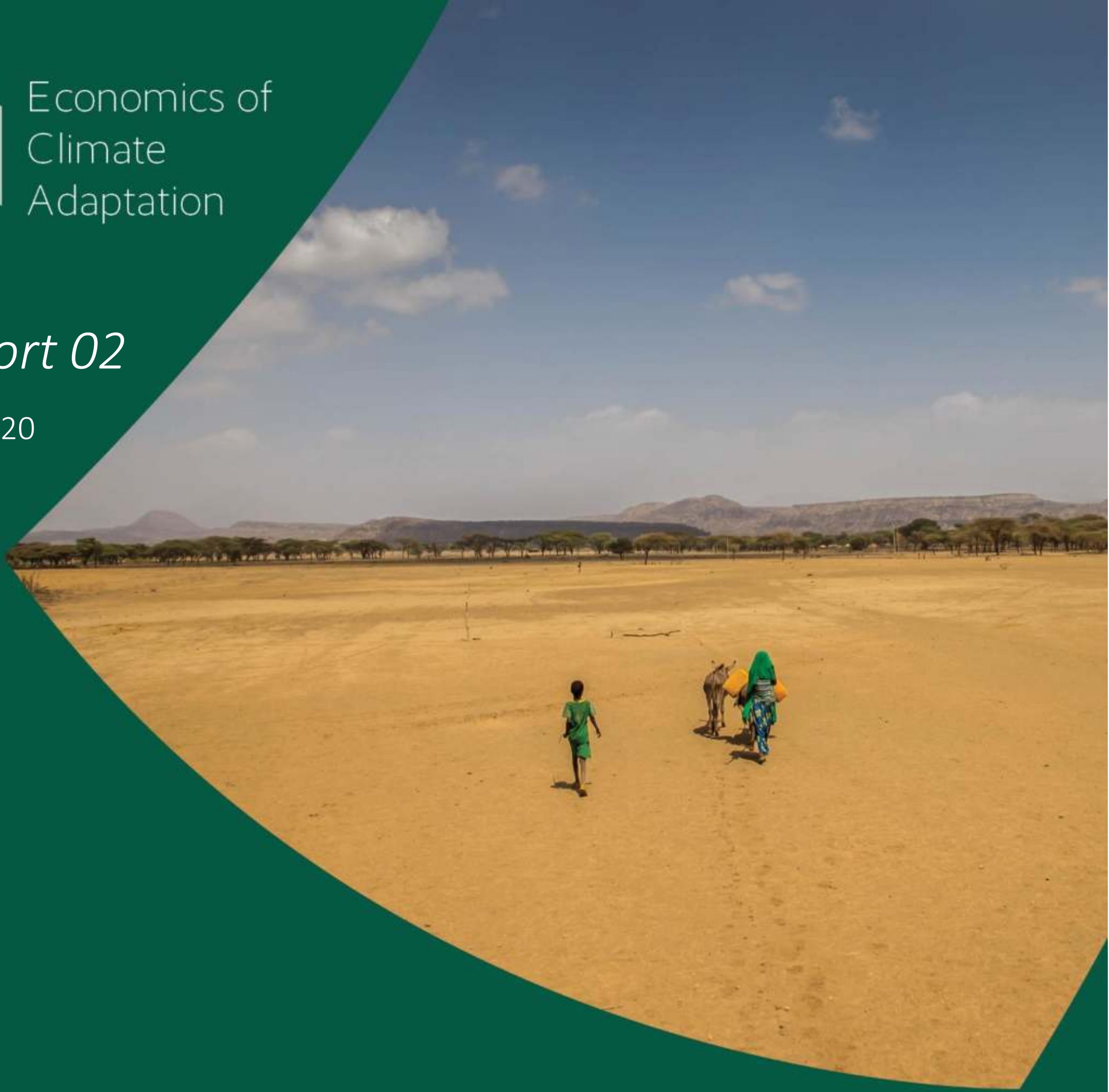
Economics of Climate Adaptation



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Base Data Report

Ethiopia

Drought Risk

UNITED NATIONS UNIVERSITY
UNU-EHS

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List of Acronyms

AR5	IPCC Fifth Assessment Report
BMZ	German Ministry for Economic Cooperation and Development
CMIP5	Coupled Model Intercomparison Project Phase 5
CORDEX	Coordinated Regional Climate Downscaling Experiment
CPI	Consumer Price Index
CSA	Central Statistical Agency
DMP	Dry Matter Productivity
EbA	Ecosystem-based Adaptation
ECA	Economics of Climate Adaptation
ESA	European Space Agency
GCM	Global Climate Model
CGCM3	Third Version Coupled Global Climate Model
GDP	Gross Domestic Product
GNI	Gross National Income
ISF	InsuResilience Solutions Fund
KfW	German Development Bank
MAMSL	Meter above mean sea level
MoARD	Ministry of Agriculture of the Federal Democratic Republic of Ethiopia
NDVI	Normalised Difference Vegetation Index
NMA	National Meteorological Agency
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SLA	Sustainable Livelihoods Approach
SPI	Standardised Precipitation Index
SPEI	Standardised Precipitation Evapotranspiration Index
TLU	Tropical Livestock Unit
UNU-EHS	United Nations University – Institute for Environment and Human Security

Context

Storms, floods, droughts and other extreme weather events can threaten urban and rural areas, from small regions to entire nations. Along with growing populations and economies, losses from natural hazards are rising in the world's most exposed regions as our climate continues to change. The Economics of Climate Adaptation (ECA) is a decision-making support framework that integrates climate vulnerability and risk assessments with economic and sustainability impact studies to determine the portfolio of optimal adaptation measures for diverse climate risks.

The United Nations University - Institute for Environment and Human Security (UNU-EHS) in cooperation with and funded by the InsuResilience Solutions Fund (ISF), is implementing the Economics of Climate Adaptation (ECA) framework in the Afar and Somali regions in eastern Ethiopia to identify the most cost-effective measures to address drought hazards. The ISF is funded by German Development Bank KfW and commissioned by the German Ministry for Economic Cooperation and Development (BMZ). Currently, the Economics of Climate Adaptation (ECA) methodology is being implemented in three different countries (Vietnam, Honduras and Ethiopia).

The inception phase of the ECA study in the two regions of Ethiopia has been concluded with the definition of the scope of the project, including the target hazard to be addressed and the key assets to be considered. The most appropriate time horizon is being determined through the consultation of several experts in Ethiopia to align the study with national (long-term) strategies and regional plans. Until this process is finalised two time-horizons of 10 and 30 years will be considered.[1] The present and following phases will determine the distribution of risk levels within the research area and evaluate different measures to mitigate such risk through a cost-benefit analysis. These phases will be supported by the modelling tool CLIMADA, which amongst others:

1) provides a comprehensive mapping of hazards, exposed assets and people and their specific vulnerability,
2) implements state-of-the-art probabilistic risk modelling techniques to integrate different economic development and climate impact scenarios, and
3) allows assessing a comprehensive portfolio of adaptation measures, quantifying the damage aversion potential and cost-benefit ratio for each measure.

[1] As no final decision was made with regard to the time horizon we suggest to cover both a 10 and 30 year horizon as discussed during the workshop. Although a 10 year horizon was favoured by the participants as most national strategies seem to have either 5 or 10 year periods the study team decided to also add a 30 year horizon in order to have a secondary long term focus. This will allow the study team to better incorporate and reflect the long term costs and benefits of the to be selected adaptation measures in the following steps of the study. The definition of the time horizon is further planned to be validated through key informant interviews conducted by a local consultant which are currently on hold as described in Chapter 4 "Data Collection and Evaluation".

This report will brief the reader on the state of data collection needed for running CLIMADA after thorough research with support from local authorities and other stakeholders.

The document is divided into five sections, the first two highlighting the most relevant factors regarding the selected hazard and assets in the two regions. The third section presents future climate and socio-economic scenarios for the potential time horizons defined during the inception workshop. The fourth section presents a general overview of the collected data, with a quality assessment regarding their usability for the ECA study, as well as the proposed proxies for those data sets that are insufficient for running CLIMADA or might lead to too high uncertainties in the final results. The last section concludes and details the next steps

1. Hazard Selection

1.1 Study Area Description

The Afar and Somali regions are located in (south-) eastern Ethiopia. With an estimated population of 1.8 and 5.7 million people in Afar and Somali respectively, these regions are among the poorest in the country[2]. The study area experiences a desert-like climate and is described as a lowland region. In response to its extreme conditions, including one of the world's hottest climates, low rainfall, sparse arable land and limited access to water, large shares of the population in Afar and Somali depend on semi-nomadic livestock farming (pastoralism)[3]. Most people basing their livelihood on agro-pastoral and pastoral activities are living in poverty, according to both human development indicators and multidimensional poverty[4].

As in similar settings, the availability of quantitative data on the lowland regions of Ethiopia is limited, especially in remote rural areas which make up most of Afar and Somali. The scientific literature on the study regions is based on surveys with relatively small sample sizes of households and with a heavy bias towards urban areas, which are more easily accessible[5]. Similarly, available longitudinal data have a low level of accuracy as it is structured around administrative units and therefore fail to capture the fluidity of pastoral systems[6].

The socio-economic characterization of Afar and Somali presented in the sections below, may, therefore, explain certain areas better than others within the study regions, but this gap is expected to be improved through the surveys that are being undertaken in local communities.

1.1.1 Afar

Afar has an area of over 95,000 km^2. It is part of what is known as the *Afar Triangle* or *Afar Depression* which includes the lowest point in Africa at -155 MAMSL. Its uneven topography oscillates around a mean of 550 MAMSL and reaches up to 2,900 MAMSL at the border with the Wollo highlands to the West of the region. Afar is crossed by the River Awash, born on Mount Warqe to the west of Addis Ababa and disgorging in Lake Abbe on the border with Djibouti. Other essential water bodies include Lake Caddabassa along the River Awash, Lake Afrera in the North of the region and Lake Karum, a salt lake

[2] National Planning Commission. (2017). *Ethiopia's Progress towards Eradicating Poverty: An Interim Report on 2015/16 Poverty Analysis Study.* Addis Ababa.
[3] Birch, I. (2018). *Economic growth in the lowlands of Ethiopia*. K4D Helpdesk Report. Brighton, UK: Institute of Development Studies.
[4] Ibid.
[5] World Bank. (2016). *Priorities for ending extreme poverty and promoting shared prosperity: systematic country diagnostic*. Report No. 100592-ET. Washington, DC: World Bank Group.
[6] Lind, J., Sabates-Wheeler, R. & Kohnstamm, S. (2016). *Changes in the drylands of Eastern Africa: implications for resilience-strengthening efforts*. Brighton: Institute of Development Studies.

close to the border with Eritrea. Figure 1 provides an overview of the location of Afar within Ethiopia, its major water bodies and elevation pattern[7].

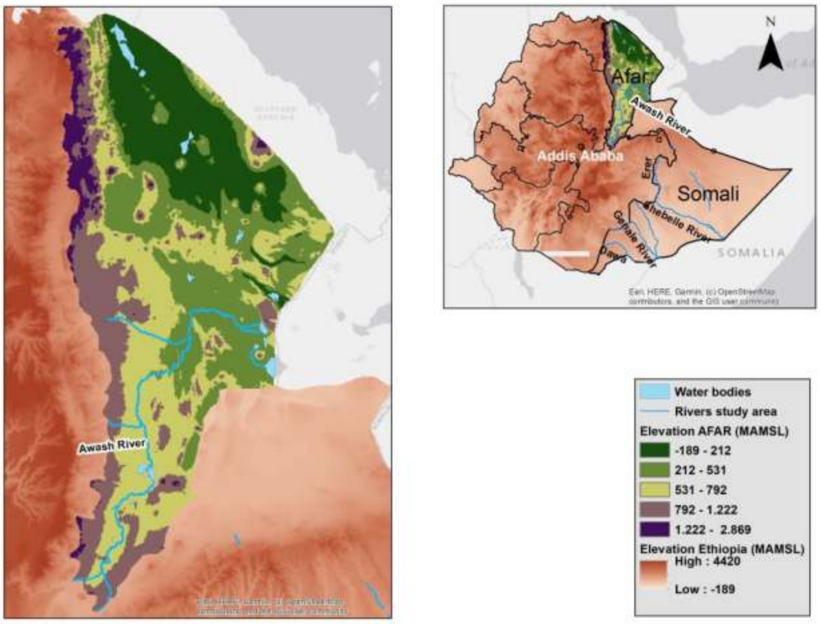

Figure 1: Topography of Afar. Source: based on data by OCHA Ethiopia (2018)[8]

The annual average rainfall in Afar ranges from 220 mm in a drought year, such as 2015, up to 400 mm[9]. There are two rainy seasons, **Belg** and **Kiremt**, peaking in April and August respectively, the latter being a monsoon-type rainy season and the former a smaller springtime rainfall[10]. Afar has the lowest level of precipitation in the country, presenting ever drier conditions the further it gets from the mountainous areas and the closer it gets to the border with Eritrea and Djibouti[11]. Average temperatures in the region range between 25°C to over 32°C, with lower values during December and warmer ones during June[12]. The Dallol locality in the far North of Afar is one of the hottest places year-round anywhere on Earth, reaching temperatures of up to 48°C and having average annual rainfalls of as low as 100 mm.

According to the last official national census in 2007, around 90% of the rural population in Afar depended on pastoralist activities, while the remaining 10% combined pastoralism with agriculture[13]. These numbers have been changing considerably during the last years though, as livestock farming is becoming increasingly challenging due to the privatization of natural resources in the region, which has significantly restricted the access of pastoralists to water and food for their herds[14]. This phenomenon

[7] ANNEX 3 provide large resolution views of maps presented in this report
[8] OCHA Ethiopia. (2018). *Ethiopia – Elevation Model.* 'ethdem90m'. Retrieved on 16.06.2020 from https://data.humdata.org/dataset/ethiopia-elevation-model
[9] World Food Program (2019*). Comprehensive Food Security and Vulnerability Analysis (CFSVA).* Addis Ababa: Central Statistical Agency.
[10] Wakie TT, Evangelista PH, Jarnevich CS, Laituri M (2014). *Mapping Current and Potential Distribution of Non-Native Prosopis juliflora in the Afar Region of Ethiopia.* PLoS ONE
[11] Fazzini M, Bisci C, Billi P (2015). *The Climate of Ethiopia. Landscapes and Landforms of Ethiopia, World Geomorphological Landscapes*. Springer Science
[12] Ibid.
[13] USAID and the Government of Ethiopia. (2010). *An Atlas of Ethiopian Livelihoods. The Livelihoods Integration Unit*. USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.
[14] Birch, I. (2018). *Economic growth in the lowlands of Ethiopia*. K4D Helpdesk Report. Brighton, UK: Institute of Development Studies.

is referred to in literature as rangeland fragmentation and it has been driven by the government's perception of a low economic contribution of pastoralist activities to the region[15]. This has moved large financial resources from the state into more profitable projects like irrigation systems for industrial crops including cotton and sugar, even though per hectare returns for pastoralism are higher than for industrial agriculture[16].

Efforts from the government to increase productivity and reduce land degradation have led to land titling campaigns that next to infrastructure investments aimed at boosting sedentarization amongst pastoral communities[17]. The policy has not resulted in the expected outcomes and has widened the poverty gap as not all parcels have the same quality and not all families are used to agriculture as means for their livelihood[18]. This policy has built a market for investors coming from the highlands to rent land for their projects given that only the residents of the agro-pastoral kebeles are awarded with land titles[19]. The sedentarization approach has therefore benefited the top income minorities in Afar but has pushed the majorities further into poverty as their options for income diversification are little, given the arid conditions of the territory and the low levels of technical and academic training amongst the local population[20].

Although poverty and wealth are difficult to define in comparable terms for pastoralists, calorie consumption as a measure for energy-deficient households and accessibility to the means to get those calories (own livestock, crops, purchasable goods and food aid), provide a basis to estimate food security as a proxy for wealth[21]. In urban Afar, 50% of the households in 2016 suffered from different levels of energy deficiency (<2,550 Kcal per adult equivalent per day), while in the rural areas that number is estimated to be 38%[22]. In terms of accessibility to means of calories, groups identified as the poorest in Afar rely mainly on food aid or on purchases they can make when temporary jobs are available. The average group has better access to grow their livestock and feed on its meat and milk. While for the better-off group there is a possibility for crop growing in addition to sufficient availability of livestock that covers their needs[23].

Another measure of poverty for pastoralists is related to the size of their herds. This measure is increasingly hard to use to compare households given the high declines in herd sizes during the last decades, but a threshold of 4.5 Tropical Livestock Units (TLU)[24] per capita has been identified as a minimum to keep pastoralists out of poverty, i.e. provide sufficient milk for their consumption and

[15] Lind, J., Sabates-Wheeler, R. & Kohnstamm, S. (2016). *Changes in the drylands of Eastern Africa: implications for resilience-strengthening efforts*. Brighton: Institute of Development Studies.
[16] Ibid.
[17] Pearson, 0. (2017). *The Multifaceted Commodification Processes and Transformations of Pastoralists in Lowland Ethiopia*. Faculty of Applied Computer Sciences University of Augsburg, Germany
[18] Ibid.
[19] Ibid.
[20] Birch, I. (2018). *Economic growth in the lowlands of Ethiopia*. K4D Helpdesk Report. Brighton, UK: Institute of Development Studies.
[21] USAID and the Government of Ethiopia (2010*). An Atlas of Ethiopian Livelihoods. The Livelihoods Integration Unit*. USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.
[22] WFP Ethiopia and Central Statistical Agency (2019). *Comprehensive Food Security and Vulnerability Analysis (CFSVA)*. Addis Ababa, Ethiopia: CSA.
[23] USAID and the Government of Ethiopia. (2010). *An Atlas of Ethiopian Livelihoods. The Livelihoods Integration Unit*. USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.
[24] The Tropical Livestock Unit is defined by a weight equivalent of 250kg living weight. Conversion factors for the four relevant livestock types here are: Camel: 1.0 TLU, Cattle: 0.7 TLU, Sheep and Goat: 0.1 TLU. For further details see e.g. Jahnke, H. E. (1982). *Livestock Production Systems and Livestock Development in Tropical Africa*. Kiel: Kieler Wissenschaftsverlag Vauk.

offspring for sales and the related purchase of cereals[25]. 80% of households in Afar do not meet this minimum level[26].

1.1.2 Somali

Somali has an area of around 315,000 km^2. The three major rivers crossing the region are the Shebelle, Genale and Dawa in the South, there are some smaller rivers more to the centre of the region, e.g. the Fafem. With an average elevation of 720 MAMSL, Somali is mostly flat as it extends through the *Afar Depression* and the Western and Southern Lowlands, but since it also meets the final segment of the Hararge Highlands it reaches up to 2,500 MAMSL to the North-East of the region. Figure 2 provides an overview of the location of Somali within Ethiopia, its major water bodies and elevation pattern.

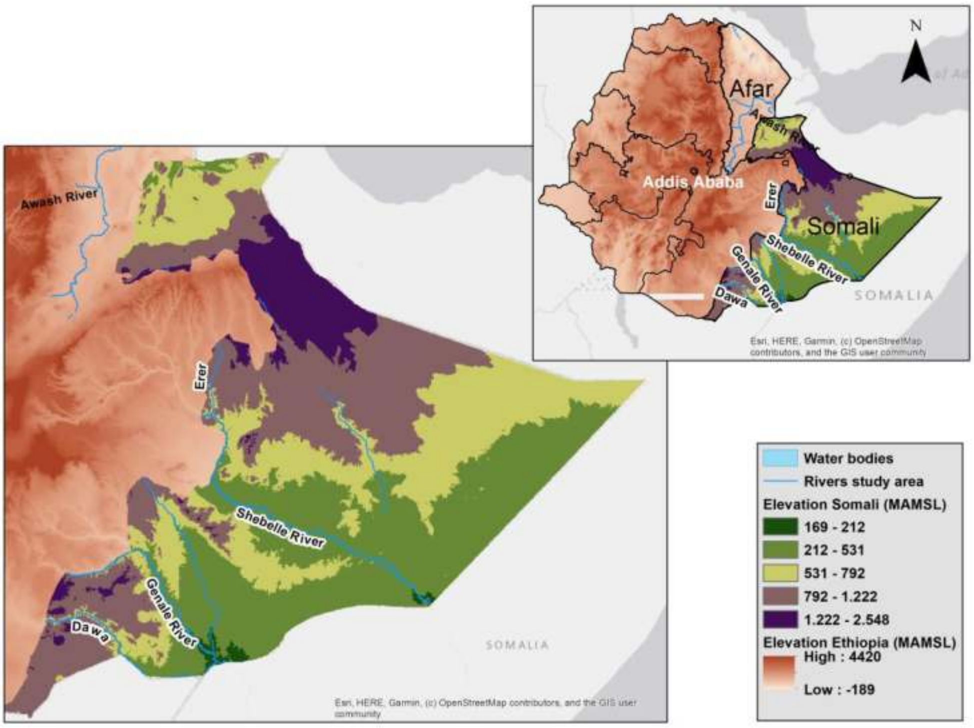

Figure 2: Topography of Somali. Source: Based on data by OCHA Ethiopia (2018)

Rainfall patterns in Somali vary significantly with the topography. Up in the Hararge Highlands, at around 1,650 MAMSL, the average rainfall during the spring (Belg) is 250mm and during the monsoon-type season (Kiremt) is 330mm, these numbers fall for the dry season (Bega) to 140mm. Down in the lowlands, at around 300 MAMSL, the precipitations during Belg and Kiremt are 135mm and 9mm respectively, with a raise for Bega to 95mm. Precipitation patterns in northern and southern Somali present different peak seasons, with stronger rainfall during Kiremt in the North but during Belg in the South[27]. Similarly, temperatures differ throughout the region, with average values of 26°C on the

[25] De Haan, C. (Ed.). (2016). *Prospects for livestock-based livelihoods in Africa's drylands.* World Bank Studies. Washington, DC: World Bank Group. doi: 10.1596/978-1-4648-0836-4
[26] Catley, A. (2017). *Pathways to resilience in pastoralist areas: a synthesis of research in the Horn of Africa*. Boston: Feinstein International Center, Tufts University.
[27] USAID and the Government of Ethiopia. (2010). *An Atlas of Ethiopian Livelihoods. The Livelihoods Integration Unit*. USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.

highlands and 35°C in the lowlands during March and April, the hottest months of the year, and 23°C and 12°C in the same areas during December, the coldest month[28].

According to the last official national census in 2007, around 55% of the rural population in Somali depends on pastoralist activities, 15% on crops, while 30% combines pastoralism with agriculture[29]. With over 2 million people living from pastoralism, Somali is the region with the highest population depending on this activity in the country, having around 55% of the total pastoral households in the country[30]. As explained in Chapter 1.1.1, these numbers have declined while other sources of income are rising as pastoral activities are increasingly hard to undertake. Unlike Afar, Somali's growing urban economy is driving a regional flow of remittances that may be reducing poverty throughout the rural areas[31].

In terms of poverty quantification, 18% of the urban population suffered from energy deficiency in 2016 and 16% in rural Somali[32]. The accessibility of calories is significantly better in Somali than Afar due to higher availability of arable lands which allow parts of the population to diversify their livelihoods to include crop growing[33]. Even within the poor and very poor groups, the number of households that can rely on subsistence agriculture due to their crops and livestock reaches almost 50% everywhere except for the northern area of Somali at the border with Afar. Consequently, the average and better-off groups are also significantly less reliant on aid or on temporary jobs to satisfy their calorie needs[34].

Concerning the poverty threshold of herd size per capita, 90% of households in Somali do not have the 4.5 TLU per person defined as the minimum requirement to be considered as non-poor[35]. The contrast in the pictures offered by the accessibility to means of calories and caloric deficiency versus the one from the herd size illustrates the complexity of characterizing poverty within the study region in comparable terms. While the inhabitants of Somali have smaller herds, they can compensate calories through crop growing, whereas in Afar the households have on average larger herds but cannot access calorie sufficient diets. This challenge is also relevant when quantifying the vulnerability of the different communities to droughts and other hazards.

1.2 Relevance of Drought for the Afar and Somali Regions

The effects of droughts on crop productivity and chances of failure, as well as on wild dry matter production needed by pastoralists to feed their livestock, are amongst the highest contributors to food insecurity in Afar and Somali[36]. During the El Niño period of 2015/16, the rise in crop failures and food

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[28] Fazzini M, Bisci C, Billi P. (2015). *The Climate of Ethiopia. Landscapes and Landforms of Ethiopia.* World Geomorphological Landscapes. Springer Science

[29] USAID and the Government of Ethiopia. (2010*). An Atlas of Ethiopian Livelihoods. The Livelihoods Integration Unit*. USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.

[30] Birch, I. (2018). *Economic growth in the lowlands of Ethiopia.* K4D Helpdesk Report. Brighton, UK: Institute of Development Studies.

[31] Ibid.

[32] WFP Ethiopia and Central Statistical Agency (2019). *Comprehensive Food Security and Vulnerability Analysis (CFSVA)*. Addis Ababa, Ethiopia: CSA.

[33] USAID and the Government of Ethiopia. (2010). *An Atlas of Ethiopian Livelihoods. The Livelihoods Integration Unit.* USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.

[34] Ibid.

[35] Catley, A. (2017). *Pathways to resilience in pastoralist areas: a synthesis of research in the Horn of Africa*. Boston: Feinstein International Center, Tufts University.

[36] WFP Ethiopia and Central Statistical Agency (2019*). Comprehensive Food Security and Vulnerability Analysis (CFSVA)*. Addis Ababa, Ethiopia: CSA.

prices, and the reduction of income especially in rural areas, were reported as a major cause for food shortages in the study region on the 2016 Welfare Monitoring Survey (WMS)[37].

Similarly, the 2017 Central Statistical Agency and Living Standards Measurement Study (LSMS) identified drought on its top of major shocks negatively affecting households, second only to an illness of a household member[38]. 21% from the nearly 5,000 surveyed households across Ethiopia identified affectations due to droughts in the last 12 months and 76% of those highlighted droughts as the most severe shock they encountered during that period[39]. These results coincide with the statistics reported by EM-DAT on historical damages which linked over 97% of the people impacted by natural disasters in Ethiopia to droughts, both in terms of fatalities and non-fatalities[40], see figure below.

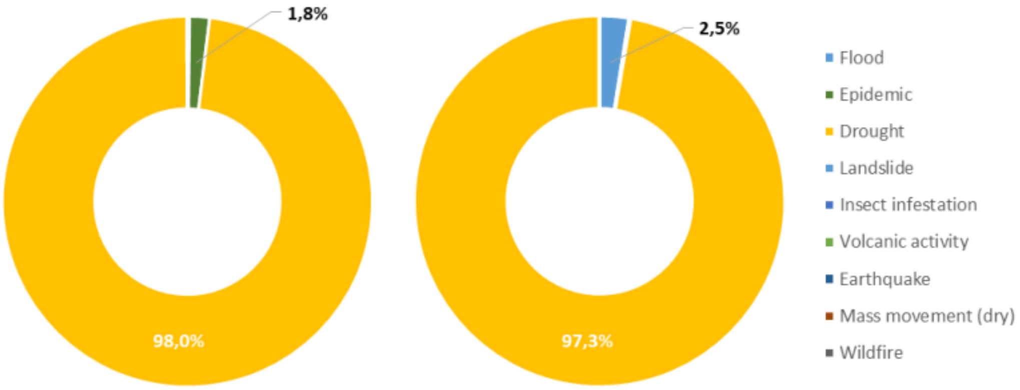

Figure 3 Fatalities (left) and affected people (non-fatalities, right) by natural disasters, 1961 -2019. Source: Based on data by EM-DAT [41]

When it comes to coping mechanisms, 34% of the LSMS respondents relied on their savings to face the drought periods, 15% received unconditional support from the government and 13% were forced to sell their livestock. Over 25% of the surveyed households that reported drought as a relevant shock during the previous year, reported only their faith practices as a support system or took no measures at all, suggesting a lack of access to financial means or other relieve options[42].

The resilience of pastoral households to droughts is directly linked to the size of their herds[43]. The 2017 baseline survey report for the Regional Pastoral Livelihoods Resilience Project in Ethiopia, from the International Livestock Research Institute (ILRI), concluded that especially in Afar the pastoral population significantly increases the units of livestock sold in a drought year compared to non-drought one. According to the ILRI's results, in Afar, 71% more households are willing to sell camels and almost 60% more households are willing to sell goats and cattle in a drought year. While in Somali the situation

[37] Ibid.
[38] World Bank and Central Statistical Agency (2017). *LSMS—Integrated Surveys on Agriculture Ethiopia Socioeconomic Survey (ESS) 2015/2016*. Addis Ababa, Ethiopia: CSA.
[39] Ibid.
[40] EM-DAT. (2020). *EM-DAT Data Base*. Retrieved from EM-DAT: https://www.emdat.be/
[41] EM-DAT. (2020). *EM-DAT Data Base*. Retrieved from EM-DAT: https://www.emdat.be/
[42] WFP Ethiopia and Central Statistical Agency (2019). *Comprehensive Food Security and Vulnerability Analysis (CFSVA)*. Addis Ababa, Ethiopia: CSA.
[43] Gebremedhin, B., Woldehanna, M., Flintan, F., Wieland B. and Poole, J. 2017. *Baseline survey report for the Regional Pastoral Livelihoods Resilience Project in Ethiopia.* ILRI project report. Nairobi, Kenya: International Livestock Research Institute (ILRI).

is similar only in regards to camels and cattle but differs in that it includes a drastic reduction in the selling of goats and sheep[44].

Finally, and in addition to the precedent left by past droughts supporting the urgency of addressing drought risks to protect the communities in the study regions, there is a generalized concern for the effects of climate change in pastoral livelihoods in the Ethiopian lowlands. As recent droughts appear to be having larger impacts than previous ones, a factor that seems to be playing a major role is the fragmentation of natural resource bases linked to the changes in precipitation patterns. This fragmentation closes off the mobility and flexibility needed by pastoral communities to manage risk[45]. An overview of the projected effects of climate change on drought in the study area are described in further detail in chapter 3.1 "Climate scenarios".

1.3 Approach to drought analysis for the ECA study

Droughts are regular events with slower onsets and larger geographical reach than other climate-related disasters like floods and storms. The definition of drought changes depending on the duration and the intensity of the water deficiency. **Meteorological droughts** are mostly reflected in a reduction in the water balance, with lower precipitation and higher temperatures and evapotranspiration. **Agricultural drought** causes soil water deficiency and stress for plants including crops, livestock and biomass in general. **Hydrological droughts** affect water bodies like rivers, lakes and wetlands. And **socio-economic droughts** are identified when communities and societies are significantly impacted by the aforementioned conditions[46].

By defining the type of drought to be managed, relevant actors can select the key variables that need to be monitored and the thresholds that should be considered to allow for proper adaptation[47]. For studying droughts in Afar and Somali, CLIMADA is considering the meteorological and agricultural drought definitions, as well as the socio-economic variables relevant for pastoral and agro-pastoral communities.

Many indices exist for **meteorological drought** and they not only vary in their data requirement but also in their level of complexity[48]. The most commonly used indices worldwide are the Standard Precipitation Index (SPI) and, its variant, the Standard Precipitation and Evapotranspiration Index (SPEI), which express the gap between a given period and the average observed values on standard deviation units[49]. These indices are the most commonly used for studying droughts in Ethiopia as well[50], mainly due to the restricted amount of data collected on the ground by weather stations, particularly in the study area[51].

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[44] Ibid.
[45] Birch, I. (2018). *Economic growth in the lowlands of Ethiopia.* K4D Helpdesk Report. Brighton, UK: Institute of Development Studies.
[46] Wilhite, D.A.; and M.H. Glantz. (1985). *Understanding the Drought Phenomenon: The Role of Definitions*. Water International 10(3):111–120.
[47] World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2016(. *Handbook of Drought Indicators and Indices* (M. Svoboda and B.A. Fuchs). *Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2*. Geneva.
[48] Ibid.
[49] Wilhite and Glantz.(1985)
[50] Ibid.
[51] Fazzini M, Bisci C, Billi P. (2015). *The Climate of Ethiopia. Landscapes and Landforms of Ethiopia.* World Geomorphological Landscapes. Springer Science

There are some limitations related to the use of the SPI and the SPEI especially in arid areas like Afar and Somali. In regions where the average precipitation is low but there are periods of significant rainfall, both indices can miss small decreases in rainfall which are nevertheless significant for locals. CLIMADA enables the user to select not only between indices but also the length of the period to compensate for this issue.

Concerning **agricultural drought**, indices mostly refer to soil moisture data to measure and monitor the intensity of droughts[52]. Soil moisture data has the complication that needs to be locally measured, requiring capacities and infrastructure often scarce in developing countries. The alternative is to monitor the changes on vegetation between periods, and a commonly used index is the Normalized Difference Vegetation Index (NDVI), which relies on remote sensing imagery to quantify and identify these changes[53]. The weakness of this method is the short term of the databases available, given the relatively short history of public data imagery. CLIMADA incorporates the NDVI as part of its toolkit of indices, and in the case of Ethiopia, it will be used to determine the past impact of droughts in vegetation and project future scenarios.

For **socio-economic drought** for pastoral and agro-pastoral communities, the main variable to be determined is the losses in livestock caused by this natural hazard. A useful indicator for determining the potential of a region to grow nutrients for local consumption is the Dry Matter Productivity (DMP) which can also be measured through satellite imagery[54]. This index measures the balance between the carbon gained by photosynthesis and the carbon released by plant respiration, to estimate the vegetation growth rate in kilogram/hectare/day (kg/ha/day)[55]. This index will be used to determine the relationship between changes in the selected meteorological indices and the potential of the study region to feed the livestock of the pastoralists.[56] Figure 4 below presents the distribution of the average DMP in 2015 in the study region, for illustration purposes.

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[52] World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2016). *Handbook of Drought Indicators and Indices* (M. Svoboda and B.A. Fuchs*). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2*. Geneva.
[53] Ibid.
[54] Swinnen, E.; Van Hoolstm R. ; Totém C.(2019.) *Copernicus Global Land Operations "Vegetation and Energy" - QUALITY ASSESSMENT REPORTDRY MATTER PRODUCTIVITY (DMP)*. Copernicus Global Land Operations.
[55] Ibid.
[56] In the literature (e.g Kassam, A.H., van Velthuizen, H.T., Fischer, G.W., Shah, M.M. (1991). Agro-Ecological Land Resources Assessment for Agricultural Development Planning. A Case Study of Kenya. Resources Data Base and Land Productivity. Rome: Land and Water Development Division, Food and Agriculture Organization of the United Nations and International Institute for Applied Systems Analysis.) dry matter is identified as a suitable indicator for animal feed requirements. To maintain bodyweight a TLU (250 kg) requires 6.25 kg of dry matter per day, translating to 2.5 kg dry matter per 100 kg bodyweight.

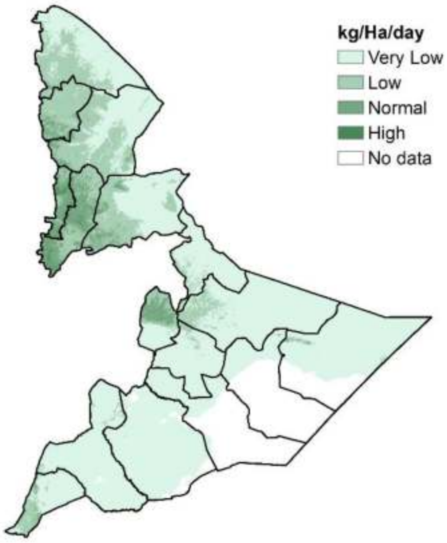

Figure 4 Average DMP distribution in 2015 for Afar and Somali; Source: Based on data from Copernicus Services [57]. Categories: 0 – 23 kg/Ha/Day (very low), 23 – 46 (low), 46 – 92 (normal), 92 -148 (high), 148-320 (very high).

[57] Copernicus Global Land Operations. (2020). *Copernicus Global Land Service.* Retrieved from Copernicus: https:// https://land.copernicus.vgt.vito.be/PDF/portal

2 Selection of Assets

During the Inception Workshop held in December 2019 in Addis Ababa, the present stakeholders agreed on the five asset categories of People, Livestock, Crops and Farming Land, Household Assets, and Environmental Assets, each with several sub-categories. The following chapter will provide further information on each category and the respective sub-categories.

2.1 People

As the first asset group 'people' were identified, while the workshop participants emphasised the importance of especially vulnerable groups, such as the elderly, children, disabled, and women. People and their level of vulnerability are defined here according to the definition of the Intergovernmental Panel on Climate Change[58] based on the three components of vulnerability, namely

- exposure,
- adaptive capacity, and
- sensitivity.

Exposure, although there most likely are localised differences, e.g. based on differing altitudes, in this case, it is assumed to be relatively uniform across each of the two regions as droughts are slow on-setting events and are experienced across wide areas, unlike floods or storms that take very distinct paths.

Adaptive capacity, defined by the 5th IPCC report[58] as 'the ability to adjust, take advantage of opportunities, or cope with consequences', on the other hand, differs greatly between livelihoods, individual households and locations. Therefore for this study, a normalised indicator on the household level was calculated.

Following the approach[59] using and adopting the Sustainable Livelihoods Approach (SLA)[60] to assess the adaptive capacity of the European agricultural sector to droughts, an indicator to estimate the adaptive capacity was developed. The SLA initially interprets welfare as a function of multiple forms of capital, or capacity, that actors can use to recover and increase their resilience. In general, the framework relies on five types of assets:

1. **Human capacity**, e.g. health and education
2. **Social capacity**, e.g. close social bonds aiding cooperative actions

[58] IPCC. (2014). *Impact, adaptation and vulnerability. Part A: Global and sectoral Apects Working Group (WG) II Report.* P. 118.
[59] Williges, K., Mechler, R., Bowyer, P., & Balkovic, J. (2017). *Towards an assessment of adaptive capacity of the European agricultural sector to droughts.* Climate Services, 7, 47-63. doi:10.1016/j.cliser.2016.10.003
[60] Ellis, F. (2000). Rural Livelihoods and Diversity in Developing Countries. Oxford: Oxford University Press.

3. **Natural capital**, e.g. natural resource base, water and biological resources, and actions to sustain the productivity
4. **Physical capacity**, e.g. items produced through economic activity including infrastructure and equipment
5. **Financial capacity**, e.g. access to financial resources combining or contributing to wealth.

Based on these categories the index was developed taking all but the "social capacity" category into account. In this study, the proxies used are presented in Table 1.

Table 1: Proxies used to estimate the Adaptive Capacity of households for this Study.

Human capacity	Natural capital	Physical and Financial capacity
Number of enrolled pupils [61]	Proximity (5 km) to water, natural flows as well as manmade e.g. canals [62]	Percentage of people living below USD1,005 per year [63]
Number of hospital beds per 1,000 people[61]	Dry Matter Productivity (DMP)[64,65] of the surroundings	Per person livestock holding (Camel, Cattle, Sheep, Goat) aggregated in Tropical Livestock Units (TLU)[66,67].
		Access to financial services[68]

To reach the final adaptive capacity index all categories are given equal weights. Figure 5 displays the distribution of the normalised adaptive capacity indicator in the two observed regions on the woreda level with dark green, i.e. a value close to or equal to one indicates a relatively high adaptive capacity.

[61] UNISDR (2015). *GAR15 Global Exposure Dataset for Ethiopia*. Ethiopia. Retrieved 16.06.2020 from https://data.humdata.org/dataset/gar15-global-exposure-dataset-for-ethiopia

[62] Humanitarian OpenStreetMap Team (2020). *HOTOSM Ethiopia Waterways (OpenStreetMap Export)*. Retrieved 16.06.2020 from https://data.humdata.org/search?q=hotosm_eth

[63] UNISDR (2015)

[64] Dry Matter Productivity describes the increase in dry biomass of the vegetation in kg of dry matter per hectare per day. For more information see Smets, B., Swinnen, E., & van Hoolst, R. (2019). *Vegetation and Energy. Product User Manual. Dry Matter Productivity (DMP) Gross Dry Matter Productivity (GDMP) Collection 300m*. (I1.22), 1. Copernicus Global Land Operations.

[65] Copernicus Global Land Service. (2020). Dry Matter Productivity. DMP and GDMP 300m.

[66] The Tropical Livestock Unit is defined by a weight equivalent of 250kg living weight. Conversion factors for the four relevant livestock types here are: Camel: 1.0 TLU, Cattle: 0.7 TLU, Sheep and Goat: 0.1 TLU. For further details see e.g. Jahnke, H. E. (1982). *Livestock Production Systems and Livestock Development in Tropical Africa*. Kiel: Kieler Wissenschaftsverlag Vauk.

[67] USAID and the Government of Ethiopia. (2010). *An Atlas of Ethiopian Livelihoods*. The Livelihoods Integration Unit. USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.

[68] Central Statistical Agency. (2016). *Socioeconomic Survey 2015-2016, Wave 3. Living Standards Measurement Study*. Retrieved on 01.06.2020 from https://microdata.worldbank.org/index.php/catalog/2783/

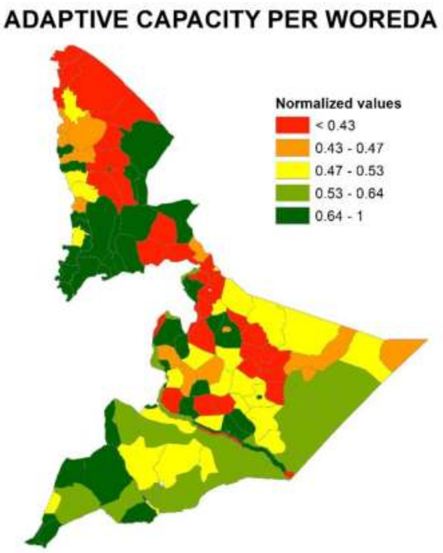

Figure 5: Adaptive Capacity Indicator on the Woreda level. Source: UNU-EHS.

Finally, **sensitivity** describes to which degree a system is affected, in this case by drought. This parameter will be defined by the modelling exercise in CLIMADA.

Further, Figure 6 indicates population distribution. Larger urban settlements, e.g. the regional capital cities, are highlighted by dark green pixels surrounded by lighter green pixels (smaller urban settlements).

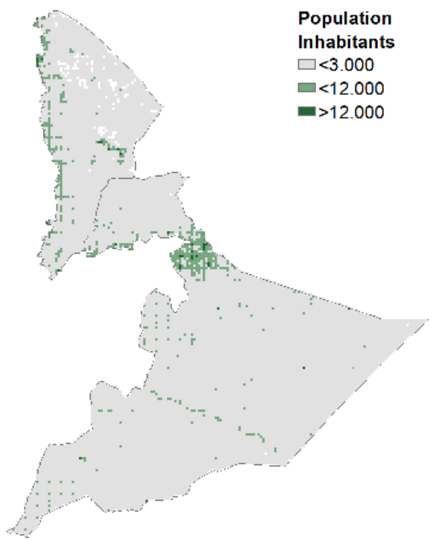

Figure 6: Population density on a 5x5km grid. Source: UNU-EHS based on data by UNDRR (2015).

2.2 Livestock

Afar and Somali regions are traditionally depending on pastoral or agro-pastoral lifestyle. Henceforth, livestock was identified as an important asset to be considered in this study. Livestock is not only a source of food and milk for most of the population but also is the key investment opportunity among pastoralists.[69]

Four major livestock categories (Camel, Cattle, Sheep and Goat) were emphasized during the Inception Workshop and subsequently confirmed through data provided by the Central Statistical Agency of Ethiopia (CSA)[70]. The report records for 2018/19 roughly 2.4m cattle, 5.9m sheep, 12.9m goats, and 3.6m camels were living in Afar and Somali. These livestock categories represent the most important breeds in Ethiopia[71].

Based on their different characteristics the four types of livestock handle drought and other shocks differently[72].

Figure 7, adapted from *An Atlas of Ethiopian Livelihoods*[73], shows the average number of each type of livestock per person. It indicates the distribution of livestock types in the Afar and Somali. Figure 8 summarises the three previous maps and aggregate it in Tropical Livestock Units (TLUs).

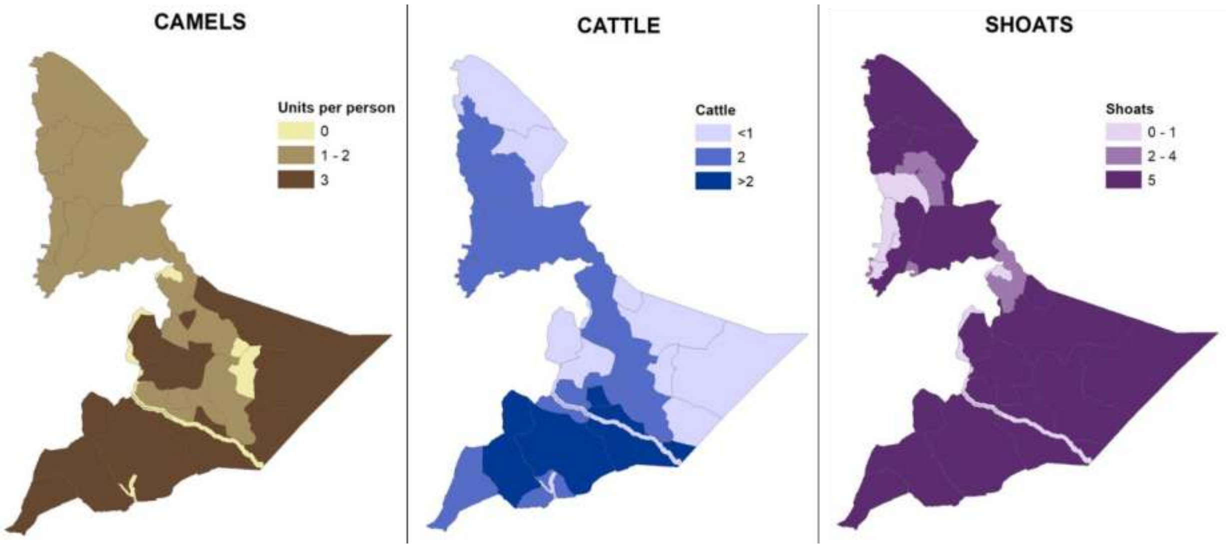

Figure 7: Camels, Cattle and Shoats (Goats and Sheep) held per Person. Source: UNU-EHS based on USAID and the Government of Ethiopia. (2010).

[69] USAID and the Government of Ethiopia. (2010). *An Atlas of Ethiopian Livelihoods*. The Livelihoods Integration Unit. USAID and the Government of Ethiopia, Disaster Risk Management and Food Security Sector, MOARD.
[70] Central Statistical Agency. (2019). *Agricultural Sample Survey 2018/19 [2011 e.c.]. Volume II. Report on Livestock and Livestock Characteristics (Private Peasant Holdings).* Addis Ababa: Federal Democratic Republic Of Ethiopia.
[71] USAID and the Government of Ethiopia. (2010)
[72] Catley, A., Admassu, B., Bekele, G., & Abebe, D. (2014). *Livestock mortality in pastoralist*. Disasters. 38: 500-516.
[73] USAID and the Government of Ethiopia. (2010)

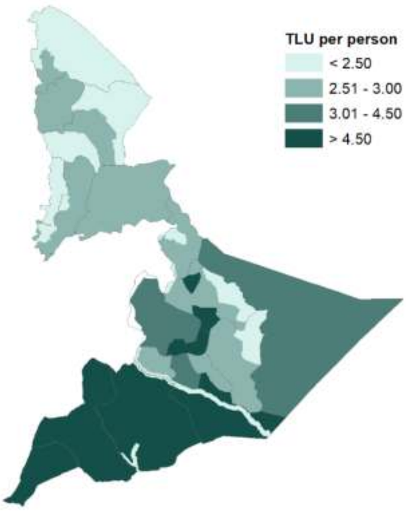

Figure 8: Average number of TLU held per person. Source: UNU-EHS based on USAID and the Government of Ethiopia. (2010).

2.3 Crops and Farming Land

A secondary source of livelihood for the majority of people, crop and farming land are selected as the third category of assets. As reported by the USAID and CSA[74] the main crops grown in Afar (see Figure 9, dark green indicating higher abundance) are 'sorghum, maize and/or millet' or 'wheat and barley'. More seldom, 'fruits and vegetables' are grown in the vicinity of water bodies and the capital city of the region, Semera.

Although there is relatively more agriculture in Somali (see Figure 9, dark green indicating higher abundance) crops preferences are similar to Afar. Also, 'pulses' and 'oilseeds' are cultivated along the Shebelle River. In both regions, wheat and barley are only grown in higher areas. In general, agricultural land concentrates around rivers and waterbodies, with few infrastructures for irrigation, such as canals and dams.

[74] Ibid.

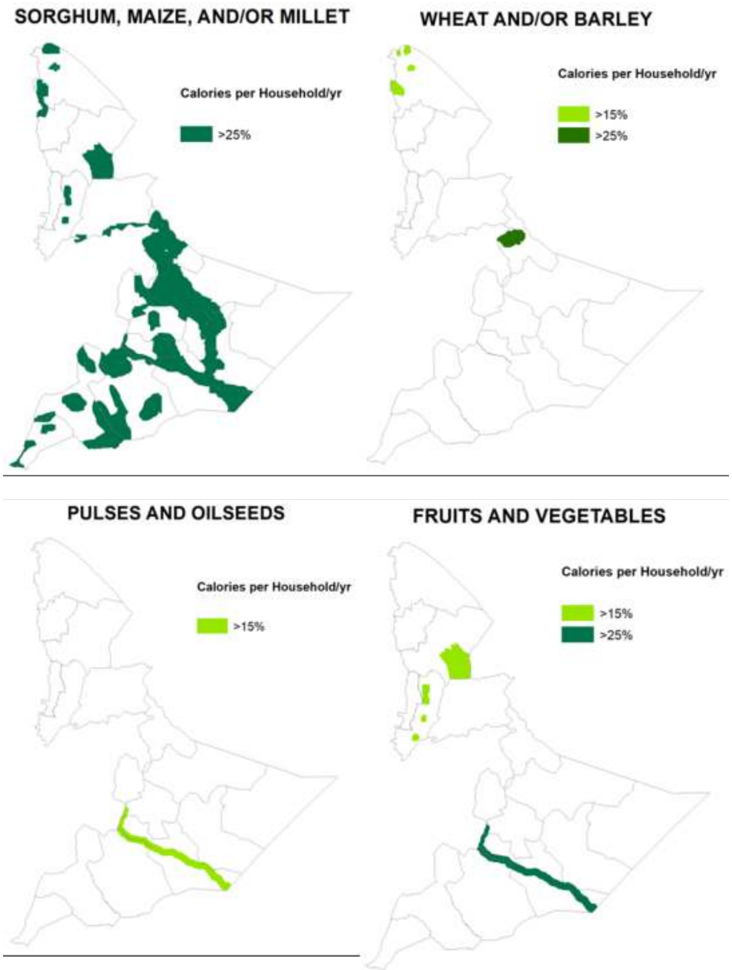

Figure 9: Crops grown in Afar and Somali regions by percentage of minimum calories required per household per year (white <5%, light green 5-25%, dark green >25%)

2.4 Natural Resources

The category of environmental assets is split into the two sub-categories of 1) rangelands, including forest areas and trees, shrubs, and bushes, and 2) water resources, for instance, lakes and rivers, as well as artificial irrigation schemes.

2.4.1 Rangelands

Rangelands are mainly unfenced areas with natural vegetation and plant communities dominated by grasses, forbs and shrubs with efficient nutrient and water utilization. The land's resources are commonly used and managed by pastoralists and agro-pastoralists for grazing and browsing by livestock[75].

[75] Egge, M., Tongdeelert, P., Rangsipaht, S., & Tudsri, S. (2011). *Collective actions and the management of collectively provided rangeland resources and activities in Awbere district of Somali regional state*. Ethiopia. Kasetsart Journal - Social Sciences, 32(3), 516-525.

In the Afar region, agro-pastoralism, which has emerged due to the development of small-scale irrigation schemes, accounts only for roughly 10% of the economy.[76] The landcoveris characterized by a spatial heterogeneity composed of scattered dry shrubs, acacia woodland (comprising different Vachellia species), bushland, grassland and wooded grassland[77,78]. Some of the native grasses and forbs vegetation include dryland adapted *Chrysopogon*, *Cymbopogon (lemongrass)*, *Cyndone*, and *Sporobolous*[79]. The encroachment of large-scale agricultural schemes deprives pastoralists of their resting place during the dry season and is increasingly responsible for the loss of customary practices in the case of Afar pastoralists[80].

In the Somali region, little information is available about rangelands condition. Some areas have long been under the traditional rotational grazing system but some are changing to private area enclosures. The predominant grazing pattern in the region is based on seasonal movement between wet and dry season pastures, also called transhumance[81]. The degradation of biological rangeland resources has become a challenge with negative impacts on the pastoral ecosystems, livestock production and dependant livelihoods. Depending on the area in the Somali region, different factors are influencing the rangeland degradation. Some rangelands are encroached by invasive woody plants (mainly *Acacia nubica*, *Apis mellifera* and *Prosopis juliflora*) which encourages a shift towards camels and goats who are better equipped for such woody plants (for further details on invasive species see ANNEX 2). Another factor for degradation has been the reduction of herbaceous and woody layers in combination with recurrent droughts. Also, overgrazing reduced the abundance of woody plants and influenced species composition of important fodder plants, causing lower grazing and browsing capacities of the rangelands[82].

Similar to Afar, there are different grass species abundant in the rangelands. The most dominant species, identified by the pastoralists, include *Chrysopogon, Panicum maximum, Heteropogon contortus, Chloris virgata,* and *Cenchrus ciliaris,* respectively[83].

2.4.2 Land cover & Land use

The main land use types in the Afar and Somali region can be described as follows[84,85]. Figure 10 provides a more detailed overview of the land cover patterns in the two regions.

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[76] Bekele K, Haji J, Legesse B, Schaffner U. (2018). *Economic impacts of Prosopis spp. invasions on dryland ecosystem services in Ethiopia and Kenya: Evidence from choice experimental data.* Journal of Arid Environments 158:9–18. https://doi.org/10.1016/j.jaridenv.2018.07.001
[77] Shiferaw H, Bewket W, Alamirew T, Zeleke G, Teketay D, Bekele K, Schaffner U, Eckert S. (2019). *Implications of land use/land cover dynamics and Prosopis invasion on ecosystem service values in Afar Region, Ethiopia*. Sci Total Environ 675:354–366. https://doi.org/10.1016/j.scitotenv.2019.04.220
[78] Atanga N, Treydte A, Birner R. (2013). *Assessing the Sustainability of Different Small-Scale Livestock Production Systems in the Afar Region, Ethiopia.* Land 2:726–755. https://doi.org/10.3390/land2040726
[79] Wakie TT, Laituri M, Evangelista PH. (2016*). Assessing the distribution and impacts of Prosopis juliflora through participatory approaches.* Applied Geography 66:132–143. https://doi.org/10.1016/j.apgeog.2015.11.017
[80] Tilahun M, Angassa A, Abebe A, Mengistu A. (2016). *Perception and attitude of pastoralists on the use and conservation of rangeland resources in Afar Region, Ethiopia*. Ecol Process 5:149. https://doi.org/10.1186/s13717-016-0062-4
[81] Meshesha DT, Moahmmed M, Yosuf D. (2019). *Estimating carrying capacity and stocking rates of rangelands in Harshin District, Eastern Somali Region, Ethiopia*. Ecol Evol 9:13309–13319. https://doi.org/10.1002/ece3.5786
[82] Kassahun A, Snyman HA, Smit GN. (2008). *Impact of rangeland degradation on the pastoral production systems, livelihoods and perceptions of the Somali pastoralists in Eastern Ethiopia.* Journal of Arid Environments 72:1265–1281. https://doi.org/10.1016/j.jaridenv.2008.01.002
[83] Meshesha DT, Moahmmed M, Yosuf D. (2019). *Estimating carrying capacity and stocking rates of rangelands in Harshin District, Eastern Somali Region, Ethiopia*. Ecol Evol 9:13309–13319. https://doi.org/10.1002/ece3.5786
[84] Shiferaw H, Bewket W, Alamirew T, Zeleke G, Teketay D, Bekele K, Schaffner U, Eckert S. (2019*). Implications of land use/land cover dynamics and Prosopis invasion on ecosystem service values in Afar Region, Ethiopia*. Sci Total Environ 675:354–366. https://doi.org/10.1016/j.scitotenv.2019.04.220
[85] Meshesha DT, Moahmmed M, Yosuf D. (2019). *Estimating carrying capacity and stocking rates of rangelands in Harshin District, Eastern Somali Region, Ethiopia*. Ecol Evol 9:13309–13319. https://doi.org/10.1002/ece3.5786

Bareland: Areas without any vegetation either due to erosion or mismanagement (especially overgrazing); land cover permanently sand or rocks including volcanic black rocks or roads.

Grass, shrub and woodland: Different types of pure or mixed trees such as palm trees, *Vachellia* woodland with grass as undergrowth. Shrublands and bush thickets consisting of mixed native shrubs and wooded bush thickets consisting of native species.

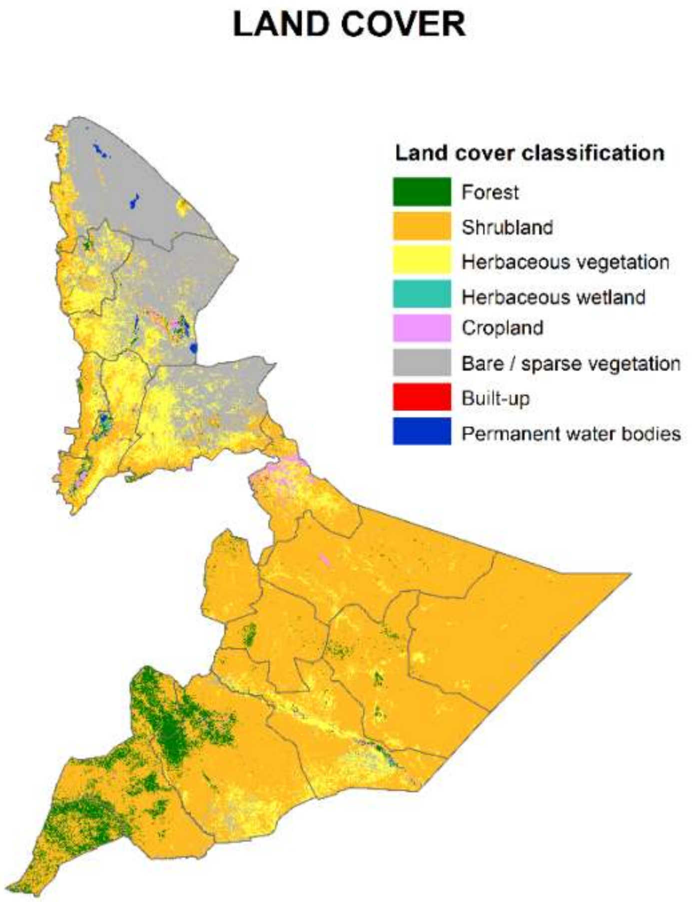
Grassland: Areas covered with natural grass and small shrubs, or dominated by grass, it includes areas used for communal grazing as well as a bare land that is seasonally grass-covered.

Natural Forest: Mainly dominated by native *Vachellia spp*. found in riverside/ riverine forest ecosystems.

Prosopis juliflora: Areas invaded by Prosopis at different cover gradients (abundance), monoculture or mixed stands together with other vegetation but dominated by Prosopis.

Salt Flats: Areas mostly in and around shallow lakes & ponds, used for salt production.

Waterbodies: Permanent lakes, and freshwater (rivers and streams). They also include wetlands which dry up during the dry season, intermittent ponds and water points, perennial marshy areas, and man-made dams for hydroelectric and irrigation purposes.



Land cover	Afar		Somali	
	Absolute area (km²)	%	Absolute area (km²)	%
Forest	1,586	1.66%	19,949	6.35%
Shrubland	19,220	20.12%	242,966	77.34%
Herbaceous vegetation	22,220	23.26%	31,133	9.91%
Herbaceous wetland	210	0.22%	63	0.02%
Cropland	1,643	1.72%	3,142	1.00%
Bare / sparse vegetation	49,923	52.26%	16,870	5.37%
Built-up	10	0.01%	31	0.01%
Permanent water bodies	716	0.75%	0	0.00%
Total	95,529	100%	314,153	100%

Figure 10: Land cover in Afar and Somali. Source: UNU-EHS based on data provided by Copernicus Global Land Service. (2020).[86]

2.4.3 Water Resources

Awash River basin in Afar: The **Awash River** is the main water flow into the region flowing from the highlands of central Ethiopia, at an altitude of about 3,000 m above sea level and is ending as a chain of saline lakes. The total length of the river is ca. 1,200 km with a catchment area of 113,700 km² [87]. Its

[86] Copernicus Global Land Service. (2019). *Vegetation and Energy. Moderate Dynamic Land Cover Change*. Collection 100m. Version 2.1.. Retrieved on 23.06.2020 from https://land.copernicus.eu/global/products/lc.

[87] Hailemariam, K. (1999). Impact of climate change on the water resources of Awash River Basin, Ethiopia. *Climate Research*, *12*(2-3), 91-96.

course is entirely within the boundaries of Ethiopia and empties into interconnected lakes that begin with Lake Gargori and drains into Lake Abbe at the border with Djibouti. The Awash River forms a valley, flowing north-eastward through the southern part of the Afar Region, and provides a narrow green belt which enables pastoralism and agriculture for the people living in the area. However, some parts are running dry during the annual dry season. The Awash River consists of eleven tributary rivers, which drain the highlands eastwards and therefore increase the water level of the Awash River in a short period especially during August and September and cause flooding in the low-lying alluvial plains along the river course. Tributaries to Awash River such as Kessem, Kenena, Hawadi, Ataye Jara, Mille and Logiya rivers contribute most to the lowland flooding in Afar[88].

Lakes in the Afar Region: The largest lake in the Afar region is the **Lake Abbe** (ca. 320 km², max. depth 37 metres) which is a hypersaline (salt) lake, lying on the Ethiopia-Djibouti border. The Lake Abbe is one of a chain of six connected lakes, which includes the lakes Gummare, Bario and Afambo. At Lake Abbe ends the Awash River. Here lies the so-called Afar Triangle, the central meeting place of the three tectonic plates, which is a defining feature of the Afar Depression[89]. Located in the North of Afar lies **Lake Afrera** (ca. 100 km², max. depth 80 metres), a hypersaline lake within the Afar Depression where rock salt has been mined. The lake has one island (Franchetti Island) which is considered to be the lowest-lying island in the world[90]. Other lakes located within the boundary of Afar are Lake Gummare (freshwater lake, 60 km²), Lake Karum (salt lake, 50 km²), Lake Afambo (freshwater lake, 35 km²), Lake Bario (22 km²) and Lake Caddabassa.

Rivers in the Somali Region: The **Shabelle River** originates from the Ethiopian highlands and flows southeast through the Somali region and takes in numerous tributaries coming from the Harar Plateau from the North. The Shabelle River is ca. 2,520 km long, with a catchment area of ca. 280,000 km² [91]. Most of the tributaries do not carry water at all times of the year[92]. The South of the region is drained by the two perennial rivers **Dawa** and **Ganale**, which join at the Somali border to form the Jubba River. Both rivers form a basin with a catchment area of circa 170,000 km² and are partially used for irrigated farming[93].

In the North, near the border of Djibouti and Somaliland/Somalia, the **Ayesha River** can be found with a length of ca. 800 km. The Ayesha River is an intermittent river that drains to a large extent every year with no measurable streaming flows. The rivers' basin is part of the East African Rift (Afar Triangle) where three tectonic plates are pulling away from one another.

Irrigation & Artificial waterways: Pastoralists in the Afar and Somali regions are increasingly confronted with competition for dryland natural resources and face difficulties to access rangelands with sufficient pastures and water sources. Pursuing a traditional pastoral livelihood system is therefore made more

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88 Yenesew Mengiste Yihun. (2015). *Agricultural Water Productivity Optimization For Irrigated Teff (Eragrostic Tef) In A Water Scarce Semi-Arid Region Of Ethiopia*. Taylor & Francis Group, Leiden, Netherlands.

89 Beyene, Alebachew & Abdelsalam, Mohamed G. (2005). *Tectonics of the Afar Depression: A review and synthesis.* Journal of African Earth Sciences. **41** (1–2): 41–59. *doi:10.1016/j.jafrearsci.2005.03.003*

90 Hughes, R.H & Hughes, J.S. (1992). *A Directory of African Wetlands*. IUCN, Gland, Switzerland and Cambridge, UK / UNEP, Nairobi, Kenya / WCMC, Cambridge, UK, 820pp.

91 FAO Somalia Water and Land Information Management, 14.08.2020, http://www.faoswalim.org/article/juba-and-shabelle-rivers-and-their-importance-somalia

92 Michalscheck, M., Petersen, G., & Gadain, H. (2016). *Impacts of rising water demands in the Juba and Shabelle river basins on water availability in south Somalia.* Hydrological Sciences Journal. 61(10), 1877-1889.

93 Girma, M. M.; Awulachew, S. B. (2007). *Irrigation practices in Ethiopia: Characteristics of selected irrigation schemes.* Colombo, Sri Lanka: International Water Management Institute. 80p. (IWMI Working Paper 124)

difficult. Over the past decades, the Ethiopian government has initiated programs that facilitate the permanent settlement of pastoral communities based on large scale irrigation schemes that aim to establish hectares of grazing rangelands or other forms of irrigated agriculture (e.g. production of cotton and sugarcane)[94].

The lower Awash River basin supports many large-scale commercial farms and several irrigated small farms. The economic irrigation potential for the Awash River basin is estimated to be 206,000 ha, by which 23,300 ha are under traditional and modern small-scale irrigation and 64,700 ha are developed under state farms and private investors[95]. These include agro-industries such as sugar factories and horticultural farms, ranches and cattle fattening.

The Asaita and Dubti woredas of the Afar region represent a prominent area (see Figure 11) in which the Ethiopian government commits to promoting irrigation development, mainly in the form of participatory irrigation resource management. In these initiatives, (agro) pastoralists stay involved in the management of irrigated pastures and the utilization of land resources[96]. A prominent example of such an irrigation development project is the Tendaho Irrigation Project in Asaita woreda, which is in the centre of the so-called *Afar triangle*. This irrigation project was only made possible by the construction of the Tendaho Dam in 2014. The earth-filled Tendaho Dam in eastern Afar at the Awash River in Dubti woreda, was primarily constructed for this large-scale irrigation project, planned to irrigate 50,000 ha of land for sugarcane production[97].

[94] Kidane, D., Teketay, D., & Mekonnen, A. (2019). *Contributions of Tendaho Irrigation Project to the improvement of livelihoods of agropastoralists in the Lower Awash Basin, northeastern Ethiopia.*
[95] Yenesew Mengiste Yihun. (2015). *Agricultural Water Productivity Optimization For IrrigatedTeff (Eragrostic Tef) In A Water Scarce Semi-Arid Region Of Ethiopia*. Taylor & Francis Group, Leiden, Netherlands.
[96] Kidane et al. (2019)
[97] Tilahun, A., Shishaye, H. A., & Gebremariam, B. (2017). *Sediment inflow estimation and mapping its spatial distribution at sub-basin scale: the case of Tendaho Dam, Afar Regional State, Ethiopia.* Ethiopian Journal of Environmental Studies and Management, 10(3), 315-339.

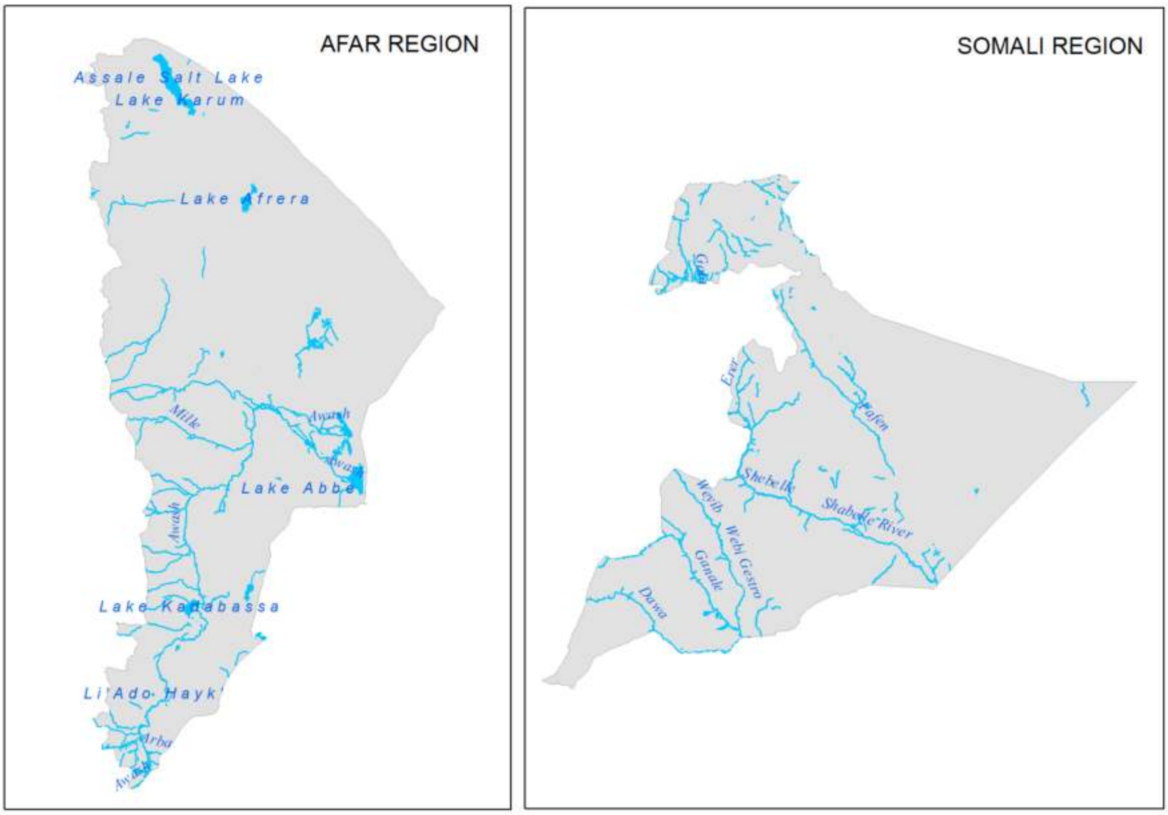

Figure 11: Map of existing water bodies in the Afar and Somali Region. Source: UNU-EHS based on data provided by the Humanitarian OpenStreetMap Team (2020).

Groundwater availability. Hydrological data in Ethiopia is generally scarce in most of the regions. Ayenew, T. et al. (2008) conducted comprehensive hydrological field surveys on national scale in order to identify and classify different types of aquifer types and their hydraulic parameters, such as groundwater recharge. Below, 30Figure 12 indicates a zoning of groundwater availability and recharge zones. Generally, the Afar region has an aquifer recharge capacity of less than 50 mm/year.

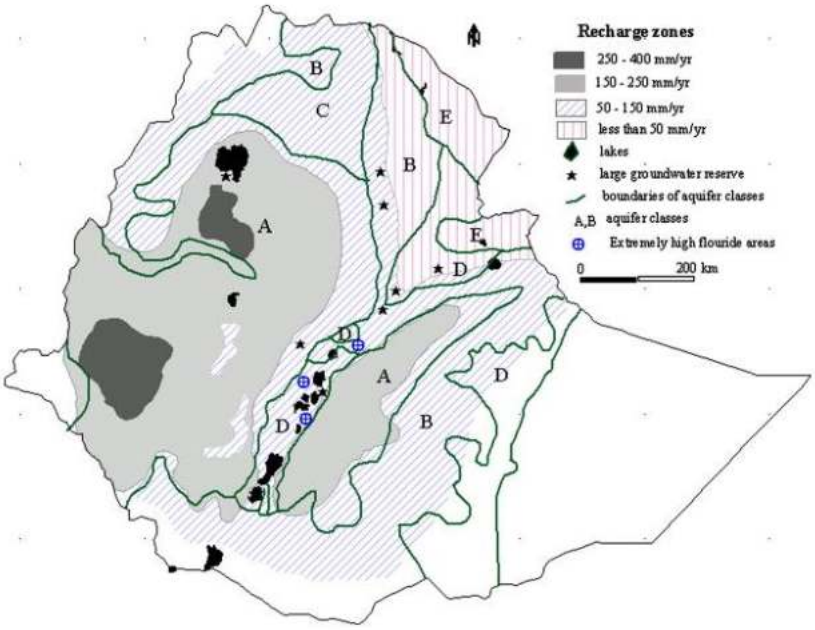

Figure 12: Groundwater recharge and availability map. Note: A = wide spread good quality groundwater at a relatively shallow depth (dominantly highland volcanic aquifers recharged by high rainfall); B = large groundwater reserve with fair to bad quality often localized in lower elevation areas (rift valley and volcanic in pediment covered with thick sediments and intermountain grabens); C = low to moderate groundwater reserve with fair quality (highland trap series volcanic aquifer with less sediment cover and recharge); D = medium to high groundwater reserve in the volcanic and sediments recharged by rainfall and rivers in places with serious salinity problem; E = Low groundwater reserve with moderate quality recharged by seasonal floods and streams. Adopted from Ayenew, T. et al. (2008)[98]

[98] Ayenew, T., Demlie, M., & Wohnlich, S. (2008). Hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers. *Journal of African Earth Sciences*, *52*(3), 97-113.

3 Scenario Development

3.1 Climate scenarios

3.1.1 Introduction

The objective of this section is to review different climate scenarios for Ethiopia. The following section will comment on projections of future climate in Eastern Africa and Ethiopia. It will focus on several aspects of climate scenarios in the areas related to drought, precipitation and temperature highlighting scientific consensus and actual debates.

3.1.2 Overview

For Ethiopia and particularly its northern regions, climate change impacts on water resources are of major concern given the sustainability of water resources and agricultural production[99]. There is growing evidence that climate change will have both serious and multiple effects, especially in the drier parts of this region already suffering from profound water shortages and heat stress[100,101]. In general, observed warming over northern Ethiopia is larger than the global average[102,103]. Although there is a general agreement about drought reasons - precipitation and temperature - other factors appear to play a role[104]. Recent studies show that climatic regionalization, seasonal cycles, intra-seasonal variability, inter-annual variability, recent trends, and seasonal forecasting influence the climate in Eastern African.

The spatial distribution and the frequency of drought occurrence have increased in recent years. Nearly every two-three years northern Ethiopia experiences localized droughts with differing levels of intensity[105]. The 2015–2016 drought affected over 10 million people in the country, which shows the magnitude and the proportion of the problem[106].

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[99] Conway,D. and E.L.F. Schipper. (2011). *Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia.* Global Environmental Change, 21(1), 227-237

[100] Hadgu, K. Tesfaye, G. Mamo. (2015). *Analysis of climate change in Northern Ethiopia: implications for agricultural production*. Theor. Appl. Climatol., 121 (3), pp. 733-747, 10.1007/s00704-014-1261-5

[101] Araya, A., L. Stroosnijder. (2011*). Assessing drought risk and irrigation need in northern Ethiopia*. Agric. For. Meteorol., 151, pp. 425-436, 10.1016/j.agrformet.2010.11.014

[102] Hadgu, K. Tesfaye, G. Mamo. (2015). *Analysis of climate change in Northern Ethiopia: implications for agricultural production*. Theor. Appl. Climatol., 121 (3), pp. 733-747, 10.1007/s00704-014-1261-5

[103] Conway and Schipper (2011)

[104] Nicholson, S. E. (2016). *The Turkana low-level jet: Mean climatology and association with regional aridity*. Int. J. Climatol., 36(6), 2598–2614, doi:10.1002/joc.4515.

[105] Edossa, D., M.S. Babel, A.D. Gupta. (2010). *Drought analysis in the Awash River Basin, Ethiopia*. Water Resour. Manag., 24, pp. 1441-1460, 10.1007/s11269-009-9508-0

[106] Tesfaye, S. Taye, T. Birhane, E., van der Zee, E. (2019). *Observed and model simulated twenty-first century hydro-climatic change of Northern Ethiopia*. Journal of Hydrology: Regional Studies, 22, ISSN 2214-5818, 10.1016/j.ejrh.2019.100595.

In more recent years, droughts have become more frequent and more severe, extending in some cases over two or more rainy seasons[107,108]. This has heightened the concern about possible climate change over Eastern Africa. The greatest changes appear to have occurred during the long rains, which have been declining over the decades. In the central Ethiopian highlands, rainfall declined by 25% to 30% after 1996[109]. As a consequence, droughts have been more frequent throughout Ethiopia since roughly 1999[110].

3.1.3 Current Climate Trends in East Africa

In recent decades, North African annual and seasonal observed trends in mean near-surface temperature indicate overall warming that is significantly beyond the range of changes due to natural (internal) variability[111]. The equatorial and southern parts of Eastern Africa have experienced a significant increase in temperature since the beginning of the early 1980s[112]. Near-surface temperatures have increased by 0.5°C or more during the last 50 to 100 years over most parts of Africa, with minimum temperatures warming more rapidly than maximum temperatures[113].

The mean annual total rainfall and potential evapotranspiration are estimated at 570 and 2,800 mm, respectively[114] Precipitation is generally scant, irregular, and unpredictable. This could lead to extreme weather causing destructive floods. In 2020, several floods were reported during the summer Kiremt rain in areas in the Somali regions affecting more than 470,000 persons. These floods caused severe damage to infrastructure and affected people's livelihoods [115]

Nevertheless, most areas of the African continent lack sufficient observational data to conclude trends in annual precipitation over the past century[116]. Also, in many regions of the continent discrepancies exist between different observed precipitation data sets[117].

3.1.4 Global Climate Models

Global Climate Models (GCMs) are used to project changes in the Earth's climate. The prevailing generation of models associated with the fifth Assessment Report from IPCC (AR5) from the Coupled

[107] Funk, C. C., and A. Hoell. (2015). *The leading mode of observed and CMIP5 ENSO-residual sea surface temperatures and associated changes in Indo-Pacific climate*. J. Clim., 28(11), 4309– 4329, doi:10.1175/JCLI-D-14-00334.1.
[108] Nicholson, S. E. (2016). *An analysis of recent rainfall conditions in eastern Africa*. Int. J. Climatol., 36(1), 526– 532, doi:10.1002/joc.4358.
[109] Rosell, S., and B. Holmer. (2015). *Erratic rainfall and its consequences for the cultivation of teff in two adjacent areas in south Wollo, Ethiopia*. Nor. Geogr. Tidsskr. Nor. J. Geogr., 69(1), 38– 46, doi:10.1080/00291951.2014.992805
[110] Viste, E., D. Korecha, and A. Sorteberg. (2013). *Recent drought and precipitation tendencies in Ethiopia*. Theor. Appl. Climatol., 112(3–4), 535– 551, doi:10.1007/s00704-012-0746-3
[111] Barkhordarian, A., J. Bhend, and H. von Storch. (2012). *Consistency of observed near surface temperature trends with climate change projections over the Mediterranean region*. Climate Dynamics. 38(9-10). 1695-1702
[112] Tesfamariam, B. G., Gessesse, B., & Melgani, F. (2019). *Characterizing the spatiotemporal distribution of meteorological drought as a response to climate variability: The case of rift valley lakes basin of Ethiopia*. Weather and Climate Extremes, 26. https://doi.org/10.1016/j.wace.2019.10023
[113] Nicholson, Sharon E, David J Nash, Brian M Chase. (2013). *Temperature Variability over Africa during the Last 2000 Years*. HOLOCENE 23.8: 1085–1094
[114] Fazzini M, Bisci C, Billi P (2015). *The Climate of Ethiopia. Landscapes and Landforms of Ethiopia, World Geomorphological Landscapes*. Springer Science
[115] OCHA (2020) Ethiopia: Floods impact thousands of people. 29 May 2020. Access on 18.08.2020 https://www.unocha.org/story/ethiopia-floods-impact-thousands-people
[116] Kim,J., D.E.Waliser, C.A. Mattmann, C.E. Goodale,A.F. Hart, P.A. Zimdars, D.J. Crichton, C. Jones, G. Nikulin, B. Hewitson, C. Jack, C. Lennard, and A. Favre. (2013). *Evaluation of the CORDEX-Africa multi-RCM hindcast: systematic model errors*. Climate Dynamics, doi:10.1007/s00382-013-1751-7
[117] Ibid.

Model Intercomparison Project Phase 5 (CMIP5), includes more than 40 models from more than 20 modelling centres. Unsurprisingly, with such a disparate set of processes, locations, and variables, few models can stand out consistently, in either a positive or negative way, in such a variety of contexts[118]. GCM simulations show different results of climate change over northern Ethiopia. There are high levels of confidence in projecting future temperature increase over the region[119].. However, the climate change effects for precipitation might not be similar throughout this region. For instance, mean annual precipitation is expected to decrease[120] , increase[121] or remain unchanged[122], and both frequency and intensity of events exhibited much disparity[123].

It is difficult to apply the raw data of GCMs at a local scale without downscaling due to their relatively coarse resolution[124]. The CORDEX, or Coordinated Regional Climate Downscaling Experiment, offers global coordination for developing high-resolution climate projections and precipitation models by downscaling GCMs to Regional Climate Models (RCMs)[125]. However, a recent study[126] showed that downscaled precipitation models are often too sensitive to the relief for Northern Ethiopia. The simulated precipitation is too small for low-altitude areas and too large for high altitude areas.

In this ECA study, the local scale is less relevant as we are addressing two entire regions. We, therefore, recommend, based on the possible shortcomings of downscaling in low lands to use GCM outputs for future calculation of drought indices in CLIMADA. GCMs such as CGCM3[127] have recently shown good results for Ethiopia[128] and we recommend its utilization for the study.

3.1.5 Climate Scenario Definition

In this study, it is important to decide which scenarios and what GCMs should be used for future simulation. However, there is no consensus on which of the four Representative Concentration Pathways (RCPs; RCP2.6, RCP4.5, RCP6, or RCP8.5) is most likely; the IPCC considers all RCPs to be within the likely range of actual radiative forcing. Although RCP4.5 is widely used, we believe it would be prudent to plan for additional less optimistic scenarios. Henceforth, for this analysis, RCP4.5 and RCP8.5 were selected simply because they are most consistent. As discussed above, we suggest using CGCM3 whenever available for future simulation of precipitation and temperature within the drought model.

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[118] Rios, R., Taddia, A. and Grunwaldt, A. (2016). *Climate Change projections in Latin America and the Caribbean*. Report. IDB, New York. 32pp

[119] Teklesadik, A.D., T. Alemayehu, A. van Griensven, R. Kumar, S. Liersch, S. Eisner, J. Tecklenburg, S. Ewunte, X. Wang. (2017). *Inter-model comparison of hydrological impacts of climate change on the Upper Blue Nile basin using ensemble of hydrological models and global climate models*. Clim. Change, 141, pp. 517-532, 10.1007/s10584-017-1913-4

[120] Yimer, G., A. Jonoski, A.V. Griensven. (2009). *Hydrological response of a catchment to climate change in the upper Beles river basin, upper blue Nile, Ethiopia.* Nile Basin Water Eng. Sci. Manag., 2, pp. 49-59

[121] *S.G. Setegn, D. Rayner, A.M. Melesse, B. Dargahi, R. Srinivasan. (2011). Impact of climate change on the hydroclimatology of Lake Tana basin, Ethiopia.* Water Resour. Res., 47, Article W04511, 10.1029/2010WR009248 2011

[122] Hadgu, G., K. Tesfaye, G. Mamo. (2015). *Analysis of climate change in Northern Ethiopia: implications for agricultural production*. Theor. Appl. Climatol., 121 (3), pp. 733-747, 10.1007/s00704-014-1261-5

[123] Korecha, D., A. Sorteberg. (2013). *Validation of operational seasonal rainfall forecast in Ethiopia*. Water Resour. Res., 49, pp. 7681-7697, 10.1002/2013WR013760

[124] Feyissa, G., Zeleke, G., Bewket, W., & Gebremariam, E. (2018). *Downscaling of future temperature and precipitation extremes in Addis Ababa under climate change*. Climate, 6(3). https://doi.org/10.3390/cli6030058

[125] Pinto, I., Lennard, C., Tadross, M. (2016). *Evaluation and projections of extreme precipitation over southern Africa from two CORDEX models*. Climatic Change 135. 655–668. https://doi.org/10.1007/s10584-015-1573-1

[126] Van Vooren S, Van Schaeybroeck B, Nyssen J, Van Ginderachter M, Termonia P. (2019). *Evaluation of CORDEX rainfall in northwest Ethiopia : sensitivity to the model representation of the orography*. International Journal of Climatology. 2019; 39(5):2569–86.

[127] Third Version Coupled Global Climate Model (CGCM3): This is the third version of the Canadian Coupled Global Climate Model (CGCM3.1). The CGCM3 has a resolution of 3.75◦latitude and 3.75◦longitude.

[128] Feyissa et al. (2018)

3.2 Socio-economic Scenarios

3.2.1 Overview

The regions Afar and Somali comprise the two poorest regions of Ethiopia according to the 2016 Demographic and Health Survey[129] with 74.2% and 68.5% of the population in the lowest wealth quintile in Afar and Somali respectively. While in Ethiopia on average 52.2% and 72.4% of females and males (aged 15-49) have some form of formal education, the numbers in the two observed regions are much lower with 31.3% and 24.7% of females, and 54.5% and 55.2% of males in Afar and Somali respectively reporting some primary or higher form of formal education. In terms of occupation, two major differences exist. While the majority of women nationally are working in the agricultural sector (41.5%) with the second largest employer being the sales and services sector (36.8%) the order of those two sectors is reversed in both observed regions with 25.2% and 41.7% respectively in Afar, and 16.6% and 62.6% in Somali. For men, a similar pattern is noticeable on the national level, although with a more intense concentration in the agricultural sector with 71.7%. In the two regions, the agricultural sector is again, unsurprisingly, the major source of employment with 46.9% (Afar) and 44.9% (Somali). However, in both regions for men, there is no second sector standing dramatically. [130]

While in general polygynous unions declined in the past 20 years, 11% of women are reported to be in a polygynous union as in 2016; Afar as well as Somali lie above that average with 19% and 29% respectively, making Somali the regional state with the highest percentage.[131]

3.2.2 Population Growth Scenario

The most recent population census of the Ethiopian population was conducted by the Central Statistical Agency (CSA) of Ethiopia in 2007. In 2013 the CSA published their own Population Projections for Ethiopia for the period 2007 – 2037[132] including subnational estimates. Due to limitations in data availability, especially time-series data on key components of population projections such as age-specific mortality, fertility and (internal) migration rates, the CSA mentions in their report the limitations of the produced projections and recommends to interpret them rather as indications. This was also confirmed during interviews with CSA who confirmed that a follow-up census, planned for 2017, could not be implemented for several reasons, including the security situation in some parts of the country.

Based on this, the 2007 census builds the foundation of all major population. However, the population projection provided by the CSA does include sub-national projections on a regional level. Based on thorough literature review into population projection techniques with a focus on sub-national projections and the review of several typical sources of data it was concluded that the variety of variables such as age-specific fertility and mortality data or data on (internal) migration are not sufficiently available to perform reliable and robust population estimations. It was hence decided to rely on the

[129] Central Statistical Agence (CSA) [Ethiopia] and ICF. (2016). *Ethiopia Demographic and Health Survey 2016.* Addis Ababa, Ethiopia, and Rockville, Maryland, USA: CSA and ICF.
[130] Ibid.
[131] Ibid.
[132] Central Statistical Agency. (2013). *Population Projections for Ethiopia 2007 - 2037.* Addis Ababa.

available projections provided by the CSA. A detailed table for both regions is presented in ANNEX 1 (Table 4).

For both regions, a linear model is assumed based on CSA projections. To summarise the population estimates: For the Afar region the population growth rate is projected to continuously decrease from 3.02% in 2008 to 1.76% in 2030 and 1.35% in 2050 resulting in an average annual growth rate of 2.00%. This leads to an increase in the population from 1.377 million people in 2007 to 2.371 million in 2037 and a further estimate of roughly 3.228 million people in 2050 as presented in Figure 13.

A similar pattern is observed in the more populated Somali region. The growth rate is expected to continuously decrease from 2.63% in 2008 to 1.96% 2030 and 1.40% in 2050, or an average annual growth rate of 2.08%, resulting in an increase of population from 4.399 million to 7.697 million in the period between 2007 and 2030 and a further increase to 10.648 million in 2050 as shown in Figure 14.

The recommended population growth scenarios are therefore

- from 3.02% in 2008 to 1.76% in 2030 and 1.35% in 2050 for Afar (for annual rates see Table 4 in ANNEX 1), and
- from 2.63% in 2008 to 1.96% in 2030 and 1.40% in 2050 for Somali (for annual rates see Table 4 in ANNEX 1).

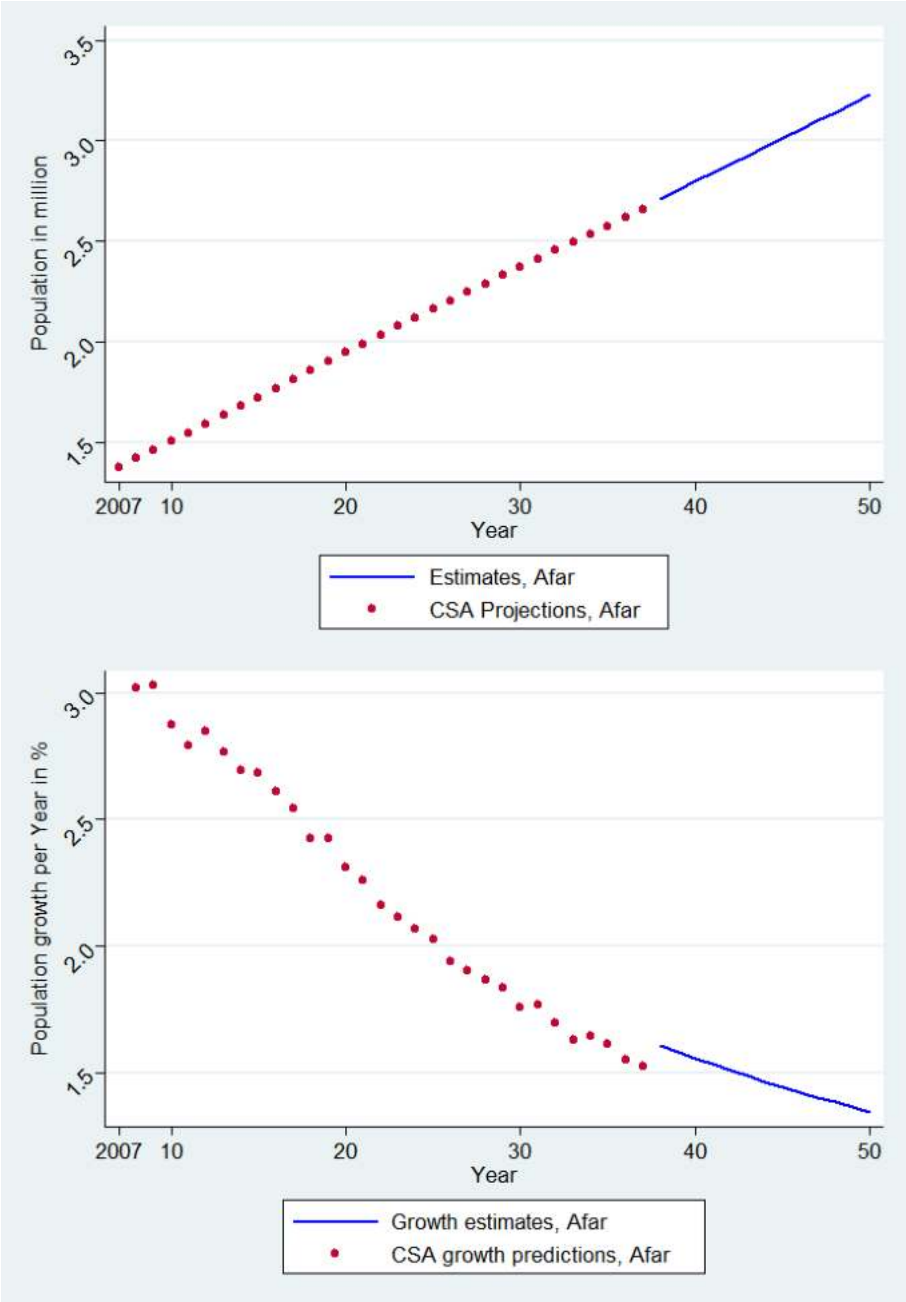

Figure 13: Population and Population Growth in Afar Region. Source: Own compilation based on data from CSA (2013).

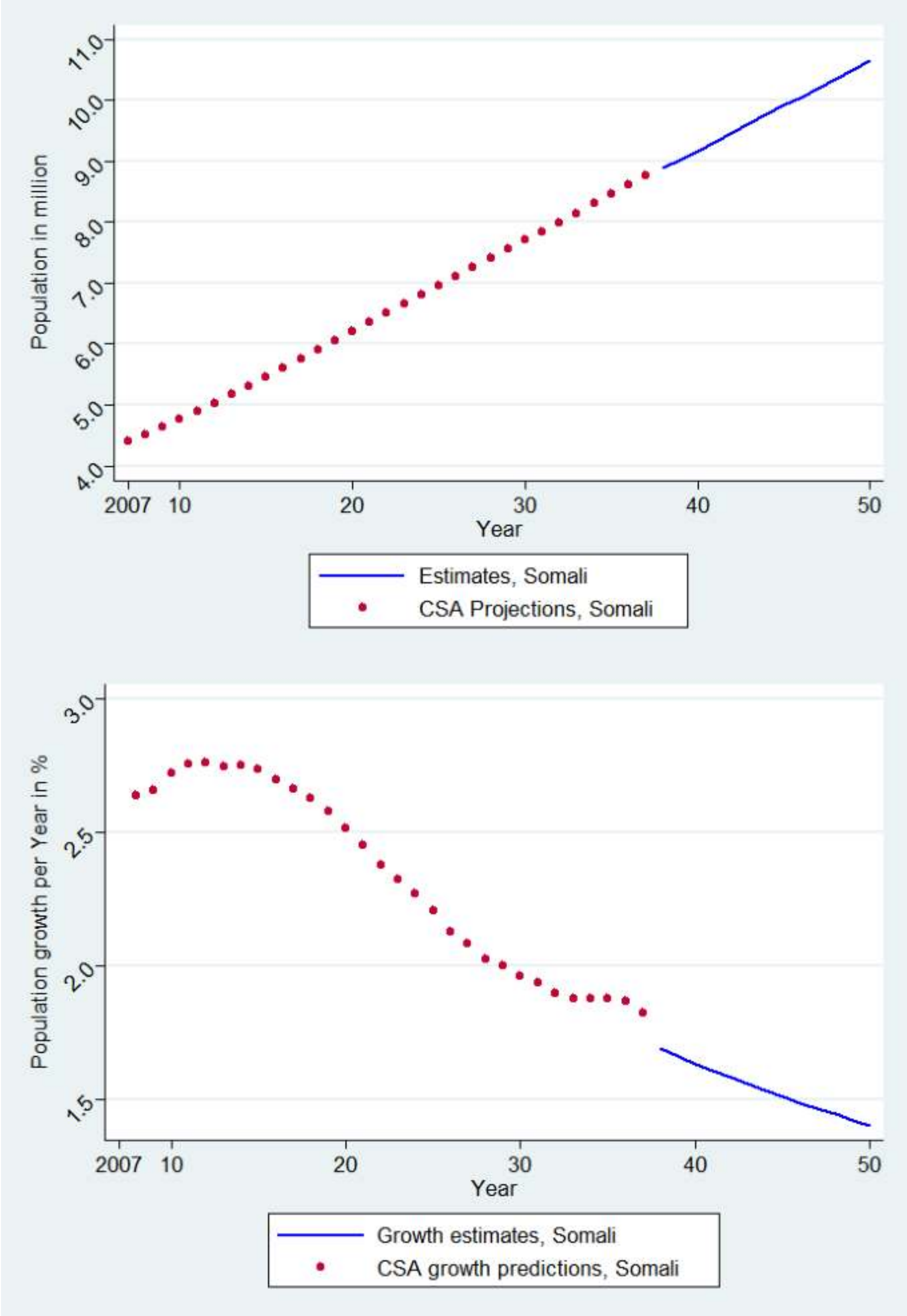

Figure 14: Population and Population Growth in Somali Region. Source: Own compilation based on data from CSA (2013).

3.2.3 Discount Rate Scenario

To approximate the discount rate in the two regions, publicly available reports provided by the CSA are used. Consumer price indices on the country and regional level are used to extract the monthly consumer price index (CPI) on the regional level between December 2006 and April 2019[133]. Since no seasonal pattern is detected in the data, a linear trend line is applied to estimate future values. Figure

[133] Central Statistical Agency (CSA). (2006-2018). *Country and Regional Level Consumer Price Indices*. Addis Ababa. Ethiopia. Available at: https://www.statsethiopia.gov.et/

15 (Afar) and Figure 16 (Somali) show future pathways (blue) for the CPI for both regions. The 95% prediction interval represented by the grey lines in the graphs shows the range in which the true value is expected to be with a probability of 95%. Based on that the average annual CPI growth rate in Afar is expected to decline slightly from 6.2% in 2018 and converge toward 4.00% in 2030 and 2.22% in 2050; in Somali a similar trend is expected from a growth rate of about 4.8% in 2018 toward 4.08% in 2030 and 2.23% in 2050 as shown in Figure 17 and Figure 18 respectively.

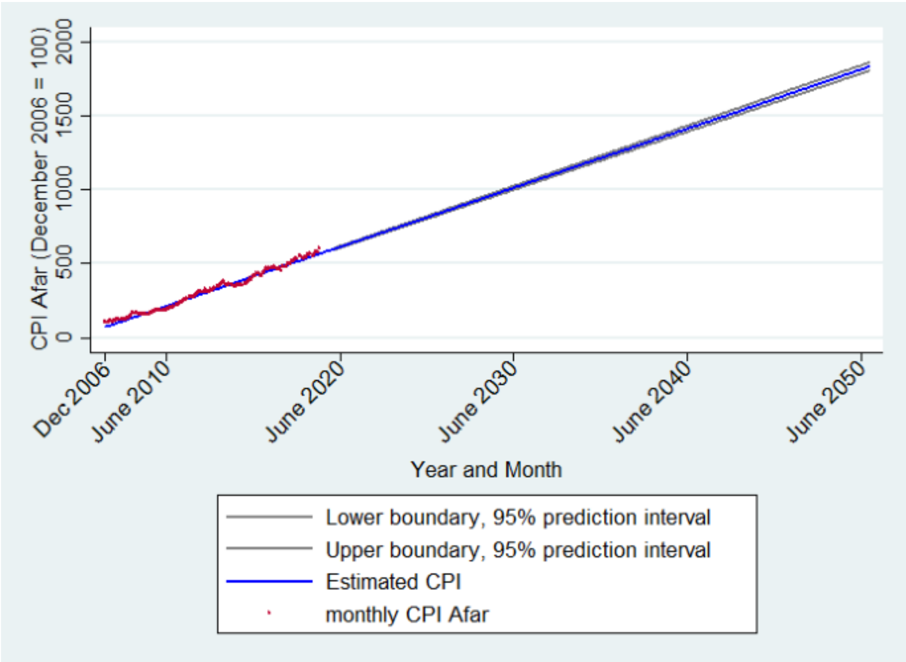

Figure 15: Actual and estimated monthly CPI in Afar Region. Source: Own compilation based on data provided by CSA (2006-2018).

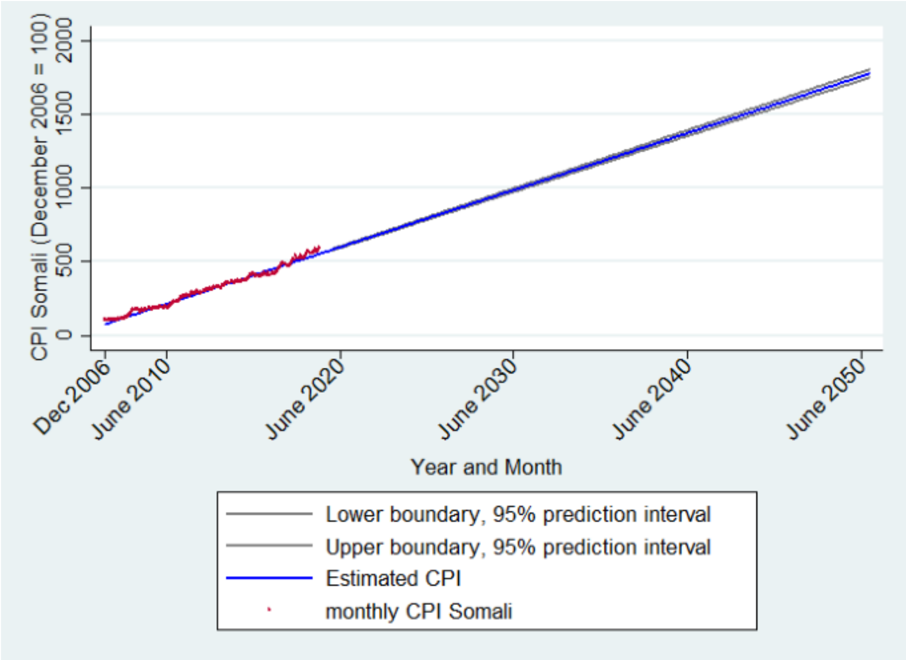

Figure 16: Actual and estimated monthly CPI in Somali Region. Source: Own compilation based on data provided by CSA (2006-2018).

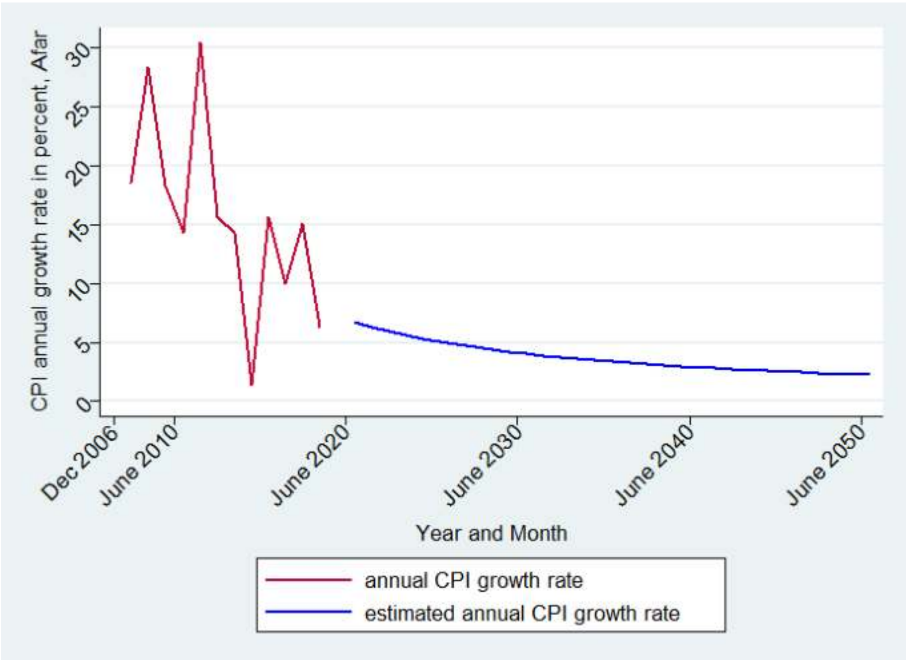

Figure 17: Average annual CPI growth rate, Afar. Source: Own compilation based on data provided by CSA (2006-2018).

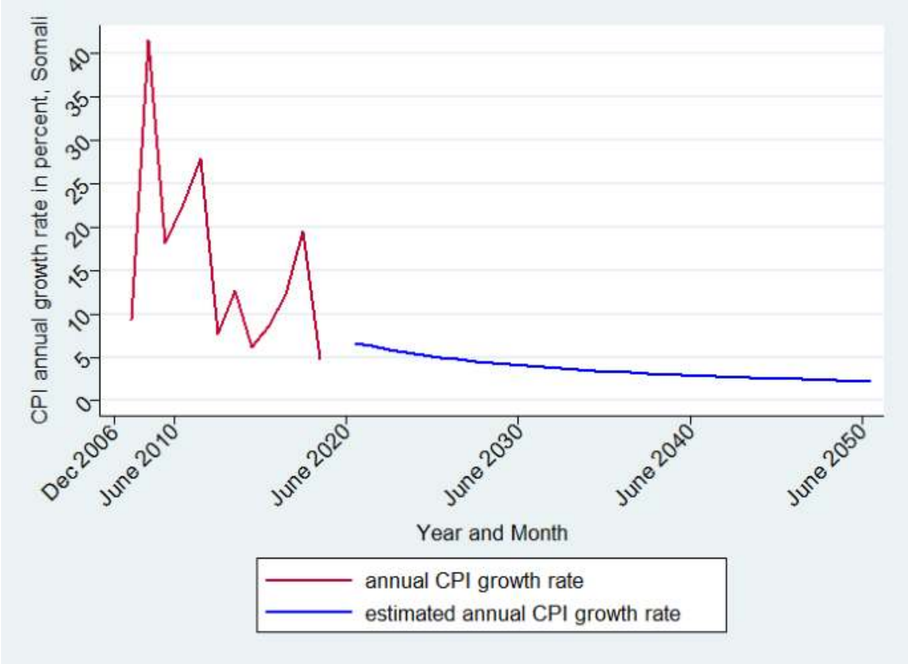

Figure 18: Average annual CPI growth rate, Somali. Source: Own compilation based on data provided by CSA (2006-2018).

3.2.4 Economic Growth Scenario

The case of economic growth in regions with a high degree of self-sufficiency is challenging. Economic growth measured by common indicators such as the gross domestic product (GDP) or the gross national income (GNI) has limited power. However, due to data scarcity and the limited capacity of CLIMADA to handle complex economic growth models (e.g. including detailed estimations of herd growth and composition or a shift in livelihood), we recommend a simple exponential projection of the national GDP for both regions. National annual data from the World Bank database[134] is used and approximated through an exponential function as presented in Figure 19 The approximation and the corresponding estimated future values follow a steady annual growth rate of about 5.82% of the actual 1981 GDP of 8.2 bn constant 2010 USD to an expected 91.6 bn constant 2010 USD in 2030 and 283.8 bn constant 2010 USD in 2050 which hence will be applied in CLIMADA.

[134] World Bank. (2020). *World Development Indicators*. *GDP (constant 2010 US$).* Retrieved 06.23.2020, from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD?locations=ET

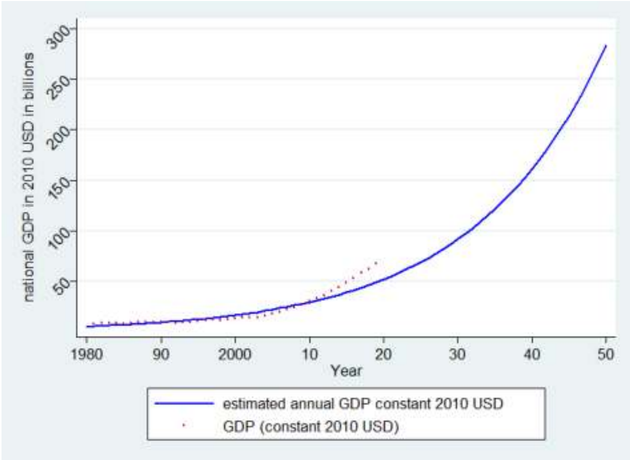

Figure 19: Actual and estimated national annual GDP in constant 2010 USD. UNU-EHS based on data from World Bank (2020).

3.2.5 Socio-economic Scenario Definition

Due to limited data, especially on the regional level, proxies estimates are applied for all relevant parameters of the socio-economic scenario in CLIMADA:

- For Afar:
  - Annual population growth rates from 3.02% in 2008 to 1.76% in 2030 and 1.35% in 2050,
  - Discount rates declining from 6.2% in 2018, 4.00% in 2030 and 2.22% in 2050, and
  - One constant economic growth rate of 5.82%.
- For Somali:
  - Annual population growth rates from 2.63% in 2008 to 1.96% in 2030 and 1.40% in 2050,
  - Discount rates declining from 4.8%, 4.03% in 2030 and 2.23% in 2050, and
  - One constant economic growth rate of 5.82%.

4 Data Collection and Evaluation

This section presents the availability of data necessary for this study. Different type of data is necessary and ranges from meteorological data, population data, asset and damage data, spatial data, socio-economic data to climate data. All data were subject to drastic quality control and stored in a dedicated database to avoid redundancy. Table 2 below presents the different data types along with their source, availability and an evaluation of their quality (green: good quality and suitable for the study; Yellow: Medium quality. Data needs to be updated; Red: Insufficient quality for the study). Where data is of insufficient quality or need additional work, we have indicated possible proxies and their sources. All proxies are acquired and are evaluated as of good quality for this study. In the case of this ECA study, almost all data were obtained from different online sources although literature, e.g. reports, provided by stakeholders interviewed in the aftermath of the Inception Workshop was relevant and helpful in finding suitable sources in most cases.

Additionally, a local field survey has been planned to ground proof the decisions taken during the Inception Workshop and the obtained data. It will further shed light on the affected people’s adaptation strategies on the local level. Following similar intentions some key informant interviews are being planned with representatives of the regional and the national government/ ministries and academics, again aiming at adaptation and mitigation (long-term) strategies on a higher level. Due to the restrictions of the COVID-19 containment measures and the recently evolving security concerns following the shooting of the musician Hachalu Hundessa and the following shut down of the internet the survey and interviews are being delayed while the situation is closely monitored.

Table 2: Summary of data collected, quality assessment and supplementary sources when relevant.

Data Item	Availability	Source	Quality	Proxy	Proxy Source
1. Impacts of past drought events					
1.1 Asset values					
1.1.1 Public assets: water resources & rangelands	No			- Proxies for asset valuation validated when possible with available local data	- scientific literature
1.1.2 Private assets					
Livestock (camels, sheep, cattle, goat)	Yes	- CSA annual livestock reports - USAID report : An Atlas of Ethiopian Livelihoods	The reports provide annual data on livestock (incl. birth rates, death and off take rates) at the regional level, for some years at the zonal too	- household survey by consultant will provide further data	
Crops	Yes	- Living Standards Measurements Survey 2015/16 (World Bank) - USAID report : An Atlas of Ethiopian Livelihoods	limited coverage of relevant regions, but covers key farming areas of regions and allows for reasonable assumptions of probable crop losses	- household survey by consultant will provide further data	
1.1.3 Population (local level)	Yes	OCHA Ethiopia	2020 projected sex and age disaggregated population by different administrative levels		
Census	Yes	CSA	Census of 2007, outdated but best available		
Distribution	Yes	Global Assessment Report 2015 by UNISDR	Note: Report is from 2015. (2017 version was reviewed but data was of lower quality)		
1.2 Historical damages					
1.2.1 Public assets: water resources & rangelands	No			- Proxies for asset valuation validated when possible with available local data	- scientific literature
1.2.2 Private assets					
Livestock (camels, sheep, cattle, goat)	Yes	CSA annual livestock reports	The reports provide annual data on livestock (incl. birth rates, death and off take rates) at the regional level, for some years at the zonal too		
Crops	Yes	Living Standards Measurements Survey 2015/16 (World Bank)	limited coverage of relevant regions, but covers key farming areas of regions and		- household survey by consultant will provide further data

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			allows for reasonable assumptions of probable crop losses		
1.2.3 Population (lives affected and lives lost due to drought, per event, woreda/kebele)	Yes	UNISDR and Ethiopian Government Agencies	provides data e.g. on affected people, houses, relocations		
1.3 Distribution of drought risk identified in previous studies (vulnerability map)	Yes	UNISDR and Ethiopian Government Agencies	provides data e.g. on affected people, houses, relocations, and affected crop, does not include livestock		
1.4 Contingency plans from regional and federal Government	No				Survey done by consultant
1.5 Distribution of drought during specific events identified in previous studies	No				Survey done by consultant
2. Remote sensing					
2.1 High resolution satellite images	No				Ad hoc
3. Climatology					
3.1 Precipitation	Yes	Data Library: UCSB CHIRPS v2p0 daily-improved global 0p05	Satellite data from CHIRPS		
3.2 Temperature	Yes	Data Library: FTP directory	Satellite data from CHIRPS		
3.3 Relative Humidity	Yes	NASA: MODIS Atmospheric Profiles	Satellite data from MODIS 7		
3.4 Evapotranspiration	Yes	The Climate Forecast System Reanalysis	The CRU TS4.04 data are monthly gridded fields based on monthly observational data calculated from daily or sub-daily data by National Meteorological Services and other external agents		
3.5 Water level	Yes	G-REALM USDA, ESA COPERNICUS	Several satellite missions Topex/Poseidon, Jason-1, Jason-2/OSTM Jason-3, ERS-1 and ERS-2, ENVISAT, SARAL, Sentinel-3A, Sentinel-3B		
3.6 Relative humidity	Yes	Goddard Satellite-based Surface Turbulent Fluxes Version 3	Satellite data from NCAR UCAR and AIRS2		
3.7 Wind speed	Yes	The Climate Forecast System Reanalysis	Satellite data from CFSR NOAA, TERRA CLIMATE and ADM AEOLUS ESA		

3.8 Soil moisture	Yes	ESA and/or NASA	ESA's SMOS satellite and ESA's historical ERS missions *11 satellite different sensors)		
3.9 Solar Radiation	Yes	GMS4, GMS5, GOES9, and MTSAT-1R TOMS/EP OMI/AURA TROPOMI	NASA, AERONET, NOAA, JAXA, JMA, ESA		
3.10 Dry Matter Productivity	Yes	Copernicus dekadel since 2014 via ESA or VITO	Sentinel Satellites.		
3.11 NDVI	Yes	NASA: MODIS Atmospheric Profiles	Satellite data from MODIS 7		
3.12 Reflectance	Yes	NASA: MODIS Atmospheric Profiles	Satellite data from MODIS 7 AVHRR		
4. Hydrology					
4.1 Water bodies	Yes	Humanitarian OpenStreetMap Team			
4.2 Types of soils	Yes	FAO	THE DIGITAL SOIL MAP OF THE WORLD; Version 3.6, completed January 2003		
5. Institutionality and governance					
5.1 Political-Administrative Division (Kebeles, Woredas, Regions)	Yes	OCHA Ethiopia			
6. Socio-economic factors					
6.1 Socio-economic census / wealth indicator	Yes	Demographic and Health Surveys (USAID), Living Standards Measurements Surveys (World Bank) and An Atlas of Ethiopian Livelihoods (CSA and USAID)	provide indicative information but not sufficient raw data to be representative for regions		
6.2 Employment / additional income sources	Yes	Demographic and Health Surveys (USAID), Living Standards Measurements Surveys (World Bank) and An Atlas of Ethiopian Livelihoods (CSA and USAID)	provide indicative information but not sufficient raw data to be representative for regions		
6.3 Evolution of wealth (GDP per capita / livestock & land ownership ...)					

GDP deflator	Yes	CSA reports "COUNTRY AND REGIONAL LEVEL CONSUMER PRICE INDICES"	regularly provide CPI data on regional level		
Economic growth	No			World Bank national GDP growth data are used to approximate economic growth	World Bank database
7. Households					
7.1 Type / size of settlements (e.g. urban vs rural)	Yes	Humanitarian OpenStreetMap Team	files on cadastre and environmental features are available		
7.2 Household conditions (number of members and housing conditions)	Yes	- Global Assessment Report 2015 by UNISDR - Living Standards Measurements Survey 2015/16 (World Bank)	on a 5x5km gird the income level of households is provided and used as approximation		
8. Areal patterns (GIS)					
8.1 Real land use / Land cover	Yes	Copernicus Global Land Service	Spatial information on different types of physical coverage of Africa's surface 2018. 100 m, in 20x20 degree tiles		
8.2 Topography	Yes	OCHA Ethiopia			
9. Cadastre and infrastructure (GIS)					
9.1 Land use (rangelands vs farm lands)	Yes	USAID report : An Atlas of Ethiopian Livelihoods	fair quality but best available		
9.2 Road system	Yes	Humanitarian OpenStreetMap Team	files on cadastre and environmental features are available		
10. Service Infrastructure (GIS)					
10.1 Health and education	Yes	Global Assessment Report 2015 by UNISDR	on a 5x5km gird the hospital beds per 1000 people and enrolment numbers are provided		
11. Strategies and policies of the regions					
11.1 Zoning of protected areas (GIS)	No				- Literature Review - part of consultant's deliverables through e.g. KII

11.2 Recovery of degraded ecosystems (bodies of water, green areas ...)	No				- Literature Review - part of consultant's deliverables through e.g. KII
11.3 Inventory of implemented measures to prevent and prepare for extreme events	No				- Literature Review - part of consultant's deliverables through e.g. KII
11.4 Contingency Plan of the regional + federal government	No				- Literature Review - to be delivered by local consultant
11.5 Community coping mechanisms and adaptation strategies	No				- Literature Review - to be delivered by local consultant

5 Conclusions and Next Steps

This report describes the state of data availability and data collection to run CLIMADA. It presents a general overview of the collected data, with a quality assessment regarding their usability for the ECA study, as well as the proposed proxies for those data sets that are insufficient for running CLIMADA or might lead to too high uncertainties in the final results. The inception phase of the ECA study in Ethiopia defined the scope, including hazards, key assets, and the time horizon (in this case two preliminary time horizons of 10 and 30 years are being considered) to be reflected in the study. This report documents and discusses data availability and quality for this purpose. Suggestions of possible proxies are made for unavailable data and data of insufficient quality. Although high-quality subnational data remain a challenge, the data presented here is of sufficient quality to successfully run CLIMADA. Further, this document showcases hazard and assets selections in the study area along with final recommendations for climate and socio-economic scenarios to be included in CLIMADA.

The overall results of the database report are summarised below:

1) A systematic review of available data and collection of proxies whenever necessary for running CLIMADA
2) Visualization and final recommendations on hazards and assets selection
3) Development of climate and socio-economic scenarios based on the latest research

Specific results of the report include:

Hazard: Droughts are selected and simulated for today and in the future for the whole area of both regions based.

Study Area: Since livestock and rangelands are considered key assets in this study and livestock are moving potentially freely within (and beyond) the observed regions the full area of both regions will be considered.

Time Horizon: As the planned Key Informant Interviews to confirm the time horizon could not take place yet as described in Chapter 4, we recommend considering a 10- year and 30- year time horizon.

Assets: Following the Inception Report, the assets listed below are supported by the collected data and displayed in this report:

- People
- Livestock
    - Camel
    - Cattle
    - Sheep
    - Goat
- Crops and Farmland

  - Sorghum, Maize, Millet
  - Wheat & Barley
  - Pulses
  - Oilseeds
  - Fruits & Vegetables
- Natural Resources
  - Rangelands
  - Water Resources

Data availability: The availability of the data is presented in this report. All data were subject to drastic quality control and stored in a dedicated database to avoid redundancy. We have selected and presented alternatives for missing data. In addition to the data gathered online from public sources, both a field survey and KIIs are planned to verify and ground proof of the data. The former will focus on assets, living conditions, experienced past damages and losses due to drought, and further on adaptation measures taken, both traditionally and non-traditionally, by the local population in the respective regions. This will add valuable information also for the later phase in which adaptation measures will be evaluated. The KIIs, take a focus on verifying the decision taken on the time horizon based on regional and national strategies and long-term plans as well as add to the list of measures from a different point of view.

Special note on COVID-19 risk assessment: In the current pandemic context, the ECA Study Team has conducted a thorough risk assessment for the project. According to our current knowledge we estimate how the current situation might impact the timeline and deliverable of the ECA study in Ethiopia. A separated detailed brief will be shared with stakeholders. The overall risk assessment level is estimated to be “medium” with an expected 3-4 months delay compared to the initial schedule. Delays are mostly caused by travel restrictions. We offer several mitigation options including digital workshops and delayed final delivery workshops. An updated time plan is provided below (see Table 3).

Concrete next steps include:

Data Validation Workshop: a short online workshop will take place in August 2020 to inform about the development of the ECA study in Ethiopia. In case an online workshop will not be feasible (i.e. due to internet blockades or limited bandwidth) alternative modes are being evaluated.

A long list of adaptation measures: A long list of possible adaptation measures will be prepared and discussed with stakeholder during a short online workshop in August 2020. After this workshop, a shortlist of measures will be selected for introduction into CLIMADA.

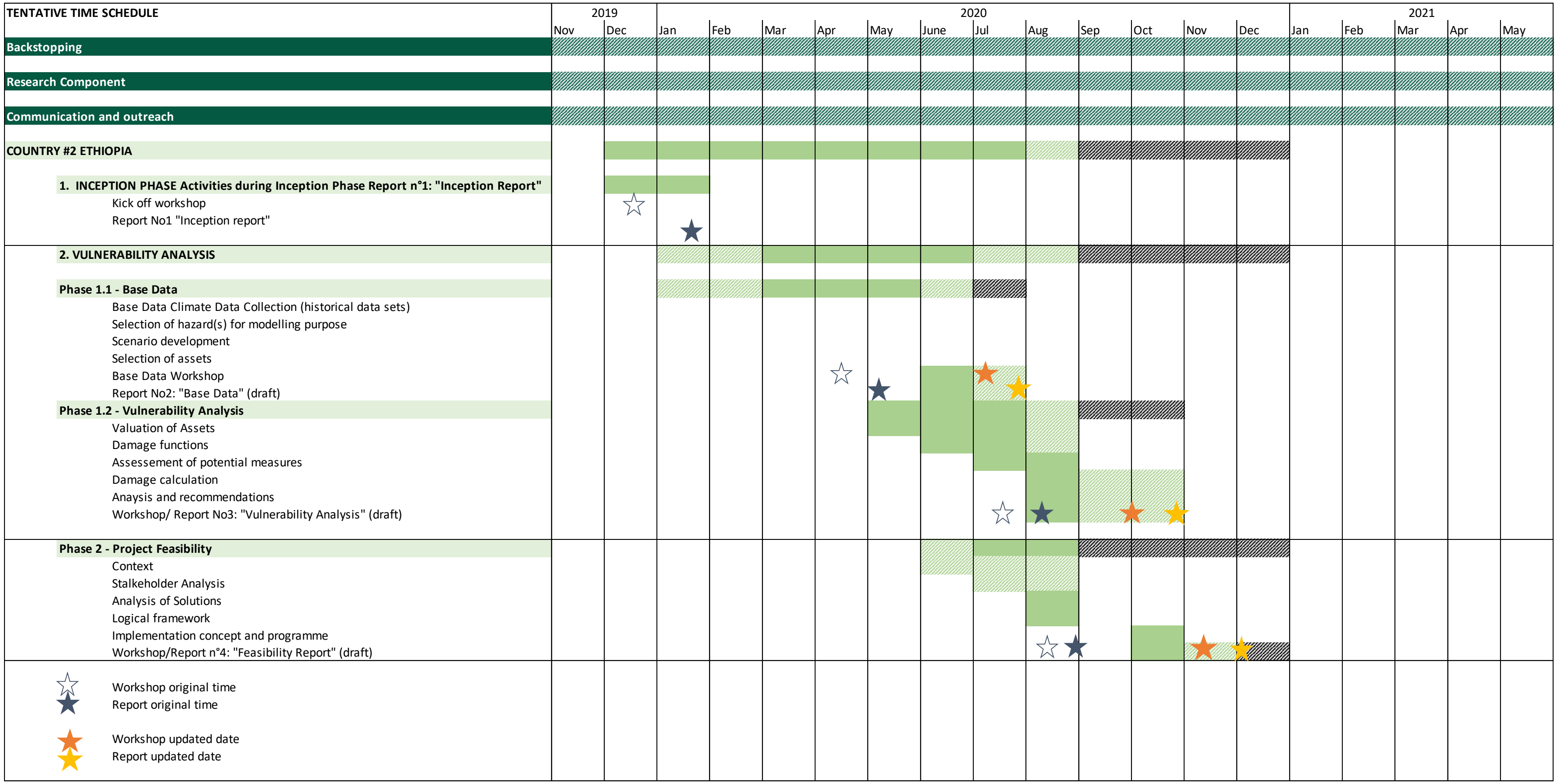
Valuation of assets: Selected assets will be given monetary values, using different methods. Values and methods will be documented in the vulnerability report.

Damage functions: Using available historical damages, desk research and expert interviews, the relationship between drought and the potential damage will be quantified by so-called damage functions. Details about damages functions will be explained in the vulnerability report.

Simulation in CLIMADA: In this step, assets values and location, as well as damage functions, will be introduced in CLIMADA for simulation. The drought model will be validated as a next step. Adaptation measures and climatic and socio-economic scenarios are also added to the model. Calibration and validation of the model are essential steps that will be performed, using historical events. Simulation of future drought events will document the effectiveness of the shortlist of adaptation measures.

Vulnerability Report (October 2020, UNU-EHS): The vulnerability report is expected to be circulated in October 2020. It will include the simulations and results of CLIMADA, the results of the drought model, and a ranking of recommended adaptation measures for Afar and Somali. It details decisions made for every step and makes recommendations on the best measures. Uncertainties linked to the modelling exercise are also discussed.

Table 3: Updated time plan of the ECA Study in Ethiopia with the original main milestones and expected delays (hatched)



Annexes

Economics of
Climate
Adaptation

ANNEX 1 – Socio – Economic Scenario Details

Table 4: Annual values of socio- economic scenario parameters. Cursive values are estimates produced by the Authors.

Year	Afar Total Population (in million)	Afar Population Growth	Somali Total Population (in million)	Somali Population Growth	Estimated CPI growth Afar	Estimated CPI growth Somali
2007	1,377		4,399		9,40%	18,50%
2008	1,419	3,02%	4,515	2,63%	41,59%	28,35%
2009	1,462	3,03%	4,635	2,66%	18,14%	18,34%
2010	1,504	2,87%	4,761	2,72%	22,68%	14,33%
2011	1,546	2,79%	4,892	2,75%	27,88%	30,47%
2012	1,590	2,85%	5,027	2,76%	7,73%	15,64%
2013	1,634	2,77%	5,165	2,75%	12,63%	14,25%
2014	1,678	2,69%	5,307	2,75%	6,22%	1,43%
2015	1,723	2,68%	5,452	2,73%	8,53%	15,58%
2016	1,768	2,61%	5,599	2,70%	12,18%	10,01%
2017	1,813	2,55%	5,748	2,66%	19,47%	15,05%
2018	1,857	2,43%	5,899	2,63%	4,78%	6,25%
2019	1,902	2,42%	6,051	2,58%	*7,14%*	*7,24%*
2020	1,946	2,31%	6,203	2,51%	*6,66%*	*6,75%*
2021	1,990	2,26%	6,355	2,45%	*6,25%*	*6,32%*
2022	2,033	2,16%	6,506	2,38%	*5,88%*	*5,95%*
2023	2,076	2,12%	6,657	2,32%	*5,55%*	*5,61%*
2024	2,119	2,07%	6,808	2,27%	*5,26%*	*5,31%*
2025	2,162	2,03%	6,958	2,20%	*5,00%*	*5,05%*
2026	2,204	1,94%	7,106	2,13%	*4,76%*	*4,80%*
2027	2,246	1,91%	7,254	2,08%	*4,54%*	*4,58%*
2028	2,288	1,87%	7,401	2,03%	*4,35%*	*4,38%*
2029	2,330	1,84%	7,549	2,00%	*4,16%*	*4,20%*
2030	2,371	1,76%	7,697	1,96%	*4,00%*	*4,03%*
2031	2,413	1,77%	7,846	1,94%	*3,84%*	*3,87%*
2032	2,454	1,70%	7,995	1,90%	*3,70%*	*3,73%*
2033	2,494	1,63%	8,145	1,88%	*3,57%*	*3,59%*
2034	2,535	1,64%	8,298	1,88%	*3,45%*	*3,47%*
2035	2,576	1,62%	8,454	1,88%	*3,33%*	*3,35%*
2036	2,616	1,55%	8,612	1,87%	*3,22%*	*3,24%*
2037	2,656	1,53%	8,769	1,82%	*3,12%*	*3,14%*
2038	*2,713*	*1,61%*	*8,878*	*1,69%*	*3,03%*	*3,05%*
2039	*2,756*	*1,58%*	*9,026*	*1,66%*	*2,94%*	*2,96%*
2040	*2,799*	*1,56%*	*9,173*	*1,63%*	*2,86%*	*2,87%*
2041	*2,842*	*1,54%*	*9,321*	*1,61%*	*2,78%*	*2,79%*
2042	*2,884*	*1,51%*	*9,468*	*1,58%*	*2,70%*	*2,72%*
2043	*2,927*	*1,49%*	*9,616*	*1,56%*	*2,63%*	*2,64%*
2044	*2,970*	*1,47%*	*9,763*	*1,53%*	*2,56%*	*2,58%*
2045	*3,013*	*1,45%*	*9,911*	*1,51%*	*2,50%*	*2,51%*

2046	*3,056*	*1,43%*	*10,058*	*1,49%*	*2,44%*	*2,45%*
2047	*3,099*	*1,41%*	*10,206*	*1,47%*	*2,38%*	*2,39%*
2048	*3,142*	*1,39%*	*10,353*	*1,45%*	*2,33%*	*2,34%*
2049	*3,185*	*1,37%*	*10,501*	*1,42%*	*2,27%*	*2,28%*
2050	*3,228*	*1,35%*	*10,648*	*1,40%*	*2,22%*	*2,23%*
Annual average / Mean of projection		2,00%		2,08%	3.82%	3.79%
Median of projection		1.47%		1.53%	3.41%	3.39%
Standard Deviation of projection		0.08%		0.09%	1.41%	1.38%

ANNEX 2 – Special Notes on the invasive species Prosopis Juliflora

Prosopis juliflora (hereafter referred to as Prosopis) is a group of closely related woody plant species and hybrids that were first introduced to the Afar region by the Ethiopian government in the late 1970s and early 1980s to combat desertification. By 2006, approximately 700,000 ha of land had been taken over by Prosopis, out of which more than 70% is located in the Afar region.[135] Prosopis was introduced for different environmental and socio-economic benefits, however, it became invasive in many places and is increasingly known for its negative ecological and socio-economic impacts[136,137].

Proposis has been reported to offer significant ecosystem and livelihood services such as microclimate regulation (e.g. as a shade tree or windbreak), improvement of soil fertility, reclaiming saline and alkaline soils, fuelwood and charcoal source, construction material, and income and livelihood diversification[138,139].

For example, many Acacia spp. trees have not been capable of surviving in the Afar region in times of acute shortage of water, whereas Prosopis shows the ability to develop a deep root network, enabling them to survive in drylands. Besides, pods from Prosopis can also be a nutritious source of food for people and especially a low cost and alternative feed ingredient for livestock. Some studies also found that the nitrogen level and the moisture content in soils of highly Prosopis infested areas were 23% and 11% to 13% for non-invested areas of Prosopis.[140] These levels are more than twice as high compared to those of low or non-infested areas.

After its introduction, Prosopis started escaping from the plantations and invading the surrounding natural and semi-natural ecosystems, thereby threatening biodiversity, reducing fodder for livestock production and causing groundwater depletion[141]. Recent studies have shown that the Prosopis invasion rate is increasing, suppressing indigenous plants, while negatively affecting human health as well as livestock production. For example, the Afar people are highly dependent on the Awash River flood plain for grazing their livestock during the drought periods and for small-scale irrigation. This important ecosystem is increasingly invaded or under risk of invasion by Prosopis and limits access to watering points and grazing lands, but also provides cover for wild predatory[142]. Seeds of Prosopis can survive in livestock and warthogs' droppings and therefore serve as a vehicle for the plant to reach distant areas to have unchecked expansion throughout the region[143].

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135 Ilukor J, Rettberg S, Treydte A, Birner R. (2016). *To eradicate or not to eradicate?: Recommendations on Prosopis juliflora management in Afar, Ethiopia, from an interdisciplinary perspective*. Pastoralism 6:271.
https://doi.org/10.1186/s13570-016-0061-1

136 Shiferaw H, Bewket W, Alamirew T, Zeleke G, Teketay D, Bekele K, Schaffner U, Eckert S. (2019). *Implications of land use/land cover dynamics and Prosopis invasion on ecosystem service values in Afar Region, Ethiopia*. Sci Total Environ 675:354–366.
https://doi.org/10.1016/j.scitotenv.2019.04.220

137 Bekele K, Haji J, Legesse B, Schaffner U. (2018). *Economic impacts of Prosopis spp. invasions on dryland ecosystem services in Ethiopia and Kenya: Evidence from choice experimental data.* Journal of Arid Environments 158:9–18.
https://doi.org/10.1016/j.jaridenv.2018.07.001

138 Ilukor et al. (2016)

139 Mehari ZH. (2015). *The invasion of Prosopis juliflora and Afar pastoral livelihoods in the Middle Awash area of Ethiopia*. Ecol Process 4:173. https://doi.org/10.1186/s13717-015-0039-8

140 Ilukor et al. (2016)

141 Bekele K, Haji J, Legesse B, Schaffner U. (2018). *Economic impacts of Prosopis spp. invasions on dryland ecosystem services in Ethiopia and Kenya: Evidence from choice experimental data*. Journal of Arid Environments 158:9–18.
https://doi.org/10.1016/j.jaridenv.2018.07.001

142 Ilukor et al. (2016)

143 Mehari ZH (2015). *The invasion of Prosopis juliflora and Afar pastoral livelihoods in the Middle Awash area of Ethiopia.* Ecol Process 4:173. https://doi.org/10.1186/s13717-015-0039-8

Prosopis negatively affects the native flora by invading grasslands, shrub-lands, and woodlands (see Table 5 below).

Table 5: Plant species most affected by Prosopis. Source: Mehari ZH (2015) & Ilukor et al. (2016)

Grasses/ herbs[144]	**Trees** (native and browseable) [145]
Cymbopogon pospischilii	*Acacia tortilis*
Chrysopogon spp.	*Acacia senegal*
Andropogon canaliculatus	*Acacia nilotica*
Eragrostis cylindriflore	Combretum aculeatum
Terapogon cenchriformis	*Cadaba rotundifolia*
Cyndon dactylon	*Salvadora persica*
Setaria spp.	
Cenchrus spp.	
Hyparrhenia spp	

Nonetheless, the negative effects of Prosopis outweigh its positive effects, and appropriate silvicultural management is advised to adverse the negative effects on native species. One aspect of Prosopis eradication is the relative high level of labour and finance input for densely invaded areas. Some areas are ecologically more suitable than others for Prosopis. It is therefore recommended to manage areas that have been invaded rather recently consisting of selective and intense removal[146]. Especially in semi-arid and arid ecosystems, to avoid disservice of ecosystem services during the removal of Prosopis. Restoration of indigenous trees should be done in parallel with the reduction of Prosopis populations[147].

[144] Ibid.
[145] Wakie TT, Laituri M, Evangelista PH. (2016). *Assessing the distribution and impacts of Prosopis juliflora through participatory approaches.* Applied Geography 66:132–143. https://doi.org/10.1016/j.apgeog.2015.11.017
[146] Shiferaw W, Bekele T, Demissew S, Aynekulu E. (2019*). Prosopis juliflora invasion and environmental factors on density of soil seed bank in Afar Region, Northeast Ethiopia.* j ecology environ 43:e0193752. https://doi.org/10.1186/s41610-019-0133-4
[147] Bekele K, Haji J, Legesse B, Schaffner U. (2018). *Economic impacts of Prosopis spp. invasions on dryland ecosystem services in Ethiopia and Kenya: Evidence from choice experimental data.* Journal of Arid Environments 158:9–18. https://doi.org/10.1016/j.jaridenv.2018.07.001

ANNEX 3: Maps in Higher resolution

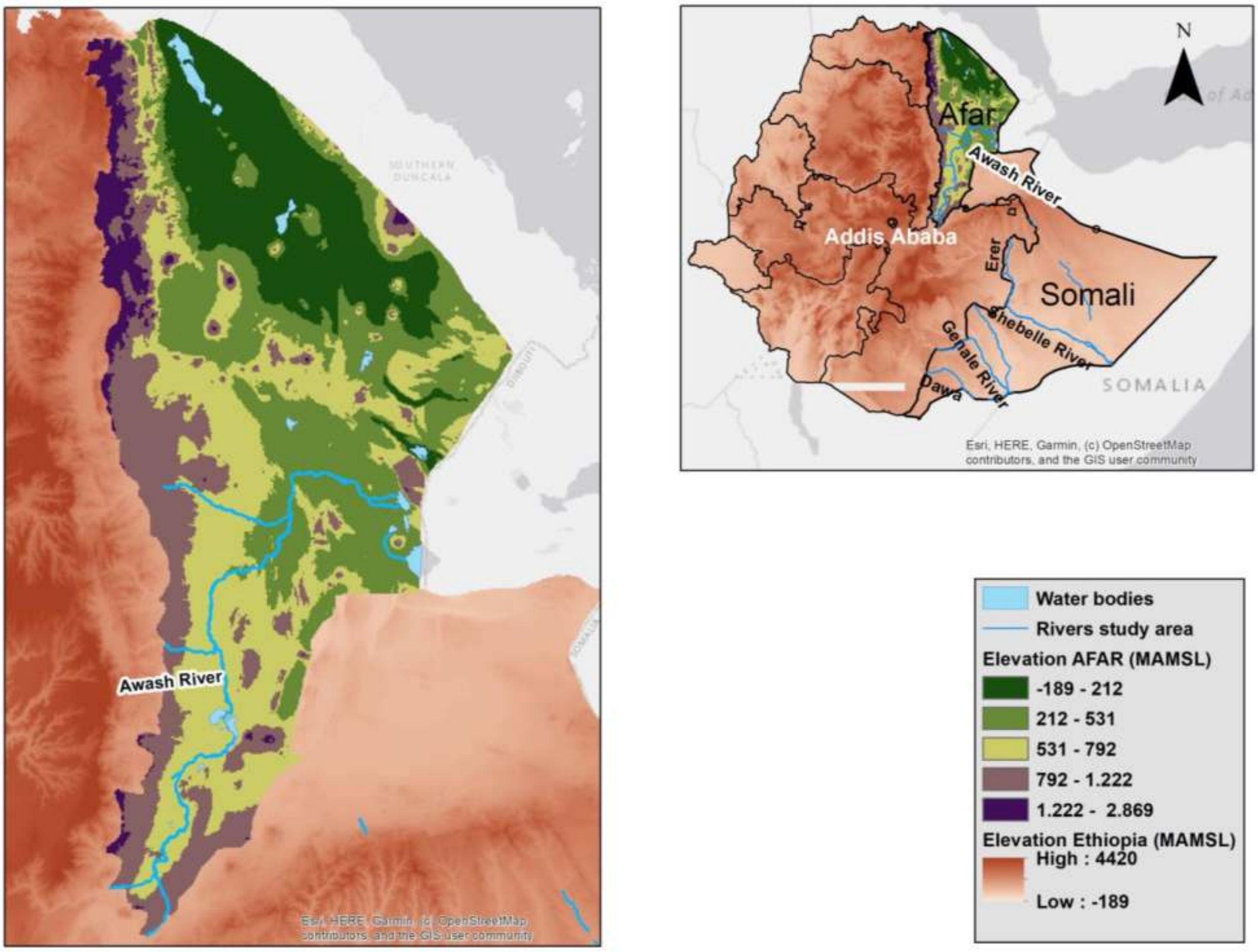

FIGURE 1: TOPOGRAPHY OF AFAR. SOURCE: BASED ON DATA BY OCHA ETHIOPIA (2018)

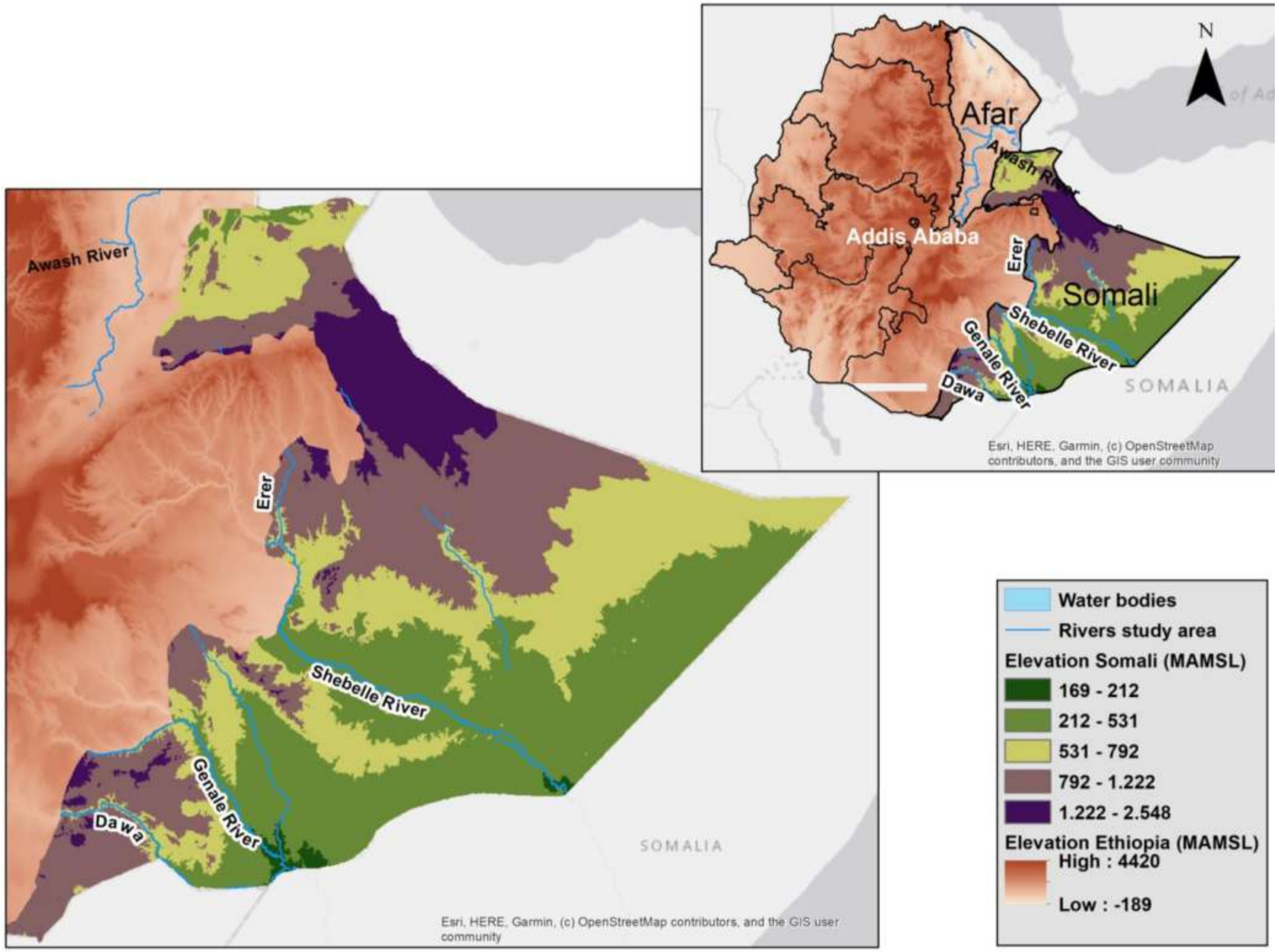

FIGURE 2: TOPOGRAPHY OF SOMALI. SOURCE: BASED ON DATA BY OCHA ETHIOPIA (2018)

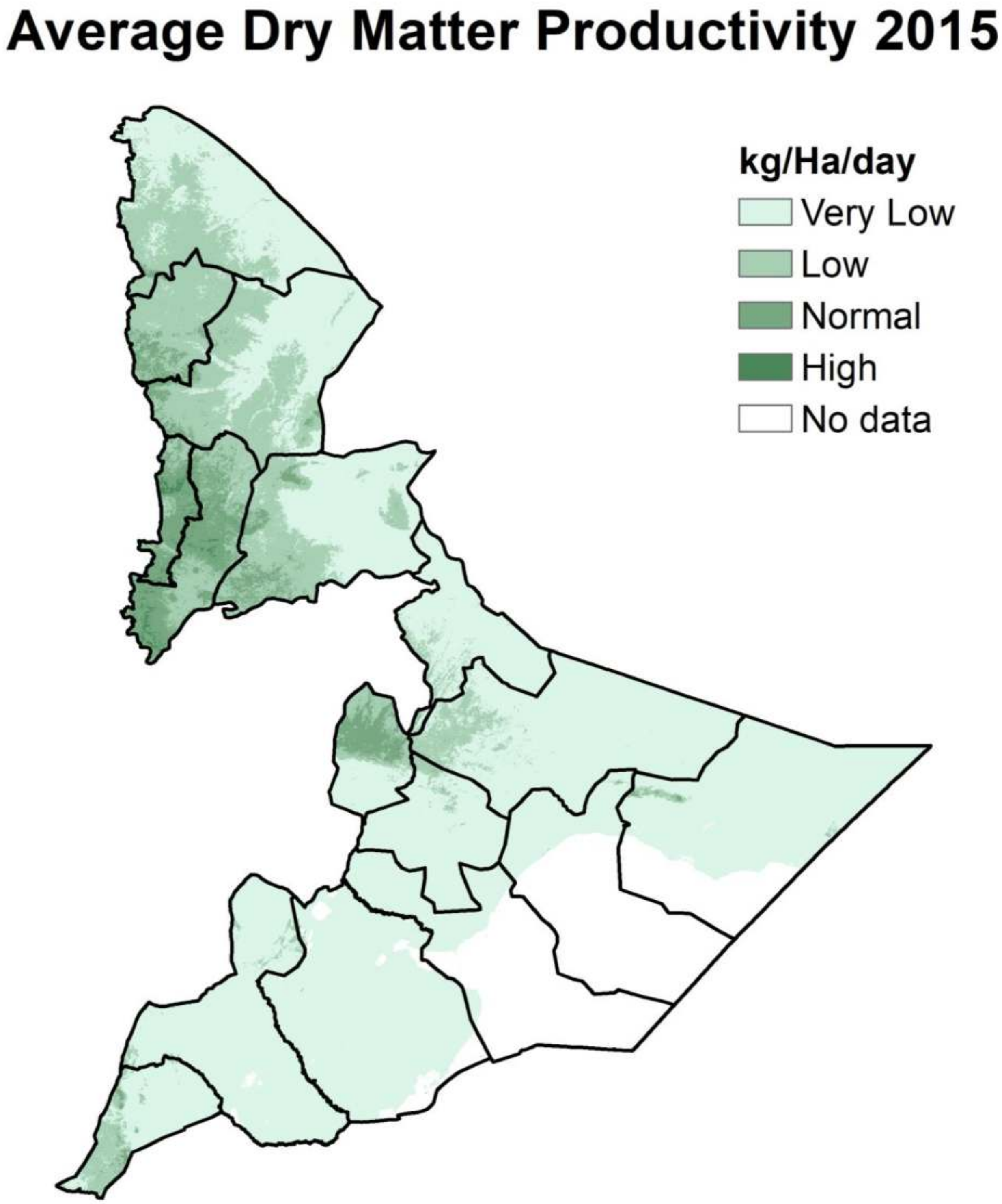

FIGURE 4: Average DMP distribution in 2015 for Afar and Somali; Source: Based on data by from Copernicus Services. Categories: 0 – 23 kg/Ha/Day (very low), 23 – 46 (low), 46 – 92 (normal), 92 - 148 (high), 148-320 (very high)

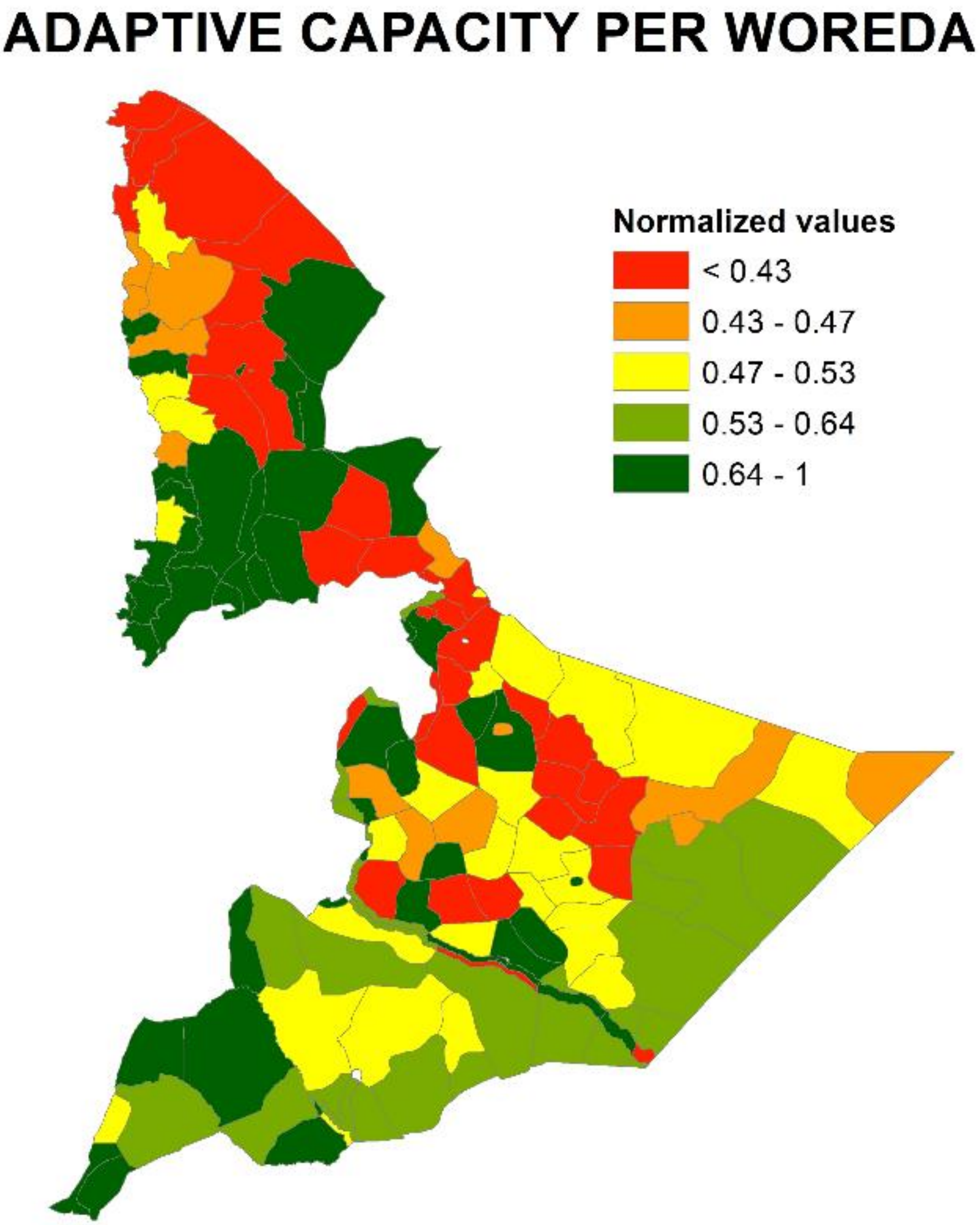

FIGURE 5: ADAPTIVE CAPACITY INDICATOR ON THE WOREDA LEVEL. SOURCE: UNU-EHS.

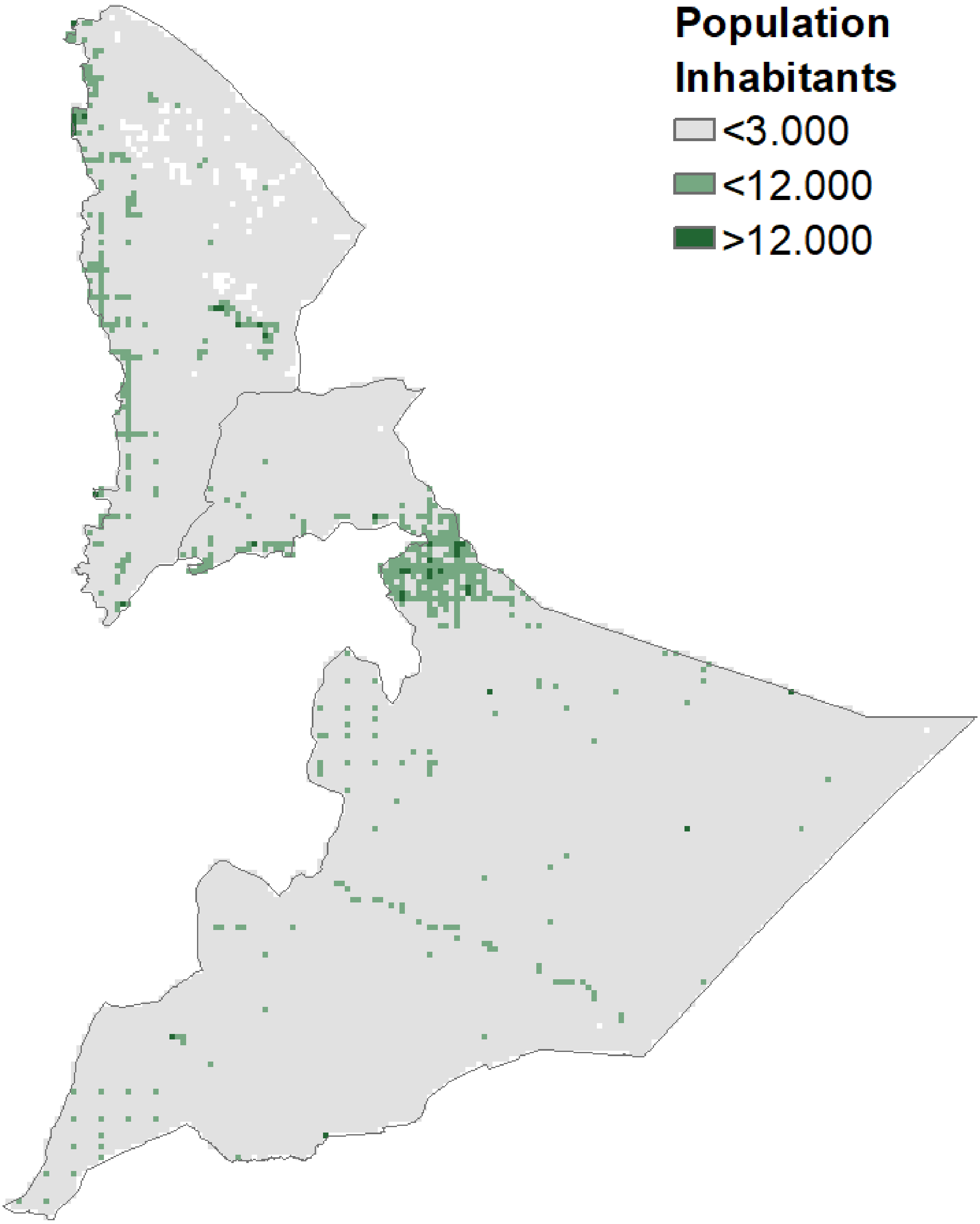

FIGURE 6: POPULATION DENSITY ON A 5X5KM GRID. SOURCE: UNU-EHS BASED ON DATA BY UNDRR (2015).

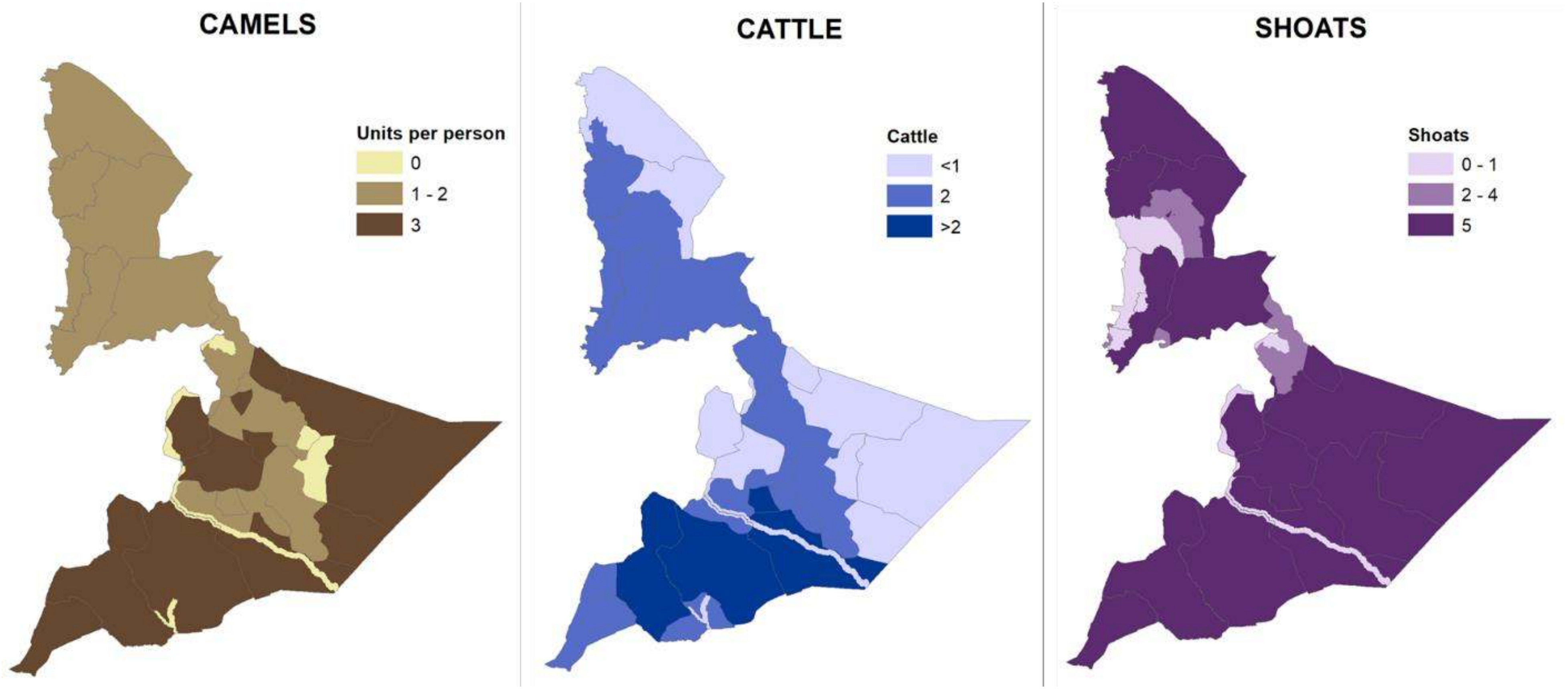

FIGURE 7: CAMELS, CATTLE AND SHOATS (GOATS AND SHEEP) HELD PER PERSON. SOURCE: UNU-EHS BASED ON USAID AND THE GOVERNMENT OF ETHIOPIA. (2010).

TROPICAL LIVESTOCK UNITS (TLU)

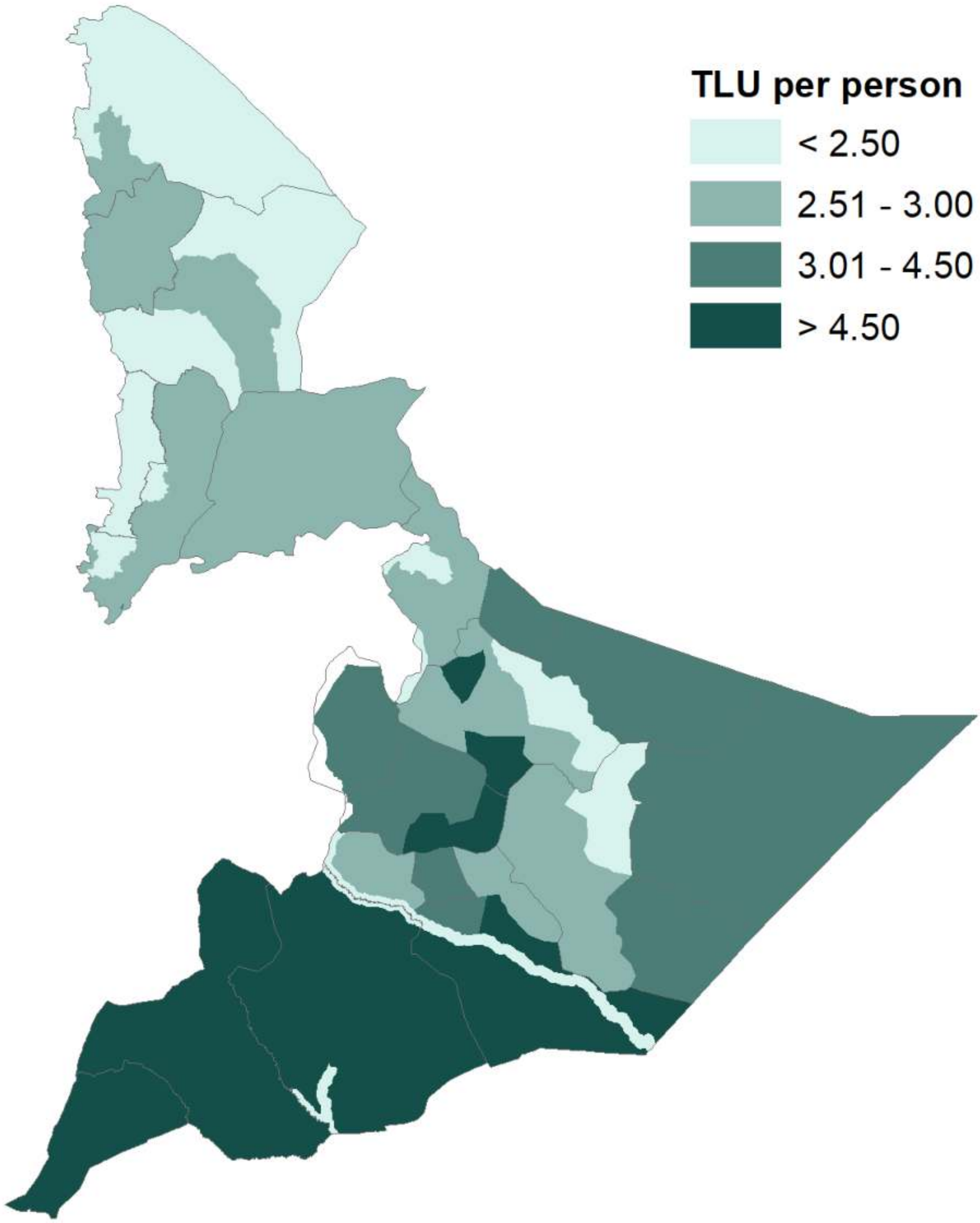

FIGURE 8: AVERAGE NUMBER OF TLU HELD PER PERSON. SOURCE: UNU-EHS BASED ON USAID AND THE GOVERNMENT OF ETHIOPIA. (2010).

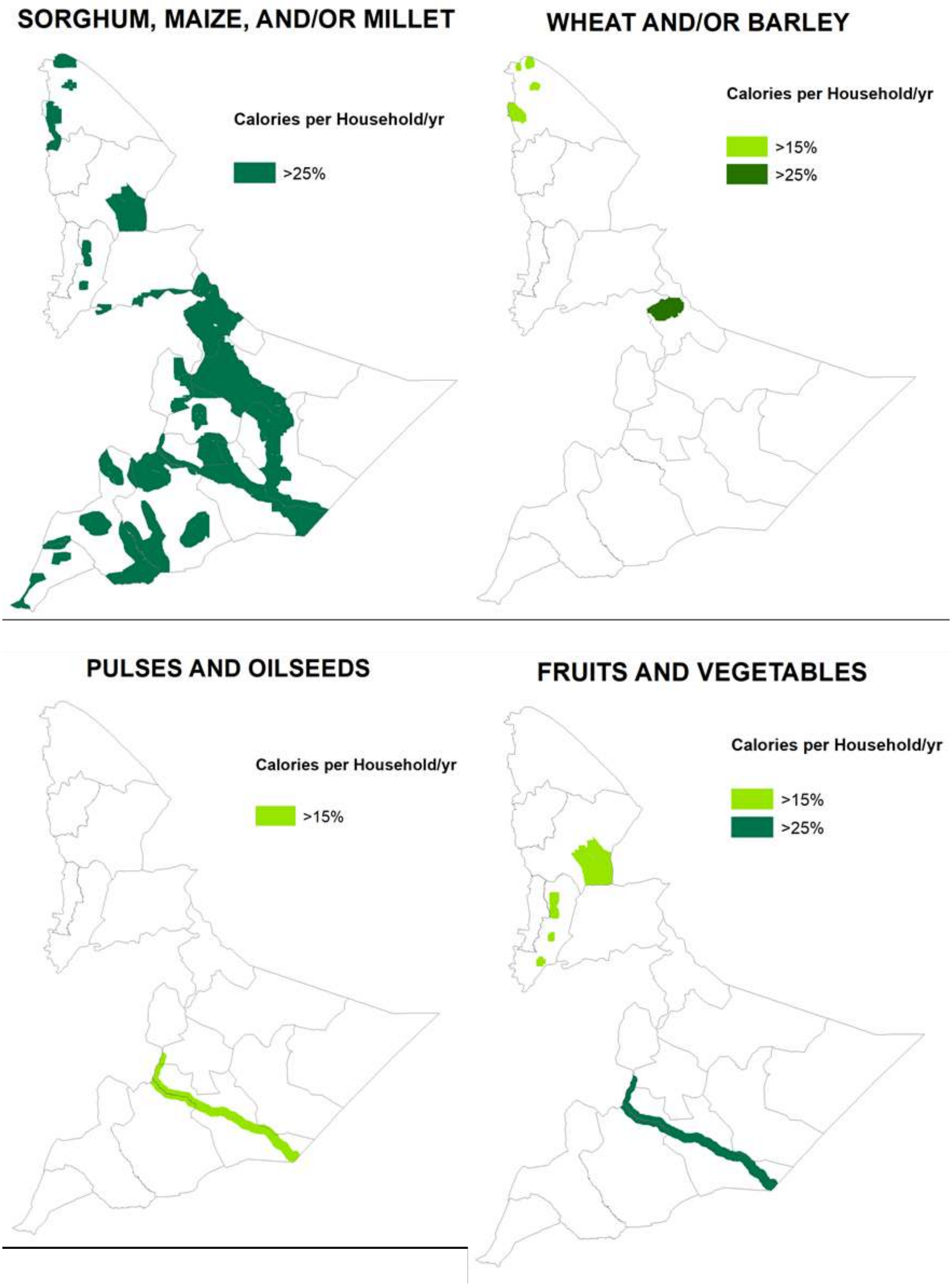

FIGURE 9: CROPS GROWN IN AFAR AND SOMALI REGIONS BY PERCENTAGE OF MINIMUM CALORIES REQUIRED PER HOUSEHOLD PER YEAR (WHITE <5%, LIGHT GREEN 5-25%, DARK GREEN >25%).

LAND COVER

Land cover classification	Afar (95,529 km^2)	Somali (314,153 km^2)
Forest	1.66%	6.35%
Shrubland	20.12%	77.34%
Herbaceous vegetation	23.26%	9.91%
Herbaceous wetland	0.22%	0.02%
Cropland	1.72%	1.00%
Bare / sparse vegetation	52.26%	5.37%
Built-up	0.01%	0.01%
Permanent water bodies	0.75%	0.00%

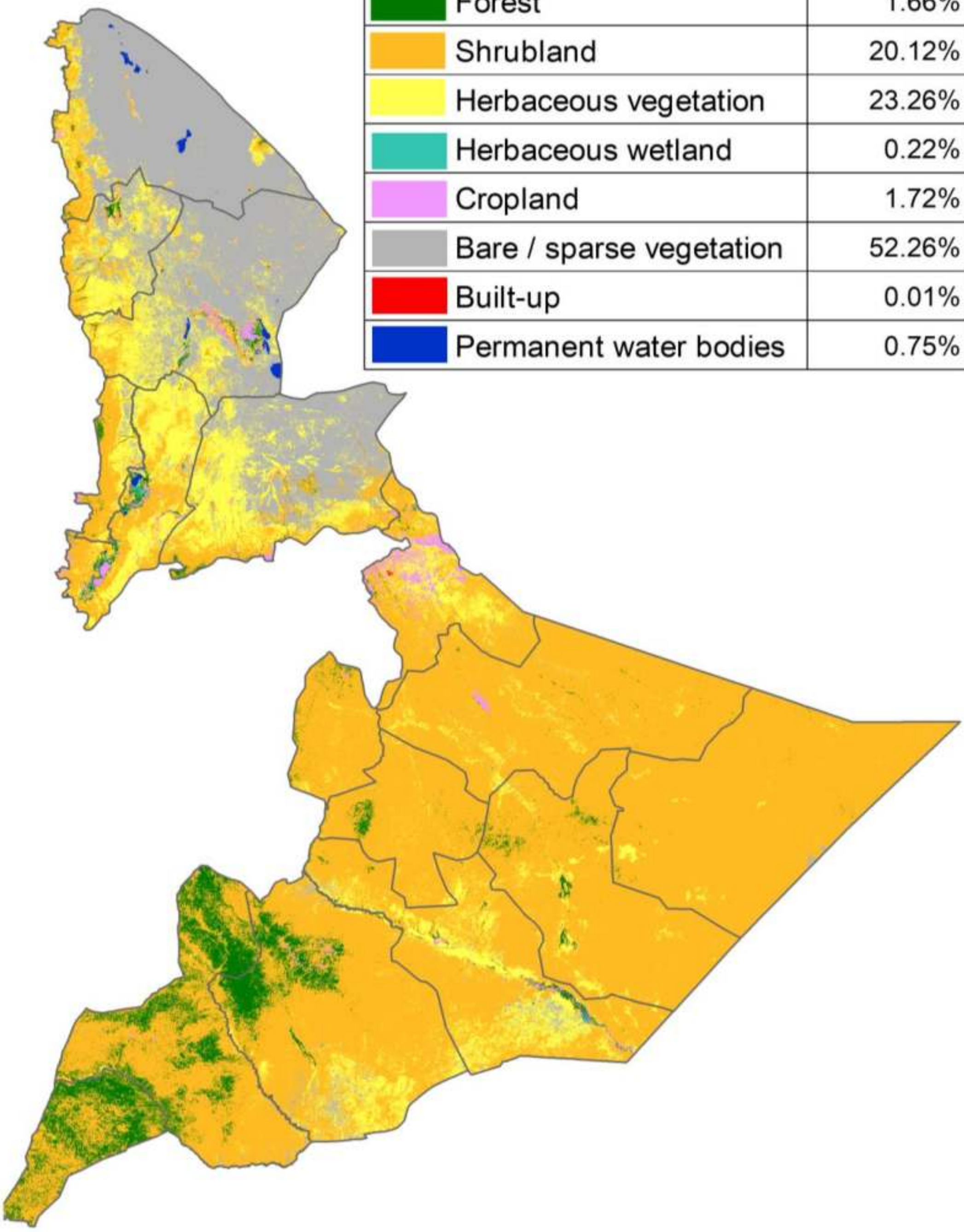

FIGURE 10: LAND COVER IN AFAR AND SOMALI. SOURCE: UNU-EHS BASED ON DATA PROVIDED BY COPERNICUS GLOBAL LAND SERVICE. (2020).

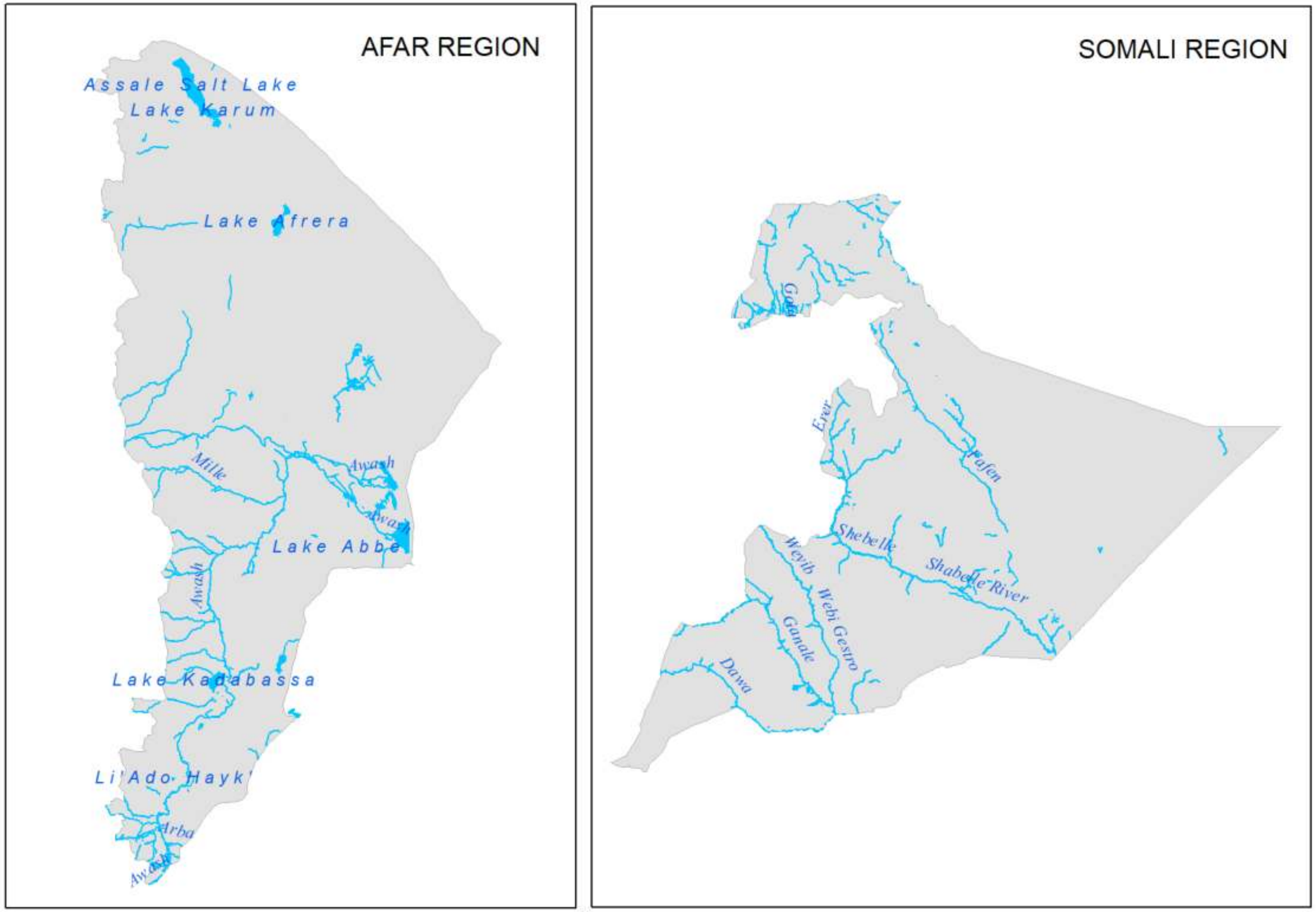

FIGURE 11: MAP OF EXISTING WATER BODIES IN THE AFAR AND SOMALI REGION. SOURCE: UNU-EHS BASED ON DATA PROVIDED BY THE HUMANITARIAN OPENSTREETMAP TEAM (2020).

FIGURE 12: GROUNDWATER RECHARGE AND AVAILABLE MAP. Note: A = wide spread good quality groundwater at a relatively shallow depth (dominantly highland volcanic aquifers recharged by high rainfall); B = large groundwater reserve with fair to bad quality often localized in lower elevation areas (rift valley and volcanics in pediment covered with thick sediments and intermountain grabens); C = low to moderate groundwater reserve with fair quality (highland trap series volcanic aquifer with less sediment cover and recharge); D = medium to high groundwater reserve in the volcanic and sediments recharged by rainfall and rivers in places with serious salinity problem; E = Low groundwater reserve with moderate quality recharged by seasonal floods and streams. Adopted from Ayenew, T. et al. (2008).

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Design: Aileen Orate (UNU-EHS)

Economics of Climate Adaptation