007 and oral interview.

As Table 4-1 has indicated the population density varies from District to district, this may be up on different conditions, may be the number of population and the extent of the districts. Around six people are living in one square kilometer in Afdera which are very scattered and the least in comparing to the others. Whereas Golina has around 70 people living within one km^2 area, meant there is crowded settlement comparing with the rest study districts. This may have different influential reasons behind, the climate and ecology, facilities and infrastructures, and suitability for living are some of them. The average density in the study area is 25.14 people living within

one km^2 which is minimal when we compared with the rest of the country. The average family size of selected districts areas are 6.43 persons per head.

4.2.2 Economic Conditions

In view of the source of income of the community, livestock are the major economic activities of the fifteen kebele and seven districts. Even though some irrigation farming practice existed in Awra, Dubti and Mille districts, livestock production occupies the largest share of means of livelihood of the people. The discussion has revealed that for 95% of the households, the major source of income is livestock production. Crop production is only an economic base for about 5% of the households.

On the other hand, the other Districts such as Afdra, Erebti, golina and Teru have no irrigation practices and the economic activity is limited to pastoral type. Therefore, there is no option for farm employment opportunities in the area.

Based on the information obtained from an open interview, from year to year, the rainfall and grass covered within the districts decreased. The natural woodland vegetation of the districts since then gradually disappeared due to overgrazing, increased demand for fuel-wood, charcoal and drought.

4.2.3. Food security

Since the last two years, the districts have been facing critical rainfall shortage and food securities of the districts are threatened at large. Among the 18 Kebeles in the selected districts, all are dependent for food aid. The pastoralist Kebeles of the district are highly affected by food shortage. Their livestock are also threatened with the rainfall shortage. So food shortage and food insecurity is one of the priority problems of the Districts. Nevertheless, the Districts have good potential for irrigation development, where huge amount of land is available. But currently, only Mille and Dubti district have a practice of irrigation and few hectares of land is irrigated under modern and traditional irrigation systems, which are still less to secure food supply in the Districts.

On the other hand, it was noted that all the selected Kebeles are within the list of Kebeles for food aid. These communities earn their income from livestock production.

4.3. Basic social services and infrastructures

4.3.1. Market Access

Marketing facilities for the pastoralists and agro-pastoralists ensure better earning by disposing livestock and livestock products at better prices and also enabling access to food items and industrial goods needed for the community. Unfortunately, there is no regular market facility for

livestock and livestock products, and transaction of other commodities in some of the district in the study area. District like Erebti and Afdera have no adequate and regular market day with in their districts.

The accesses for markets in some areas are also very poor in obtaining all-round market services. Lack of market access is among the major constraints in the study area. Markets activities done within those districts having market access are mostly simple transactions only, if they need to purchase and sell some basic commodities like industrial goods, selling large number of livestock and so on, they should travel to long distance for better availability of commodities and reasonable prices (selling and buying prices).

Though there is higher livestock potential in the area, production is yet lower. But on the other hand, an increasing demand for food crops is expected, due to the drought, and increasing population in the selected and surrounding areas. Be all these facts, in the selected Kebeles, there is no appropriate market centre; there is only a small market that holds once a week. The primary market is characterized by low market participants, majority of which are rural pastoralists that sale similar livestock products. Traders and urban consumers are less accessible or available due to low urbanization of the area and poor road and transportation systems. Cooperatives are not also organized to collect products. Altogether, livestock products from the area have limited market channel.

4.3.2. Human health

Health being one of the fundamental social development indicators that has to be covered in the irrigation development process. This is due to the fact that the health situation of an area can be affected with the intervention of development program or development of an area is possible through the full participation of healthy and physically, mentally and economically sound people. On the other hand getting health service is part of human right, and without it economic development of a country becomes inconceivable.

According to the data from Health Bureau of the Region and Afar Region Survey (2006), the current health coverage of the Afar region is 78.7 percent. The establishment of health centers based on the number of population to give services on the assumption one health center for 25000 people and one health post for 2000 people. However, the health coverage is not uniform across the study woredas and Kebeles. All the studied woredas have health posts and health centers.

4.3.3. Capacity building

The overall objective of the capacity building strategy is to undertake technical support and enhance institutional and human resource capacity; this will help the project users to optimize

the efficient use of water resources with improved land management of smallholder irrigated agriculture development. This will in turn contribute to improving food security and alleviate poverty in the area.

In view of this, it is essential to employ basic capacity building issues by implementing partners and the local government. It is highly important to facilitate the transfer and adaptation of modern institutional arrangement and management of spate irrigation schemes to attain sustainable operation of the system. In this regard, training and capacity building is required at different levels, including for Woreda staffs, development agents and pastoral group. These trainings should aims to:

- Conduct public consultation and awareness raising for the community;
- Special training on leadership and organization for water management committee, sub-committees, and team leaders;
- Strengthen technical and management capacity of the Woreda and DAs to improve and upgrade organization and management efficiency of the project.

4.4. Farming systems of the selected Districts

The major economic activity for pastoralists is animal husbandry. The harsh environment in which herders raise their livestock requires constant mobility to regulate resource utilization via a common property regime. In contrast to the mobile way of life characterizing pastoralist, agriculture as a sedentary activity is only marginally present in the lowlands of the Afar regional state in Ethiopia. The farming system of the selected districts are dominated by pastorals (except Dubti) from which agro-pastoral activity is now emerging following some permanent and temporary rivers where small scale irrigation is being developed. The people inhabiting the study area are food insecure subject to seasonal migration to the neighbouring districts or highlands with their animals for searching grazing land and water.

4.4.1. Irrigated Farming System

Small Scale traditional irrigated farming systems are practiced in districts like Dubti, Mille and Awra while in Erebti, Golina, Teru and Afdera districts have no irrigated farming practices. Irrigated farming mostly practiced by farmers with land adjacent to rivers, streams and springs and they produce mostly maize, sorghum, tomato, onion, pepper, banana, papaya, and citrus etc. The small scale traditional irrigated farming is important to practice in the agro-pastoral farming systems. That is, it is an integral part of the farming system in the selected areas.

4.4.2. Agro-Pastoral Farming System

Agro-pastoral farming system is common in Dubti, Awra and Mille districts. Information obtained from pastoral and agro-pastoral Office indicated that out of the 76 Kebeles, only 17 Kebeles are agro-pastoralists undertaking both rain fed and small-scale irrigated agricultural practices

producing mainly cereals, vegetable and fruits. All districts suffer with moisture stress especially in Afdera and Erebti which drought is a usual phenomenon. Therefore, the potential to increase spate and small scale irrigated agriculture by diversion of perennial rivers is much better in the overall project area in order to alleviate a serious problems of moisture stress.

Cultivation of early maturing crops should be practiced, using the short and erratic rain during the summer season. In fact there is shortage of rainfall in the late stages of crop development. The main copping mechanism for this short and erratic rain fall is supplementing with spate irrigation, irrigating crop lands by diverting intermittent rivers & small streams that originate from boarder districts of Amhara and Tigray regions and even collecting surface run off of the surrounding catchment.

4.4.3. Pastoral Farming System

Entirely depends on livestock (goats, camels, cattle, and sheep) to generate a source of livelihood in the selected area. This sort of livelihood is predominant mostly in Erebti, Afdera, Teru, Golina, and Awra. They are transhumant and move from place to place in search of water and grazing for their livestock during dry seasons. This considered as the best coping mechanisms to overcome drought problems in most part of their livelihood.

4.4.4. Rain-fed cultivation

In Dubti, Mille and Awra district there is a practice to produced crops mainly based on rain fed agriculture and dominated by the subsistence small-holder farming. There is no rain fed crop production in the other districts due to shortage of rainfall. The community in the assessed kebeles lack skill for undertaking spate irrigated agriculture activities. The major crops produced by rain fed agriculture are cereals mainly maize and sorghum.

4.4.5. Spate irrigation

Spate irrigation is a system of irrigation where land is irrigated by flooding. It is a unique method of irrigation which utilizes flood water, harvested from ephemeral watercourses during and immediately after a rainfall event. It is concerned with diversion of large quantities of flood flow from highlands into leveled basins in the lowland. More specifically, FAO in 1987 defined spate irrigation as “an ancient irrigation practice that involves the diversion of flashy spate floods running off from mountainous catchments where flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channeled through short steep canals to bounded basins, which are flooded to depths of 0.5 m or more. Subsistence crops, often sorghum, are planted only after irrigation has occurred. Crops

are grown from one or more irrigations using residual moisture stored in the deep alluvial soils formed from the sediments deposited from previous irrigations.

In the study area the amount and distribution of rainfall over the growing period of long season crop is low. The crops planted in the lowland of the study area particularly sorghum and maize suffer from moisture stress during the late stages of growth from (Seed filling to full maturity). To overcome this problem agro-pastoralist divert flood water to their fields as a supplementary irrigation.

This traditional practice (spate irrigation) has long history in the other parts of the country like North wollo. The diversion of flood water into the arable lands has enable agro-pastoralist to produce late maturing crops such as sorghum and to increase their yield. This practice plays a key role in alleviating the existing moisture stress problems. All the selected areas (within the 18 kebeles) are suitable for spate irrigation with the construction of check dams on the dry river and water spread weir in both sides of the river. But this type of irrigation practice is labor intensive, costly, requires frequent maintenances and skilled manpower for construction. In addition to that, the dam silt up within a year and required maintenance every years.

Figure 8: Partial view of spate irrigation using check dam and water spreading weirs

Districts like Mille, Dubti, Awra and Golina have potential to irrigate adjacent suitable land with diversion of perennial rivers (Mille, Awash, Awra and Golina Rivers).

Table 8: Number of Kebeles and farming system within the selected Districts

Zones	Districts	Number of kebeles		Farming system by kebeles			Selected kebeles (numbers)	visited Kebeles	Remarks	Flooded area (ha)
		Rural	urban	Pastoralist	Agro-pastoralist	Irrigation practices				
04	Golina	8	1	6	2	0	4	Mulena Asale	2 is not accessible	3,144
								Kelewan		5,893
04	Teru	12	1	12	0	Solar pump irrigation	4	Namaara	2 is not easily accessible	20,972
								Digdiga		12,887
02	Afdera	9	1	9	0	0	5	Kusrewad	2 is not easily accessible	13,410
								Yelabay		6,326
								Ayitura		8,278
02	Awra	10	1	6	4	Diversion from awra River (during derg regime)	4	Edelu	1 is not easily accessible	4,281
								Leykuma		6,488
								Derayitu		9,526
01	Dubti	13	3	4	9	Modern and traditional irrigation (from awash river)	4	Beyihayile	All are easily accessible	5,641
								Bebedeta and Korele		6,748
								Debel and Nahalebayir		3,363
								Gurimu Dale and Gayidaro		6,959
02	Erebti	12	1	12	0	0	1	Albo	Easily accessible	3,540
01	Mille	12	2	7	5	Modern and traditional irrigation (from awash and mille river)	3	Deyilu and graro	All are easily accessible	4,522
								Kailu and asmelmed kudu		9,016
								Sene'as and kusrtu		5,251
Total		76	10	55	17		15			136,245

Source: Personal interview with District administrative and responsible experts

4.5. Major crops grown in the selected kebeles

The main objective of this study is to assess the potentials, opportunities and constraints of agricultural production in selected woredas of Afar region. According to this assessment, made by the team, crop production does not have a deep-rooted history in most parts of the Afar region as the case in most arid and semi-arid areas of Ethiopia. This is mainly associated with low availability of moisture and higher level of evapo-transpiration due to the high temperature prevalence in such areas. As a result, the major way of life in these areas is pastoralist. Generally, two forms of transformations are observed in occupation among the community in the surveyed woredas in recent years. The first and the most important form of transformation is the transformation from pure pastoralist to agro-pastoralist. This is considered very fast especially in the past 5-10 years due to severe drought attack. The second and perhaps occurred at a very low rate is the transformation from agro-pastoralist to pure pastoralist in areas that used to produce crops using rain. This is primarily associated with the reduction of rainfall amount and its erratic distribution in recent years.

The opportunities for the growth of agricultural activities are listed as: the availability of large cultivable land and the existence of several perennial as well as seasonal rivers for irrigation and crop production, the availability of research organizations (both federal and regional) such as Werer Agricultural Research Center (WARC) and Afar Pastoral and Agro pastoral Research Institute (APARI) that are fully involved in agricultural research activities in general and crop production in particular, the presence of various non-governmental Organizations (NGOs) that involve in agricultural development activities in the region, the availability of readymade improved technologies in WARC and other research centers suitable for semi-arid and arid agriculture & the presence of strong interest for crop production by the community and the views that currently expressing is following their ancestors foot step depending only on livestock production was no longer and unalterable option based on the assessment.

This study put the major problems facing the assessed Kebeles in the growth of the agricultural sector especially the crop sub-sector. Hence, lack of crop production skills, lack of irrigation structures, flood and canal damage by siltation, Shortage of adapted varieties and seed supply, pest and animal damage, lack of farm implements and trained oxen, lack of sound and strong effort & dependency syndrome are given great attention.

Based on the assessment, the major crops grown in some study areas are Maize, sorghum, Sesame, Groundnut, Tomato, Onion and Pepper. These will become more productive with the support of spate irrigation. These potential crops also have given due emphasis to the following conditions:

- Climatic conditions and adaptation of crops to growing conditions of the area;
- The soil condition of the project area;

- Interests of the farmers to grow;
- The length of the growing periods of the various crops;
- Yield and potentials of the crops;

These crops are already cultivated by few farmers in the selected weredas, especially Awra, Dubti and Mille. This indicates that the area has suitable climate and soil for these crops. Basically, these crops are affected by moisture stress in the dry season; spate irrigation would thus help to provide need-based moisture and encourage the use of other inputs for high productivity. The land suitability evaluation has also confirmed that the land is suitable to produce these crops. Soil depth also suitable for these crops and so the selected area satisfies these requirements.

4.6. Forage species that should be introduced in the study area

The already selected sites that are potential for livestock forage development needs to be over sown by improved grass seeds & legumes which are suitable to the study area's agro-ecological zone. Accordingly improved grass & legume species have been recommended to be introduced and over sown in the selected potential sites. The recommended improved grass seeds are Buffel grass, Elephant grass and Rhodes grass.

Figure 9: Range land in Erebti (left) and Afdera (right) districts

5. MAJOR PROBLEMS WITHIN THE SELECTED DISTRICTS

5.1. Drought and flooding

The major impacts of drought indicated by the pastoralist and agro-pastoralist included crop failure, drying of water resources, loss of livestock, famine, poor health of humans and animals,

increase in food prices, decline in livestock prices and reduction of income. With regard to the extent of effect of the recent drought, most of them were affected either severely or moderately.

In all project areas flood is not a problems except Dubti and Logiya districts. This flood occurs due to the over top flow of Mille and Logiya River during the summer season.

5.2. Invention of exotic species (Prosopis juliflora)

Exotic plant species have been purposely and/or accidentally introduced throughout the world due to their economic, environmental or aesthetic values. Nonetheless, introduction of new species is not always a success and brings about the possibility of invasiveness of the species which in turn result in negative impacts (economic, environmental and social). Encroachment of range and irrigated lands by invasive species, reduction of crop yield, genetic erosion of biodiversity, disruption of water flow, poisoning of livestock, formation of impenetrable thickets, etc are some of the impacts of invasive species across a wide range of agro-ecologies.

Even though; the exact date and source of prosopis introduction to Ethiopia had not been documented, it was wrongly introduced into high potential pasturelands and irrigable areas. Local people were not made aware of the invasive nature of the tree and also were not advised on the management practices to minimize further spread. As a result the shrub rapidly invaded vast areas of agro and silvo-pastoral lands and affected the biodiversity and socio-economic environment.

A considerable of land is either invaded or is at risk of invasion from Prosopis in the Afar region and particularly Dubti and Mille Districts from study areas. Control or eradication methods for invasive species could be categorized into three broad types. Physical; invader plants are removed by machine or people mechanically. Chemical; where herbicides are used to kill invader plants and biological; where predators or pathogens are used to control the invading plant's reproduction (Geesing et al., 2004). However, experiences from America, Asia and Australia have shown that eradication of Prosopis by the different methods, especially the mechanical and chemical ones are highly expensive and mostly ineffective (HDRA, 2005). Hence, management strategies were recommended to minimize the ecological and socioeconomic impacts of the invasion and to make use of prosopis as a valuable resource to support rural livelihoods in the dry lands (HDRA, 2005; Mwangi and Swallow, 2005).

Figure 10: Partial view of flooded areas in Dubti (left) and Mile (right) Districts

5.3. Soil sodicity (alkalinity)

The important variations in alkaline soils are related to the presences or absence of salt in the profile. Electrical conductivity (EC) may vary from none to very high levels, providing in the latter case that a natric B-horizon is present. They are soils with a dense, strongly structured, clayey subsurface horizon that has a high proportion of adsorbed Na ions. The percolation of water is low due to dense nitric illuvation horizon particularly at the beginning of rainy season. The soil structure is weak and mostly structures-less due to soil particles dispersion as result of presence of excess sodium. They are hard when dry and sticky by wet condition.

The presence of even low amounts of exchangeable sodium causes deflocculation of c1ay particles when the soil is wet, i.e. the complete breakdown of soil aggregates. Large pore spaces thus disappear. This process limits water movement. For a given ESP this effect is more extreme the higher the clay content. These soils are mapped in eight selected flooded areas such as Ayitura, Kusrewad, Gurimu Debel & Nahalebayir, Beyihayile, kelewan, Deyilu & graro, Sene'as & kusrtu and GurDale & Gayidaro and covered 53,277ha of land.

Figure 11: **Sodic soils at Kusrewad (left) and Sene'as & kusrtu (right) kebeles**

6. CHARACTERIZATION OF THE SOILS IN SELECTED AREAS

The soils of the study areas were identified based on in depth review of previous studies and prefeasibility level study which enabled identification of five reference soil groups of the study Kebeles within seven districts. Accordingly, major soil groups identified include Cambisols, Fluvisols, Luvisols, Solonetz and Vertisols.

Solonetzes are the dominant soil of the study areas which accounts 53,277 ha or 39 percent of the total study areas. Fluvisols are the second dominant soil in the 18 Kebele covering 21 percent of the total area. Luvisols occupy the lowest area coverage and accounts only 12849 ha or 9 % of the total study area.

The area, percent coverage and geographical distributions of Reference soil groups are presented in table 5-1 and figure 5-1 respectively.

Table 9: Soil mapping unit, reference soil groups and their distribution

No.	Soil mapping unit	Reference soil groups	Area	
			ha	%
1	SMU1	Fluvisols	15,973	12
2	SMU2	Cambisols	28,933	21
4	SMU3	Solonetze	53,277	39
5	SMU4	Vertisols	25,213	19
6	SMU5	Luvisols	12,849	9

Total area		136,245	100

Note: SMU1 = Albo, Yelabay, Bebedeta and Korele, Mule and Asale and Kailuna asmelmed kudu, SMU2= Leykuma and Derayitu, SMU3 = Ayitura, Kusrewad, Debel and Nahalebayir, Beyihayile, Gurimu Dale and Gayidaro, Deyilu and graro, Seneas and kusrtu and Kelewan, SMU4 = Namaara and Edelu and SMU5 = Digdiga

6.1. Description of Reference soil groups of the Study Area

In this section, brief description of major soils, their characteristics and aerial distribution of each soil are also presented. According to FAO 2006, soils of the flooded area classified in five reference soil groups.

6.1.1. Fluvisols

Fluvisols accommodate young soils of alluvial deposits rather than by pedogenetic processes. The soils show very little or no profile development with evidence of stratification and weak horizon differentiation. The soils were well drained and deep to very deep and covered 28,933 ha of land. Fluvisols can be extremely variable over very short distances, particularly with regard to texture. Particle size sorting and irregular chemical characteristics with depth often reflect the deposition of alluvium of different origin over time. Due to the above mention reasons, Fluvisols have several textures within the depth and has weak to moderately developed structures. Soil consistency varied between very friable to firm when moist and none stick to stick and none plastic to plastic when wet. With the end of depositions or in dry climates where deposition is possibly infrequent, pedogenetic processes may become evident.

Based on the laboratory result, the texture of the soils varied from silt loam to silt clay throughout the mapping units. The average bulk density of the soils of the unit was 1.29 g/cm3. According to London (1991), for good plant growth, bulk densities should be below 1.4 g/cm3 and 1.6 g/cm3 for clay and sandy soils, respectively and bulk density above 1.75 g/cm3 for sand, or 1.46 to 1.63 g/cm^3 for silt and clays as causing hindrance to root penetration. Thus, the bulk density values of all the samples observed in the soils studies were within the normal range of mineral soils worldwide, which may not limit root growth; air circulation and availability of less mobile essential elements such as P and K.

Available water holding capacity of the selected area ranged from 186-246 mm/m and rated as high. The soil reactions (pH) varied from 7.55-8.09, which is slightly alkaline to moderately alkaline. The average organic carbon content was 1.33%, which indicates that very low level. The value of electrical conductivity ranged between 0.0.25 and 2.99 dS/m, which is non-saline. The soils were marked by very high CEC and high PBS with the value of 44.70 meq/100 and 97.96% respectively.

Total nitrogen and available phosphorus content of these soils were 0.12% and 46.15 ppm, respectively. These values are rated as low for total nitrogen and high for available phosphorus. The soils were non-sodic with ESP 2.49 to 13.71 % on range. The exchange complex occupied with high level of Mg (7.91me/100g) and very high level of Ca (30.93me/100g), K (1.98me/100g) and Na (2.96me/100g) throughout the selected study areas. These reference soil groups mapped in to one mapping unit (SMU1).

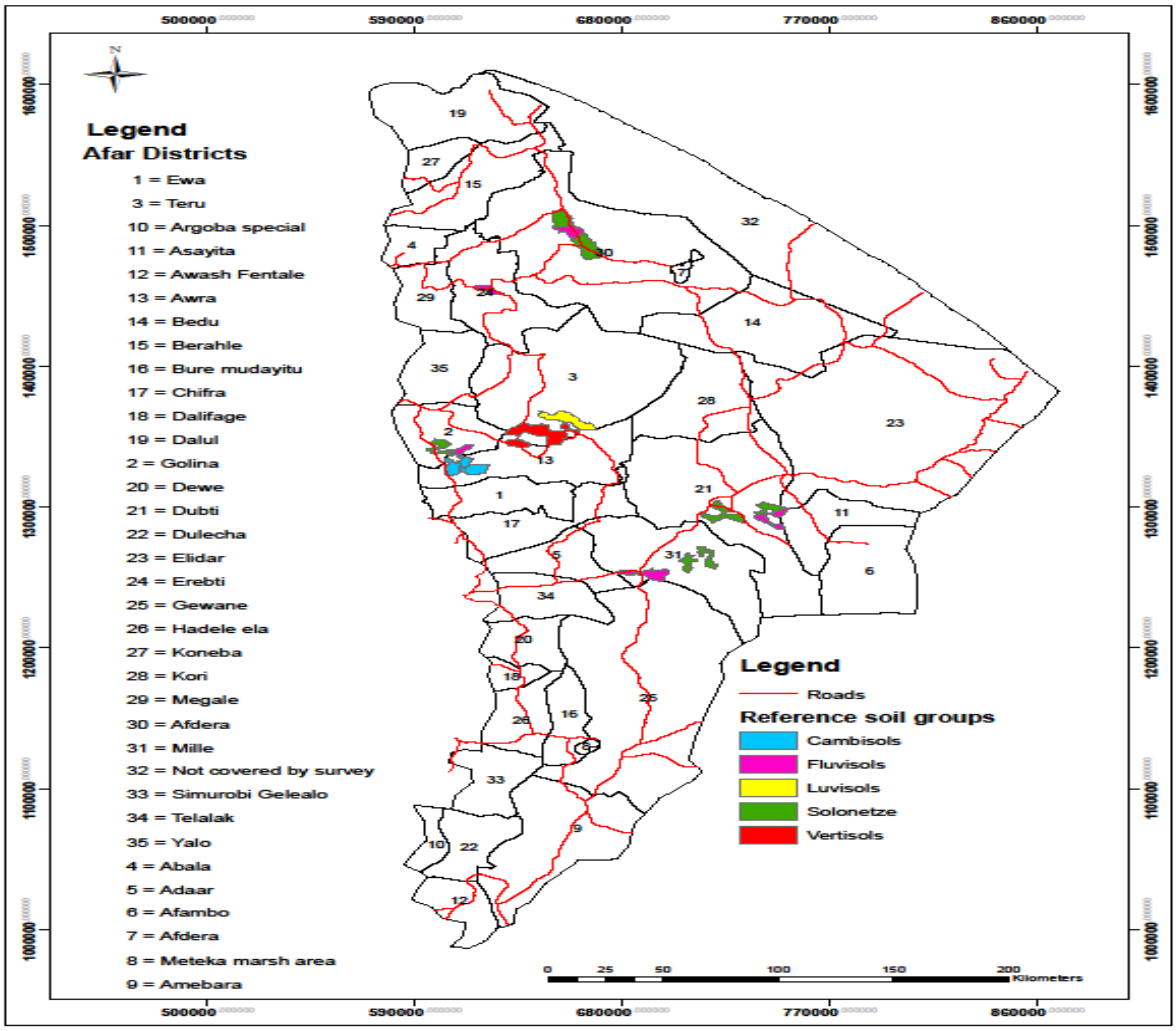


Figure 12: Reference Soil Groups of the flooded areas

6.1.2. Cambisols

Cambisols represent soils in which soil formation is characterized by a certain development of structure, or by colors indicating moderately pronounced alteration and development. They occur wherever conditions are not favorable for other soil formation processes than weathering to take place. These soils are with initial stage of soil formation, found at initial stage of profile

development marked by changes in soil structure, color and texture in the sub-soils or weakly developed soils relating to their parent material. Signs of beginning clay eluviations may be detectable in the cambic horizon, mostly brownish discoloration and/or structure formation below the surface horizon. The soils were moderately deep, well drained and comprise 15,973 ha of land and mapped into one mapping unit (SMU2).

The laboratory result showed that, the texture of the soils varied from silt loam to loam throughout the mapping units. The average bulk density of the soils of the unit was 1.40 g/cm3. Available water holding capacity of the selected area ranged from 187-241 mm/m and rated as high. The soil reactions (pH) varied from 7.77-7.84, which is slightly alkaline. The average organic carbon content was 1.30%, which indicates that very low level. The value of electrical conductivity ranged between 0.35 and 0.95 dS/m, which is non-saline. The soils were marked by high CEC and PBS with the value of 38.76 meq/100 and 98.95% respectively.

Total nitrogen and available phosphorus content of these soils were 0.12% and 46.15 ppm, respectively. These values are rated as low for total nitrogen and high for available phosphorus. The soils were non-sodic with ESP 2.77 to 7.59 % on range. The exchange complex occupied with high level of Mg (6.87me/100g) & K (0.86me/100g), and very high level of Ca (28.56me/100g) and Na (2.01me/100g) throughout the selected study areas. These reference soil groups mapped in to one mapping unit (SMU1).

6.1.3. Solonetzes

These soils are characterized by Exchangeable sodium. Solonetz are soils which have a high concentration of sodium in the natric horizon that starts 100 cm from the soil surface and have an ESP greater than 15%. They occur on flat to gently sloping topography. These soils cover about 53,277 ha or 39 % of the study area. Electrical conductivity (EC) may vary from none to very high levels, providing in the latter case that a natric B-horizon is present.

According to the laboratory result, the texture of the soils varied from loam to silt clay throughout the mapping units. The average bulk density of the soils of the unit was 1.34 g/cm3. Available water holding capacity of the selected area ranged from 179-267 mm/m and rated as high. The soil reactions (pH) varied from 7.51 to 8.23, which is slightly alkaline to moderately alkaline. The average organic carbon content was 1.18%, which indicates that very low level. The value of electrical conductivity ranged between 0.17 and 1.12 dS/m respectively, which is non-saline. The soils were marked by high (39.37 meq/100) CEC and high (266%) percent base saturation in the mapping unit.

Total nitrogen and available phosphorus content of these soils were 0.09% and 44.41 ppm, respectively. These values are rated as low for total nitrogen and high for available phosphorus.

The soils were sodic soils with ESP 100 to 113.64 % on range. The exchange complex occupied with very high level of Ca (26.46me/100g), Mg (8.13me/100g), K (35.68me/100g) and Na (36.99me/100g) throughout the soil horizons. These reference soil groups mapped in to one mapping units (SMU3).

6.1.4. Vertisols

Vertisols covered a significant area in the study area making up only 19 % of the total area and mapped into SMU4. They are mostly imperfectly to poorly drained, formed on flat to gently undulating topography. Vertisols are soils having, after the upper 20 cm have been mixed, 30 percent or more clay in all horizons to a depth of at least 50 cm; developing cracks from the soil surface downward which at some period, in most years (unless the soil is irrigated) are at least 1 cm wide to a depth of 50 cm. Vertisols have A (B) C-profiles; the A-horizon comprises both the surface mulch (crust) and the underlying structured horizon that changes only gradually with depth.

The soils which have formed (may be derived from montmorillonitic clay mineralogy) on flat to very gently sloping alluvial plains and on rarely rolling plain, cracking deeply with distinct shrink-swell properties, intersecting slickenside, at some depth between 25 and 100 cm from the surface are classified as Vertisols. These reference soil groups are marked by the presence of vertic horizon and vertic properties in their horizons.

The available water holding capacity of the selected area ranged from 186-226mm/m and rated as high. The soil reactions (pH) varied from 7.82-7.95, which is slightly alkaline. The average organic carbon content was 1.12%, which indicates that very low level. The value of electrical conductivity ranged between 0.21 and 0.92 dS/m respectively, which is non-saline. The soils were marked by very high (42.24 meq/100) CEC and percent base saturation (96.60%) in the mapping unit.

According to the laboratory result, the texture of the soils varied from loam to clay loam throughout the mapping units. The average bulk density of the soils of the unit was 1.39 g/cm3. Total nitrogen and available phosphorus content of these soils were 0.07% and 38.55 ppm, respectively. These values are rated as very low for total nitrogen and high for available phosphorus. The soils were sodic soils with ESP 2.53 to 6.5% on range. The exchange complex occupied with very high level of Ca (30.73me/100g), K (1.62me/100g), Na (2.03me/100g) and high level of Mg (6.41me/100g) throughout the soil horizons. These reference soil groups mapped in to one mapping units (SMU4).

Figure 13: **Vertisols at Teru Districts**

6.1.5. Luvisols

Luvisols are soils whose dominant characteristic is a marked textural differentiation within the soil profile, with the surface horizon being depleted of clay and with accumulation of clay in a subsurface 'Argic' horizon. Luvisols have high activity clays. The dominant characteristic of Luvisols is their argillic eluviations horizon formed by translocation of clay from the surface soil to the depth of accumulation. Normally, clay in soil is not present as individual particles but is clustered to aggregates that consist wholly of clay or of a mixture of clay and other mineral and/or organic soil material.

The investigated soils have typically a black to dark brown surface horizon over a reddish brown to strong brown argic subsurface horizon and covered 12,849 ha or 9% of the selected area. By and large, Luvisols have favorable physical properties; they have weak to moderately developed structure surface soils that are porous and well aerated. The 'available' moisture storage capacity is highest in the argic horizon. The argic horizon has a stable blocky structure but surface soils with high silt content may be sensitive to slaking and erosion. Most Luvisols are well drained but

Luvisols in some depression areas develop gleyic soil properties in and below the argic horizon. These reference soil groups mapped into soil mapping unit five (SMU5).

The available water holding capacity of the selected was 198mm/m and rated as high. The soil reaction (pH) of the mapping unit was 8.04, which is moderately alkaline. The average organic carbon content was 0.88%, which indicates that very low level. The soils were marked by high (37.02 meq/100) CEC and percent base saturation (98.6%) in the mapping unit.

According to the laboratory result, the texture of the soils was loam. The average bulk density of the soils of the unit was 1.49 g/cm3. Total nitrogen and available phosphorus content of these soils were 0.04% and 47 ppm, respectively. These values are rated as very low for total nitrogen and high for available phosphorus. The soils were non-sodic and non-saline soils with ESP 3.4% and 0.21 on range. The exchange complex occupied with very high level of Ca (26.58me/100g) & K (2.85me/100g), and high level of Na (1.26me/100g) & Mg (5.82me/100g).

7. HYDROLOGICAL ANALYSIS

The tables below are results of the hydrologic analysis using the surface runoff coefficient and the rational formula approaches respectively.

Table 10: Location of Field Validation Woredas for Flood Estimation

No	Site name	woreda	Location Coordinate			Watershed Area Km^2	Average annual rainfall value (mm)	Annual runoff coefficient	Annual Flood Volume (10^6m^3)	Basin
			Long UTM m	Lat UTM m	Altitude (masl)					
1	Ereti	Afdera	1454213	624144	695	524	300	0.02	3.14	Danakil basin
2	Kesuwad	Afdera	1487287	666917	-60.2	260	120	0.01	0.31	Danakil basin
3	Yalebhe	Afdera	1493127	658657	-65.1	584	150	0.01	0.88	Danakil basin

4	Aetu ra	Afder a	15061 91	6550 59	-78	1560	250	0.02	7.80	Dana kil basin
5	Giraro	Mille	12571 60	6981 30	459	1071	450	0.06	28.92	Awas h basin
6	Mokole	Awra	13454 10	6317 50	759	133	450	0.06	3.59	Dana kil basin
7	adumdello	Gulin a	13406 79	5953 81	975	1175	700	0.15	123.38	Dana kil basin
8	Germille	Terru	13583 81	6547 04	646.1	4300	400	0.05	86.00	Dana kil basin, Awira and Golin a rivers
9	Lemaarako bel	Terru	13532 70	6355 24	707	4300				Use Awira and Golin a river

As arid area rainfall is highly variable, the above estimate of annual runoff should be confirmed by discharge measurements for at least 2-3 years before implementing any work.

Table 11: Estimated mean areal catchment for flood runoff in different sub-basin of Afar Regional State

Area coverage classified in attitude	Area KM^2	Average rainfall value (mm)	Annual runoff coefficient	Estimated volume of flood ($10^6 m^{3/}$ year)

High land (Mountainous) 2500 masl (eastern tributaries of Awash river)	670	600	0.2	80
Between 1500----2500 m asl Golina, Awra (part eastern tributaries of Awash river and Danakil depression)	6270	500	0.08	250

Based on the above estimation, the average runoff is 796 million m^3/year over the Afar region. Most of the flood are spread in low lying areas and loss for evaporation and seepage along the river, unless stored upstream or used for spate irrigation (as naturally is growing other plants in and around the banks of the rivers).

The table below provides estimates for some of the catchments and sub-catchments in the Danakil and Awash sub-basins.

Table 12: Peak flows and the parameters required for computing flood runoffs in the rational formula

Classification of altitude around the selected sites	Area (A) coverage	C=	I (mm/yr)	Q_p (m^3/s)	Remark
Above 2500masl	670 km^2	0.25	8	1340	There were no sites included from this category
Between 15000----2500 m asl	6270 km^2	0.30	5	9405	Selected sites from Golina & Awura
Flat region	23620 km^2	0.40	1.10	10392.8	Erbeti, Teru & Dubti
Arid region	43440 km^2	0.050	0.20	434.4	Afrdera & Millie
Total	74,000 km^2				

8. LAND SUITABILITY EVALUATION

Land evaluation is the major factor which is used to provide information and recommendations on selection of suitable land, cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (FAO, 1985).

8.1. Soil and Land Suitability for Irrigated Crops

The FAO guidelines for irrigated agriculture (FAO, 1985) and (Ir.C.Sys et.al., 1993) were used in the land suitability evaluation of the potential area. Land suitability is defined as the fitness of a specific area of land for a specified kind of land use (land utilization type, LUT) under a stated system of management. The main land Utilization types (LUTs) which are considered in these evaluations are cereals (Maize and sorghum), vegetable (tomato, onion and green pepper), oil crops (Groundnut and Sesame) and forages (Elephant grass, Rhodes and Buffle grass). The suitability of land for selected crop was determined by rating each soil mapping unit which are relevant to the land utilization type. In this way the limitations of each land unit were identified for land utilization types (crop and forages).

8.2. Land Suitably Order and Classes

The land suitability orders for each land utilization type, suitable (S) and not suitable (N). The suitable order is divided in to three classes; highly suitable (S1), moderately suitable (S2) and marginally suitable (S3). Suitable land is the land on which sustained use of crops is expected to yield benefits which rationalize the inputs and development costs, without undesirable risk of damage to the land resources. The order not suitable has only two classes, temporary not suitable (N1) and permanently not suitable (N2). When a land unit is classified as temporary not suitable (N1), it suggests that although the development under consideration is physically possible, it is not considered viable under present economic or social conditions. N1 is land suitable for the proposed use but has limitation that is so severe, until this limitation is removed, the land should not be developed. However, it is expected that this overriding limitation could be removed in the foreseeable future, i.e. it is technically feasible and may be economically justifiable to so do. If the land unit is classified as permanently not suitable (N2), then the proposed development is physically impractical. N2 land is not and never will be suitable for the proposed use. It will never be technically feasible and/or economically justifiable to remove the limitations.

Table 13: Structure of FAO framework for land suitability classification: orders and classes (FAO.1985)

Category	Name	Definition
Order S	Suitable	Land on which sustained use of the considered kind is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.

Class S1	Highly suitable	Land having no specific limitations to sustained application of land use type under consideration. The class may include areas with minor limitations but these should not reduce productivity or net benefit significantly.
Class S2	Moderately suitable	Land having limitations which together are moderately sever for sustained application of a given land utilization type; production and net benefits are significant lower than for S1 land or there is a significant increase in costs.
Class S3	Marginally suitable	Land with limitations that in total are sever for sustained application of a given land use type; production will be so reduced and / or the need inputs will be so high that the use of this land will be only marginally justified.
Order N	Not suitable	Land with qualities that appear to preclude sustained uses of the kind under consideration.
Class N1	Marginally not suitable	Land having limitations that may be surmountable in time, but which cannot be corrected with existing knowledge under present social, economic and political conditions to yield acceptable levels of productivity.
Class N2	Permanently not suitable	Land having such severe physical limitations that makes it permanently not suitable for the given use usually due to physical limitations.

8.3. Land Suitability Subclasses

Land use and environmental requirements were matched with land characteristics and qualities of mapping unit to determine the land unit's suitable classes. For each suitability class, there are a number of subclasses which reflect the kind of limitations that restrict the suitability of the land for the proposed land utilization type. With the exception of highly suitable land (S1) which has no significant limitations-deficiencies other suitability classes are subdivided in to subclasses according to their dominant limitations.

Table 14: Land Suitability Limitations (subclasses)

Subclass	Description
c	**Climate (Temperature regime):** Land units having either very low or very high temperatures below or above the critical temperatures, which may cease the plant growth and may have adverse effect on rate of plant growth, depending on the type of plants and varieties to be grown. Thus adaptable crops should be carefully selected for evaluation.
m	**Moisture availability**: Land units having soil moisture deficiencies, there is a need for an increased amount and frequency of irrigation and/or selection of draught-resistant crop varieties. Surface irrigation may be more effective.
d	**Oxygen availability:** Land units having soil drainage deficiencies, ascribed to poor soil drainage that may be due to high ground water table, flooding, slow surface drainage (low physiographic position) or some combination of these. Sub-soiling, diversion ditches and under drainage may be required. Selection of more tolerant crops like rice can be another solution.

n	**Nutrient retention**: Land units having poor capacity of soil to retain added nutrients as against losses caused by leaching, ascribed to low CEC, and hence by organic matter. Thus, additional input is required to conserve organic matter and improve soil structure and require fertilizer application.
z	**Nutrient availability**: Land having poor capacity to supply crop with nutrients, ascribed to pH, texture, nutrient availability is lower in pH <5.5 and >7.5 by fixation.
y	**Sodicity hazard**: Land having higher exchangeable sodium percentage with adverse effects on crops; i.e. through direct toxicity of sodium to plants and by giving rise to massive or coarse columnar soil structure and low permeability. Gypsum application, leaching (under drainage) and/or selection of more tolerant crop varieties may be required.
r	**Rooting condition:** Land units with limited effective soil depth (effective depth is a depth to a limiting horizon having high amount of gravels, hard pan or toxic layers) and restrictive root penetration having massive, columnar or coarse sized structure coupled with very firm consistence and high amount of stones or gravels. Land having restrictive effective soil depth and/or penetrability, which impairs germination and hinders mechanical cultivation.
d'	**Drainage condition of the command area:** Land units having high and low infiltration and hydraulic conductivity due to soil texture, depth ground water table, presence and depth of impermeable layer and some other factors.

Source (FAO 1976)

8.4. Land Suitability Characterization by mapping units

Detail descriptions of physical and chemical characteristics of the selected area were already mentioned in Annex 1. The data described in this annex were major source of data for the land evaluation .The soil and land characteristics obtained from field soil survey and laboratory analysis results are the major source of data for land suitability evaluation. The suitability of these soils and mapping unit were evaluated for spate irrigated agriculture.

The major soil and land characteristic of the command area are matched against the standard soil and land requirements for selected crops (land utilization types). These matching enabled to identify the land suitability class, subclass and limiting factors for proposed crop development. Final land suitability rating of the command area by soil mapping unit and rating of individual land and soil characteristics shows the spatial distribution of land suitability classes and subclasses. The selection of class determining factors having significance in physical and economic stand point and the specific of critical limits to designate level of suitability on a factor by factor bases were carried out and later developed interaction of the relative importance of each factor and established critical limitation with the condition found in the mapping unit.

Table 15: Land suitability class, subclass and their area coverage of selected Irrigation Kebeles.

SMU	Reference soil groups	Area		Vegetables	Oil crops	Cereals	Forages
		ha	%				
SMU 1	Fluvisols	15,816	12	S2z	S2nz	S2n	S2n
SMU 2	Cambisols	28,733	21	S2z	S2nz	S2n	S2n
SMU 3	solontez	52,682	39	N2	N2	N2	N2
SMU 4	Vertisols	24,290	18	S2nz	S3n	S2n	S3n
SMU 5	Luvisols	11,979	9	S3z	S3nz	S2n	S3n
Sub total		133,500	98				-
Miscellaneous land for spate irrigation (> 4% slope)							
Sub total		2,745	2				
Grand total area		136,245	100				

Table 16: Suitable areas for the different crops

Suitability	Vegetables	Oil crops	Cereals	Forages
Moderately suitable (S2)	68,839	44,549	80,818	44,549
Marginally suitable (S3)	11,979	36,269	-	36,269
Permanently not suitable (N2)	52,682	52,682	52,682	52,682
Total suitable area for each crops (ha)	80,818	80,818	80818	80,818

8.5. Description of Identified Mapping Units Based on Suitability Classes and Subclasses

This section presented the land suitability by mapping units. Land suitability assessment had been made for some selected potential LUTs or crops under spate irrigation.

SMU 1: The mapping unit covered an area of some 15,816 ha (12%). This land unit rated as moderately suitable for Vegetables (S2z), cereals (S2nz), cereals and forages (S2n). The main limitations in the mapping units become moderately suitable, due to low organic carbon (n) and high soil pH value or slightly alkaline soil reaction (z).

SMU 2: The unit covered significant area of some 28,733 ha (21% of the total study area). These units also rated as marginally suitable (S2z) for vegetable, (S2nz) for oil crops and (S2n) for the other evaluated crops. They are downgraded, because of nutrient availability and nutrient

retention of the soils, i.e. higher pH value (z) for vegetable and oil crops, and low organic matter for oil crops, cereals and forage (n).

SMU 3: This units rated as N2 for all the evaluated crops with an extensive area of 52,682 ha (39%) of the total area. The main limitations in the mapping units become permanently not suitable, due to sodicity problems. This limitation explained by very high exchangeable sodium content.

SMU 4: This land type is classified as moderately suitable (S2n) for cereals and forage, and (S2nz) for vegetables with the extent of 24,290 ha (18%). The main limitation of the mapping unit is nutrient retention and nutrient availability. These explained by low value of organic carbon (n) and high value of soil reaction (pH value). The unit also rated as marginally suitable (S3n) for oil crops. This limitation explained by very low value of organic carbon.

SMU 5: The units covered relatively a smaller area of some 11,979 ha (9% of the total study area). These units are rated as moderately suitable (S2n) for cereals and marginally suitable for vegetables (S3z), oil crops (S3nz) and forages (S3n). The main limitations are low organic carbon content for cereals and moderately alkaline soil reaction (pH value) for vegetables and oil crops. The soils also have very low organic carbon for oil crops and forages.

8.6. Land suitability map

The land suitability maps have been prepared for cultivated of important potential crop with spate irrigation, which are available in the report at the figures indicated against them.

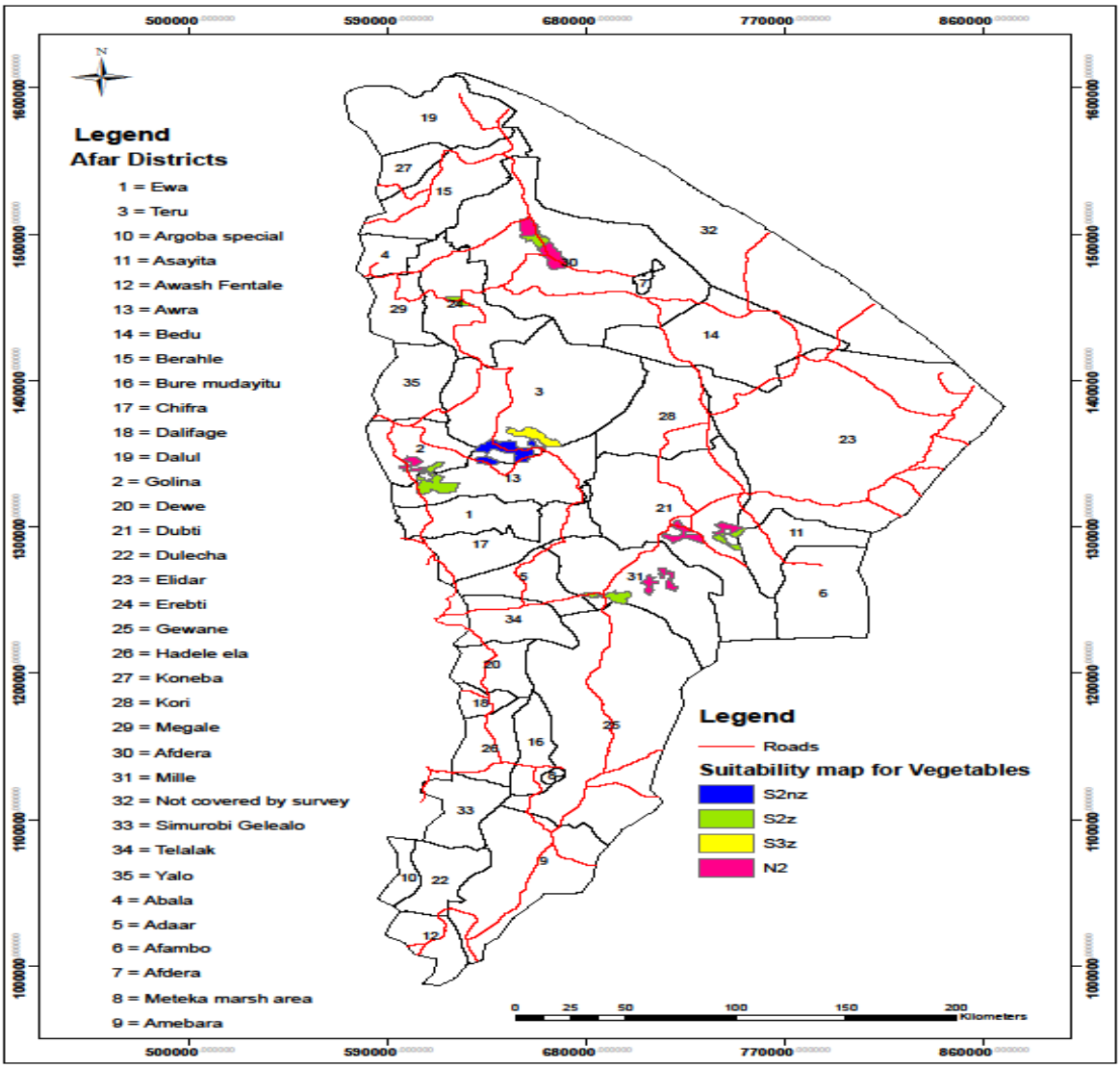


Figure 14: Actual soil and Land suitability Map for vegetables in selected Kebeles

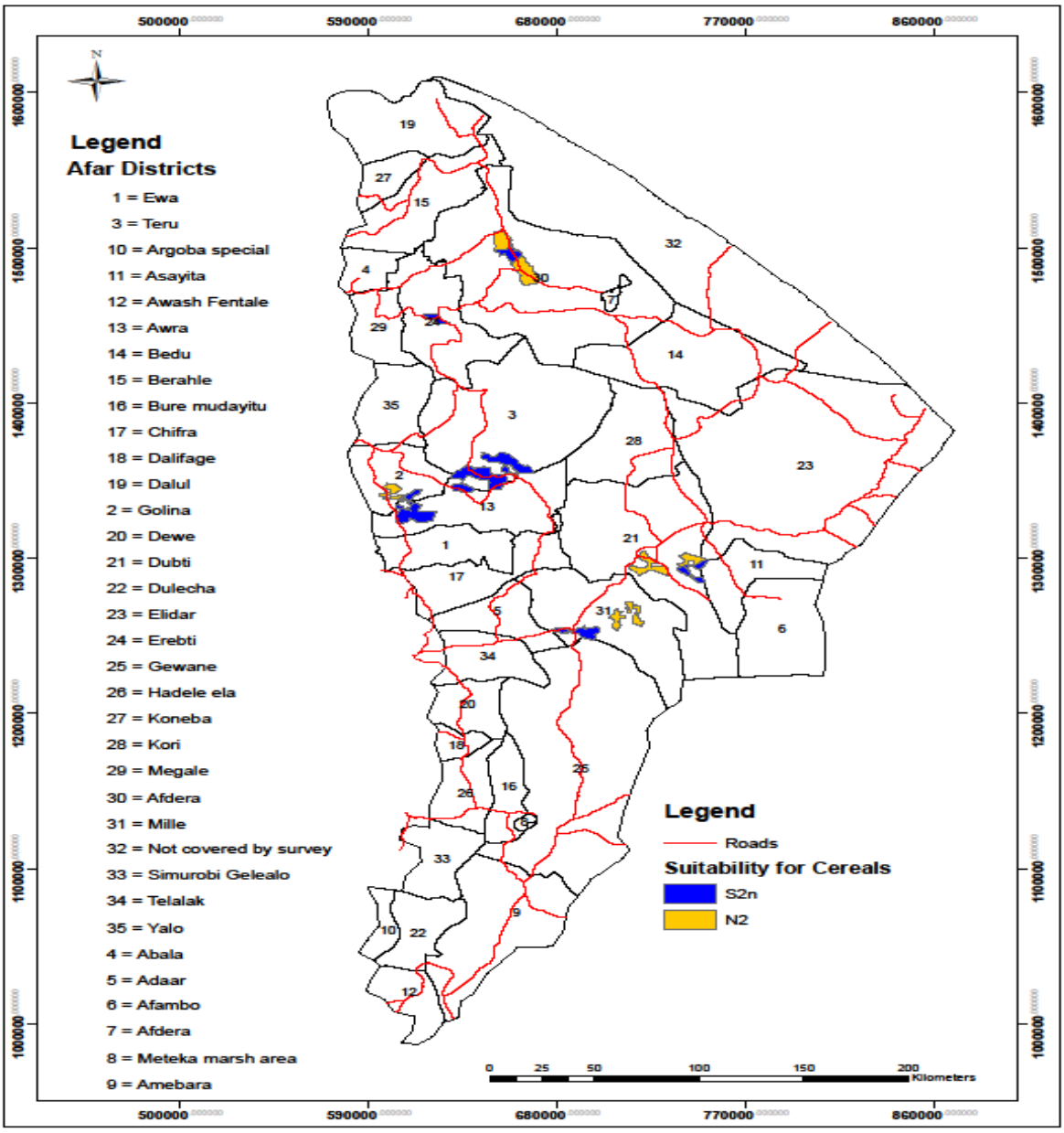


Figure 15: Actual soil and Land suitability Map for cereals in selected Kebeles

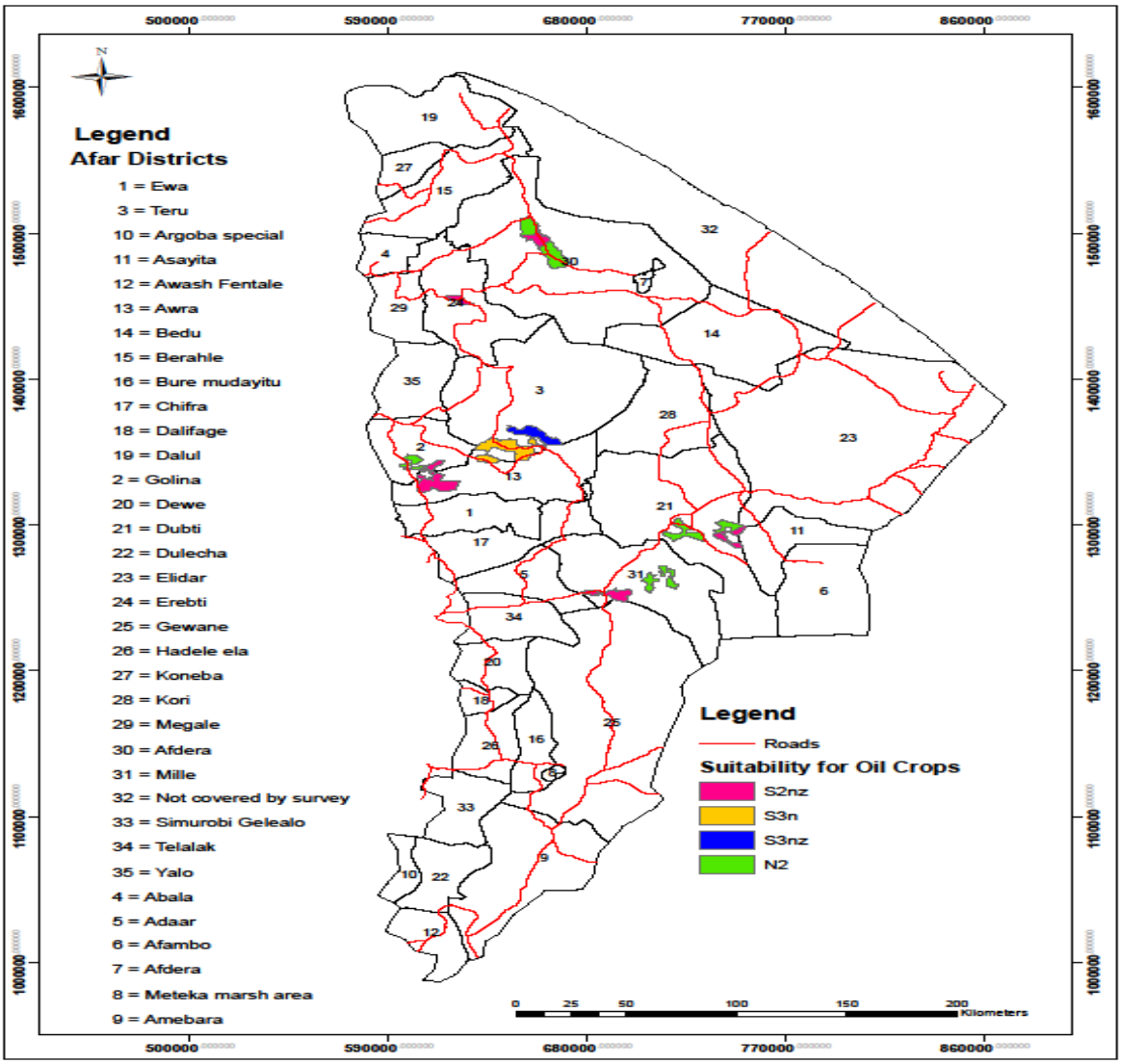
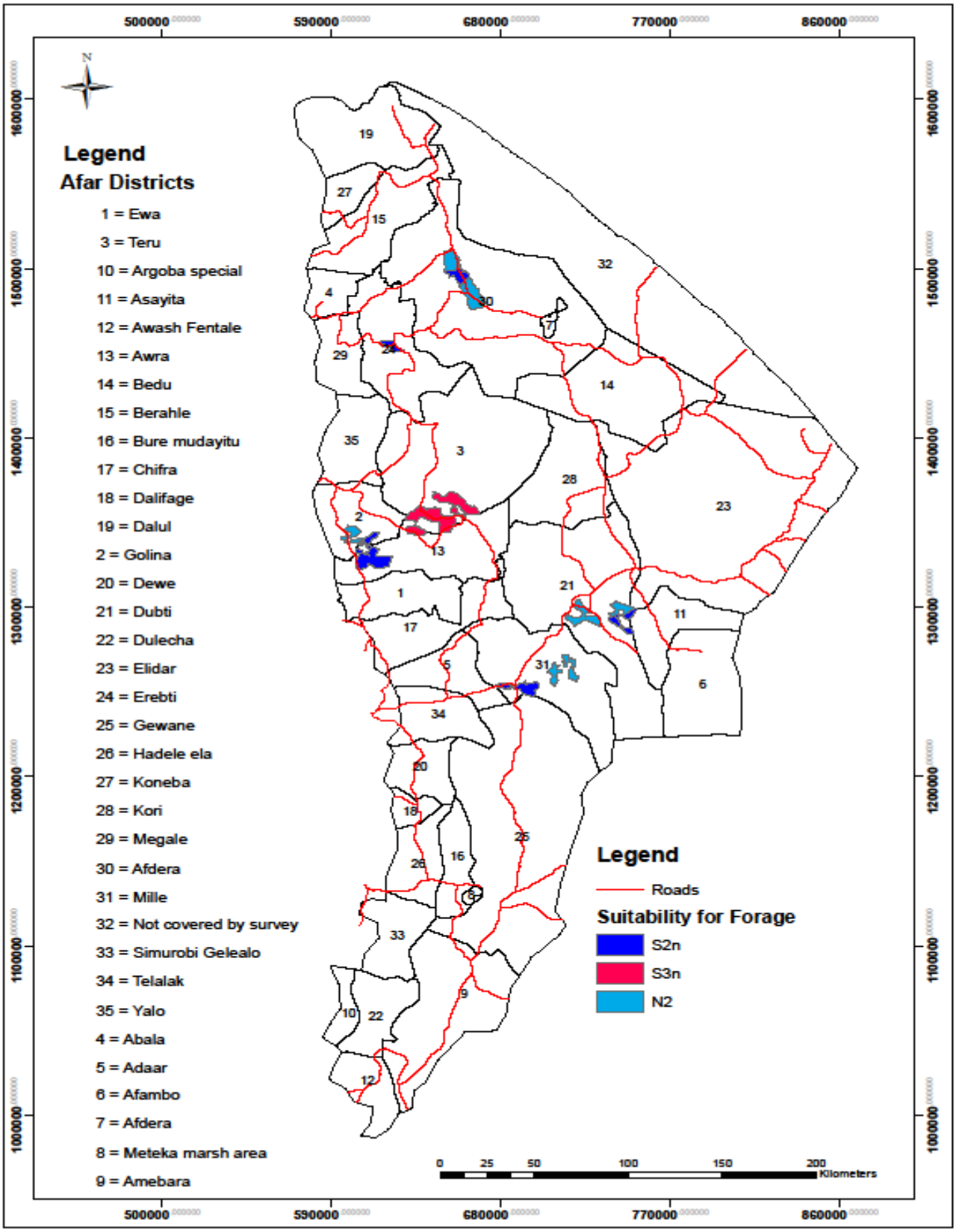


Figure 16: Actual soil and Land suitability Map for oil crops in selected Kebeles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590000
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Legend
Afar Districts
1 = Ewa
3 = Teru
10 = Argoba special
11 = Asayita
12 = Awash Fentale
13 = Awra
14 = Bedu
15 = Berahle
16 = Bure mudayitu
17 = Chifra
18 = Dalifage
19 = Dalul
2 = Golina
20 = Dewe
21 = Dubti
22 = Dulecha
23 = Elidar
24 = Erebti
25 = Gewane
26 = Hadele ela
27 = Koneba
28 = Kori
29 = Megale
30 = Afdera
31 = Mille
32 = Not covered by survey
33 = Simurobi Gelealo
34 = Telalak
35 = Yalo
4 = Abala
5 = Adaar
6 = Afambo
7 = Afdera
8 = Meteka marsh area
9 = Amebara
Legend
Roads
Suitability for Forage
S2n
S3n
N2
0 25 50 100 150 200
Kilometers

Figure 17: Actual soil and Land suitability Map for Forages in selected Kebeles

8.7. Land Suitability

Irrigation Suitability Land Classification is the systematic evaluation of lands and their designation by categories or classes based on similar physical and chemical characteristics and related economic conditions, with respect to suitability for sustained agricultural production under irrigation and irrigation service under a plan for water and land resource development

The primary objective of irrigation suitability land classification is to support irrigation project development by characterizing and delineating the lands suitable for sustained irrigated agricultural production under a given project setting. Some important land classification investigation contributions to an irrigation project planning study include assistance in determining: (1) proper land and water uses, (2) farm unit size, (3) establishment of repayment assessments, (4) benefits and costs, (5) land development needs, (6) irrigable area, (7) design of irrigation and drainage systems, (8) appraised value of land, (9) return flow water quality, and (10) irrigation requirements (USBR, 2005).

In the absence of an exhaustive soil database for the region, we have selected few important factors and used to delineate areas suitable for irrigation not necessarily just for spate irrigation. Using African Soil Database System (AFIS) data for Ethiopia we employed GIS with soil texture, soil depth, slope, and salinity layers to delineate physically suitable areas for irrigation for the region. Figures 19, 20, 21, and 22 show very suitable, moderately suitable, marginally suitable, and suitable respectively areas for the region.

These factors are important in determining the frequency of irrigation, which may influence the irrigation method, crop adaptability, and other management factors. Available water is related primarily to pore and particle size as affected by soil texture. Soil depth, soil layering, and depth to an anticipated water table are also major factors that must be considered when determining the amount of available water a soil profile can hold. Generally, fine-textured soils (clay, clay loam, or silty clay loam) will have a higher available moisture at field capacity than coarser-textured soils. However, soils with an extremely high clay content may actually have less available water than some medium-textured soils (sandy clay loam, loam, or silt loam).

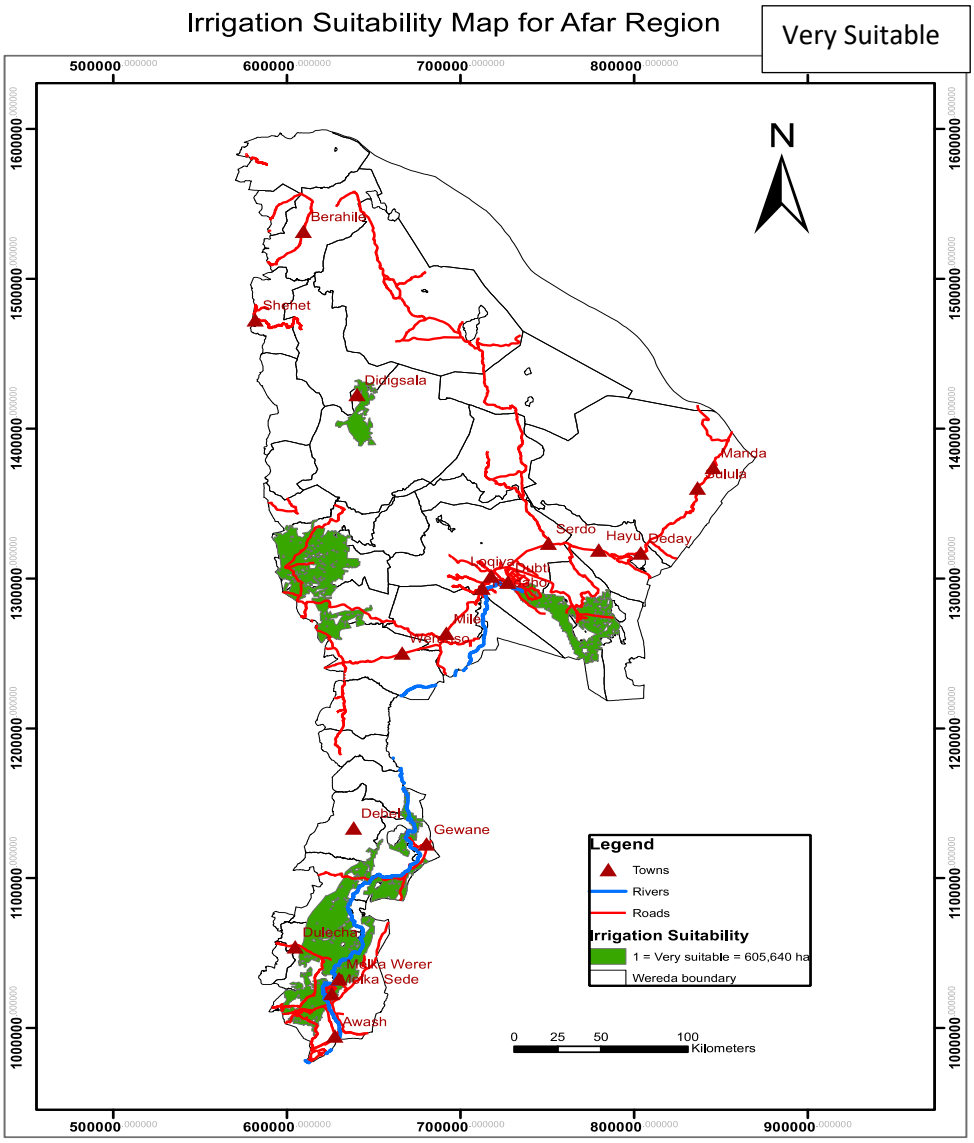

Figure 18: Irrigation suitability map (Very Suitable)

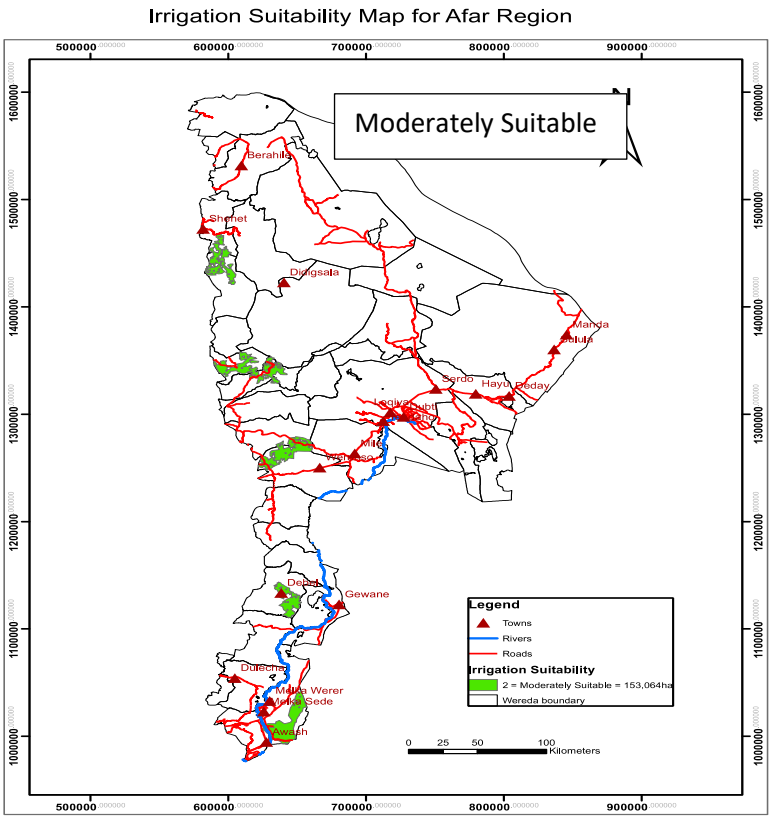

Figure 19: Irrigation Suitability Map (Moderately Suitable)

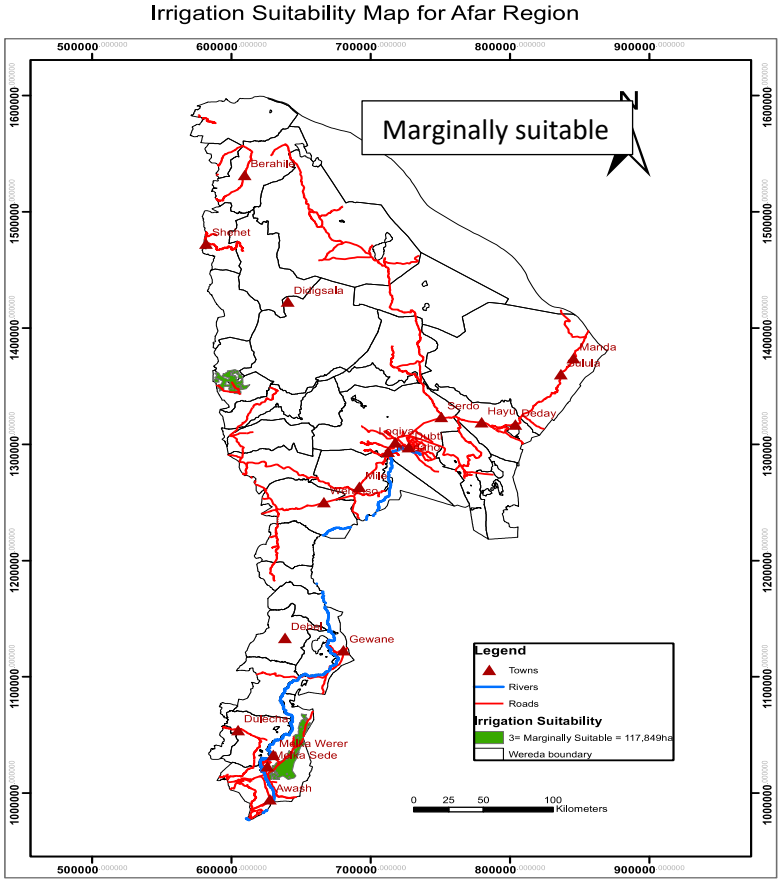

Figure 20: Irrigation Suitability Map (Marginally Suitable)

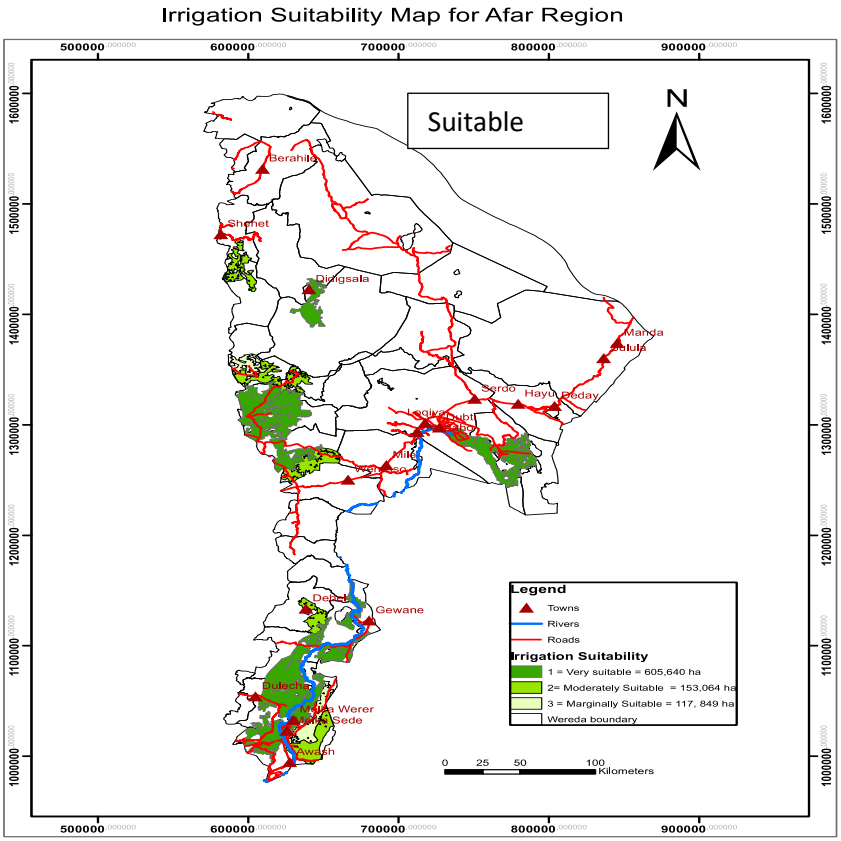

Figure 21: Irrigation Suitability Map (Total)

9. SOIL AND LAND CHARACTERISTICS FOR SPATE IRRIGATION

The aforementioned land and soil parameters in the study area have downgraded the suitability of soils of the proposed study area to moderately suitable (S2), marginally (S3) and permanently not suitable (N2) land, due to very low to low organic carbon, slightly to moderately soil pH, very high sodium content in the soil exchange sites.

Irrigated agriculture has a heavy demand of nutrient, especially nitrogen, phosphorus and Potassium. High organic matter and cation exchange capacity of soil are very important to retain and supply soil nutrient for the selected crops. However, most soils of study area have inadequate nutrient availability (low to very low total nitrogen and slightly high soil pH) and nutrient retention capacity (very low organic carbon content). The current levels of organic matter and total nitrogen in the command area are generally low. This revealed the effect of warm climate is enhancing OM oxidation resulting in reduction of OM and total N. Therefore, in order to develop sustained irrigated agricultural crops and to successfully improve the downgraded soil and lands, the following soil and land management practices should be implemented in the selected area.

Improving the content of organic matter would be an important task. This could be made by allowing crop residues to remain in the field and by using green manure crops or compost. The main consideration from a management perspective should be to conserve and increase soil organic matter content to the maximum level possible. An increase in organic matter can be achieved through manuring, plowing back of crop residues, incorporation of trash and mulching that brings better soil fertility and improved soil physical conditions of the soils such as soil structure, water holding capacity, soil climates, infiltration and permeability.

Besides, the above mentioned practices, fertilization with appropriate types and recommended rates of beneficial chemical fertilizer would be important for irrigated crop production, since soils have low to medium status of natural fertility. The already prevailing practices of ICRISAT in the other three piloting kebeles can also be fully scaled up to others i.e. the through construction of check dams and weirs some fields and flooded areas could be rehabilitated for spate irrigation development through increasing the fertility of the soils.

The high rainfall occurs in the relative uplands occasionally, during the rainy seasons the worst flood hazards occurred in the low-lying lands of the selected area. Such flood shall be controlled with appropriate flood control mechanism, if not irrigation channels will be broken, farm land will be covered with debris, drainage channels will be filled with sediments and general agricultural operation and maintenance cost will be increase. To cope-up these problems the remedial measures has to be taken by applying appropriate watershed management activities in the upper catchment, makes a river trained with a single channel, construction of dicks/bunds along the major river courses and construction of diversion ditch in the upper side of the irrigated area.

The pH of the soil in the study areas has showed values ranging from slightly too moderately alkaline in reaction. Under this high pH condition, there may be decreasing plant available nutrients such as Boron, cobalt, copper, iron, manganese and zinc. Depending on the buffering

capacity of the soils application of gypsum and sulfur, reduced pH content of the soils could be required at distinct levels.

10. CONCLUSION AND RECOMMENDATION

10.1. Conclusion

The result of this study based on samples of the districts mapped by ICRISAT for site level validation has proved the presence of potentials both in terms of floods and water. From the soil and land suitability points of view, five reference soils have been identified, which includes Luvisols, Cambisols, Fluvisols, Solonetz and Vertisols. The most extensive soils of the project sampled areas were Solonetz (53,277ha) which was followed by Cambisols 28933 ha and Vertisols (25213 ha). These soil classifications fall under the S2 classes. However, it highly demands huge mobilization of financial resources to be committed by actors at various levels.

The land suitability analysis using four factors, i.e., slope, soil texture, soil depth, and salinity resulted a total estimated area of 877,000 ha which close to what the study by ICRISAT reported as 900,000 ha. This is a validation of their work.

Similarly, the flood runoff estimated for the entire region was about 300mm for rainy seasons, which could be considered as adequate for some crops provided adjustment is made for areal extent. Therefore, crops selection and the areal extent would become serious issues for presumed flood-based irrigation development.

Above all, the implementation of flood-based irrigation developments could help to bring a number of economic and social benefits to the community. These include improved economic and environmental status through increased crop & forage production and increased production time. The community members have shown their full aspirations of engaging in such types of initiatives. The discussions held with community and stakeholders demonstrated their commitments to engage in planning, implementation and/or facilitation of economic and social development programs in the studied districts.

10.2 Recommendations

It is sought that such flood-based irrigation developments will have multifaceted benefits to the user communities and surrounding environments. However, the detail recommendations proposed in capacity building, soil fertility management and agricultural development needs due attention.

On the first place, there is a need for flood based irrigation developments to go much beyond constructing the irrigation infrastructures and focus on technical and institutional sustainability of the irrigation development practices. In order to realize the anticipated outcome from such

developments, all the extension services such as provision of inputs on time, technical support, provisions of training and establishing irrigation user association have need to be on board to achieve the predicted benefits from flood based irrigation development.

Routine soil samples should be taken in all plough-out fields (before initial land preparation) in order to determine the levels of plant available nutrients in the soil. This will provide a monitoring system for these nutrients, and over time a database of information on soil nutrient levels. It is recommended to establish strong linkage to the research Centre to understand the response of soils for fertilizer application and determination of the best variety of irrigated crops that withstand different soil deficiencies and drought.

The hydrological data was found to be so scarce mainly due to the non-existence of gauging stations in the catchments of Afar. It appears crucial to invest much on the establishment of gauging stations in all lower districts so that run offs could be easily used for development planning and recommendations.

11. REFERENCES

CSA, 2007. Population Census Result of 2007. Addis Ababa, Ethiopia

Geesing et al., 2004. Management of introduced Prosopis species: Can economic exploitation Control an invasive species? Unasylva, 217, Vol.55, 36-44.

Coordination Bureau of Finance and Economic Development; Regional Atlas of Afar Region; 2006, Semera.

FAO (1976) Framework for Land Evaluation.Soils Bulletin 32, FAO, Rome.

Food and Agriculture Organization of the United Nations. 1985. Guidelines:land evaluation for irrigated agriculture. Soils Bulletin 55, Rome, Italy: FAO.231 pp. S590 .F68 no. 55 Mann.

FAO, 1996. Agro-ecological zoning Guidelines, FAO Soils Bulletin 76, Rome, 1996

FAO in 1987. Consultation on Irrigation in Africa, Irrigation and Drainage paper 42. FAO: Rome.

FAO 2006. FAO - WRB (Food and Agricultural Organization of the United Nation – World Reference Base for Soil Resources), World Reference Base for Soil Resources Report. No. 103. Rome, Italy.

HDRA, 2005. The challenges of eradicating prosopis in Kenya: policy brief.

HDRA, 2005; Mwangi and Swallow, 2005. Invasion of Prosopis Juliflora and local livelihoods: Case study from the lake Baringo area of Kenya. ICRAF Working Paper – no. 3, World Agroforestry Centre Nairobi.

MoARD, 2005. Agro-Ecological Zones of Ethiopia on 1:2,000,000 scale. Natural Resource Management and Regulatory Department, Ethiopia, Addis Ababa

University of GHENT, (1993).land evaluation part III crop requirements, publication no.7Ir.C.Sys et.al., 1991. Crop requirement in land evaluation Brussels, Part III.

US Department of the Interior Bureau of Reclamation. 2005. Technical Guidelines for Irrigation Suitability Land Classification. Denver, Colorado.

Annex 1: physicochemical analysis of soils in the selected project areas

Districts	Afdera				Dubti				Mille			Awra			Golona		Teru		Ereb ti
Flooded Kebeles / Laboratory Analysis result	Yela bay	Ayit ura	Kusrewad		Deb el and Nah aleb ayir	Beyi hayi le	Guri mu Dale and Gayid aro	Bebe deta and Kore le	Deyil u and grar o	Kailun a asmel med kudu	Sene as and kusrt u	Ede lu	Ley ku ma	Der ayit u	Mul e and Asal e	Kel ewa n	Na mara	Dig diga	Albo
Depth (cm)	0-	0-	0-	30-	0-30	0-	0-30	0-30	0-30	0-30	0-30	0-	0-	0-	0-30	0-	0-	0-	0-30
pH-H_20	7.7	7.5	8.0	7.8	8.23	8.1	7.88	7.84	8.04	8.09	7.8	7.8	7.8	7.7	7.55	7.9	7.9	8.0	8.05
EC (mS/cm)	0.88	0.21	0.17	1.12	0.53	0.36	0.72	1.16	0.74	2.99	0.17	0.51	0.93	0.35	1.79	0.8	0.92	0.21	0.25
OC (%)	1.2	1.2	0.8	0.88	1.32	1.7	1.52	2.27	0.9	0.73	1.08	1.28	1.11	1.4	1.32	0.9	0.9	0.8	0.99
T N (%)	0.0	0.0	0.1	0.05	0.08	0.0	0.14	0.16	0.09	0.09	0.09	0.07	0.09	0.1	0.12	0.1	0.0	0.0	0.11
AV.P (mg	48.	31.	44.	66.0	29.0	48.	45.15	85.41	56.5	36.68	34.2	54.1	33.7	24.	29.1	44.	22.	47.	33.3
Sand (%)	7.5	14.92	27.84	10.88	4.3	17.66	2.4	2.6	40.11	15.28	30.13	45.4	48	10.69	23.68	9.85	25.91	48	13.92
Clay (%)	31	17	12	41.3	32.6	40	39.48	52.6	25.6	30.41	8.47	8.4	15	23	15.2	19	39	12	43.0
Silt (%)	60.	67.	59.	47.8	63.0	42.	58.12	44.7	34.2	54.31	61.4	46.	36.	65.	61.0	71.	34.	39.	43.0
Texture Class	Silty clay	Silt Loa	Silt Loa	Silty clay	Silty clay	Silty clay	Silty clay	Silty clay	Loa m	Silty clay	Silt Loam	Loa m	Loa m	Silt Loa	Silt Loa	Silt Loa	Clay loa	Loa m	Silty clay

Exch. Na	1.2	38.	0.8	42.7	46.9	47.	47.31	3.22	38.4	6.24	38.5	0.9	2.9	1.0	1.21	31.	3.1	1.2	1.16
Exch. K	0.8	37.	0.6	39.9	45.1	46.	45.82	2.64	37.5	1.04	38.0	2.0	0.6	1.0	2.3	29.	1.1	2.8	1.92
Exch.Ca	28.	26.	23.	26.7	28.9	29.	29.16	34.5	24.2	27.2	27.8	26.	28	29.	28.5	21.	35.	26.	33.4
Exch. Mg	10.	9.3	7.4	9.94	6.92	11.	6.09	7.08	8.09	9.93	8.02	5.4	6.8	6.8	6.06	6.3	7.3	5.8	8.57
CEC	41.	38.	33.	42.7	41.8	47.	41.63	48.1	38.4	45.52	38.5	36	38.	38.	38.6	31.	48.	37.	46.5
Sum of	40.	112	32.	119.	128.	124	128.3	47.4	108.	44.41	112.	34.	38.	38.	38.1	88.	46.	36.	45.0
PBS (%)	98.2	291.7	97.68	280	306.17	260.7	308.383	98.65	281.8	97.562	291.7	96.8	98.9	98.6	98.83	279	96.4	98.6	96.78
ESP (%)	3.06	100	2.60	100	112.37	100	113.64	6.70	100	13.71	100	2.53	7.59	2.77	3.13	100	6.50	3.40	2.49
FC (%)	35.3	29.3	27.2	40.5	35.9	38.3	39.5	46.7	28	33.9	27	23.5	23.7	31.6	28	30.3	36.4	23.3	40.5
PWP (%)	17.6	11.4	10	23.4	18	22.5	22.2	31.1	14.9	16.8	9.3	8.9	10.9	13.5	10.7	11.7	21.9	10	24.4
Bulk density (g/cm^3)	1.28	1.38	1.45	1.23	1.28	1.26	1.24	1.19	1.37	1.3	1.51	1.55	1.46	1.33	1.42	1.36	1.28	1.49	1.24
AWHC (mm/m)	227	247	224.37		229	199	215	186	179	222	267	226	187	241	246	253	186	198	200

Annex 2: Land suitability for Spate irrigated vegetable cultivation

Sub class/ suffix	c	m	y	a		n		z		r			k		
Land quality	Climate	Moisture	Sodicity	Salinity	Oxygen	Nutrient retention		Nutrient availability		Rooting condition			Potential for mechanization or land		Partial suitability
Land characteristics	Mean air temperature	AWHC (mm/m)	ESP (%) (top soil)	EC Ds/m (top soil)	Drainage (class)	CEC top soil)	OM (%)	pH in 1:2.5 (top soils)	Texture (class)	Effective Soil depth (cm)	Stones and rocks (%)	BD (g/cm^3) up to 1m	Slope (%)	Stones and rocks (%)	Final suitability class and
SMU	Factor rating														
SMU 1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S2z
SMU 2	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S2z
SMU 3	S1	S1	N2	S1	S1	S1	S2	S2	S1	S1	S1	S1	S1	S1	N2
SMU 4	S1	S1	S1	S1	S1	S1	S2	S2	S1	S1	S1	S1	S1	S1	S2zn
SMU 5	S1	S1	S1	S1	S1	S1	S2	S3	S1	S1	S1	S1	S1	S1	S3z

Annex 3: Land suitability for Spate irrigated Cereals cultivation

Sub class/ suffix	c	m	y	a		n		z		r			k		
Land quality	Climate	Moisture	Sodicity	Salinity	Oxygen	Nutrient retention		Nutrient availability		Rooting condition			Potential for mechanization or land		Partial suitability
Land characteristics	Mean air temperature	AWHC (mm/m)	ESP (%) (top soil)	EC Ds/m (top soil)	Drainage (class)	CEC top soil)	OM (%)	pH in 1:2.5 (top soils)	Texture (class)	Effective Soil depth (cm)	Stones and rocks (%)	BD (g/cm^3) up to 1m	Slope (%)	Stones and rocks (%)	Final suitability class and
SMU	Factor rating														
SMU 1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S2n
SMU 2	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S2n
SMU 3	S1	S1	N2	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	N2
SMU 4	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S2n
SMU 5	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S2n

Annex 4: Land suitability for Spate irrigated oil crops cultivation

Sub class/ suffix	c	m	y	a		n		z		r			k		Partial suitability
Land quality	Climate	Moisture	Sodicity	Salinity	Oxygen	Nutrient retention		Nutrient availability		Rooting condition			Potential for mechanization or land		
Land characteristics	Mean air temperature	AWHC (mm/m)	ESP (%) (top soil)	EC Ds/m (top soil)	Drainage (class)	CEC top soil)	OM (%)	pH in 1:2.5 (top soils)	Texture (class)	Effective Soil depth (cm)	Stones and rocks (%)	BD (g/cm^3) up to 1m	Slope (%)	Stones and rocks (%)	Final suitability class and
SMU	Factor rating														
SMU 1	S1	S1	S1	S1	S1	S1	S2	S2	S1	S1	S1	S1	S1	S1	S2nz
SMU 2	S1	S1	S1	S1	S1	S1	S2	S2	S1	S1	S1	S1	S1	S1	S2nz
SMU 3	S1	S1	N2	S1	S1	S1	S2	S2	S1	S1	S1	S1	S1	S1	N2
SMU 4	S1	S1	S1	S1	S1	S1	S3	S2	S1	S1	S1	S1	S1	S1	S3n
SMU 5	S1	S1	S1	S1	S1	S1	S3	S3	S1	S1	S1	S1	S1	S1	S3nz

Annex 5: Land suitability for Spate irrigated Forage cultivation

Sub class/ suffix	c	m	y	a		n		z		r			k		
Land quality	Climate	Moisture	Sodicity	Salinity	Oxygen	Nutrient retention		Nutrient availability		Rooting condition			Potential for mechanization or land		Partial suitability
Land characteristics	Mean air temperature	AWHC (mm/m)	ESP (%) (top soil)	EC Ds/m (top soil)	Drainage (class)	CEC top soil)	OM (%)	pH in 1:2.5 (top soils)	Texture (class)	Effective Soil depth (cm)	Stones and rocks (%)	BD (g/cm^3) up to 1m	Slope (%)	Stones and rocks (%)	Final suitability class and
SMU	Factor rating														
SMU 1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S2n
SMU 2	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S2n
SMU 3	S1	S1	N2	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	N2
SMU 4	S1	S1	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S1	S3n
SMU 5	S1	S1	S1	S1	S1	S1	S3	S2	S1	S1	S1	S1	S1	S1	S3n