TRIPLELINE

Climate-Resilient Community Access to Safe Water Powered by Renewable Energy in Drought-Vulnerable Regions of Ethiopia

Feasibility Study

Prepared by Triple Line | July 2022

Document Control

Document title	Feasibility Study on Climate-Resilient Community Access to Safe Water Powered by Renewable Energy in Drought-Vulnerable Regions of Ethiopia
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Date	July 2022

Note:

The Accredited Entity's name has been officially changed from the Ministry of Finance and Economic Cooperation (MOFEC) to the Ministry of Finance (MOF). This change has been communicated to the GCF Secretariat, and the necessary updates have been made in the funding proposal and its annexes, including this feasibility study document.

However, due to the nature of how certain files were originally created, the change may not be reflected exhaustively in all sections, particularly in some standalone annexes linked to the feasibility study. As a result, there may still be instances where the previous name, "Ministry of Finance and Economic Cooperation" or its abbreviation "MOFEC," appears.

We kindly ask readers to recognize this change and interpret any mention of "Ministry of Finance and Economic Cooperation" or "MOFEC" as "Ministry of Finance" or "MOF."

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Executive Summary

1. The project is designed to directly build the resilience capacity of over 267,000 non-commercialized small holder farmers and pastoralists who have been directly affected by climate change. An area of more than 3,300 hectares of land will be irrigated, close to 250,000 communities will be able to access potable water and water for over 200,000 cattle's will be available even during the extended drought seasons. This will all be delivered via renewable energy, generating over 8.5 MW just from solar power and avoiding the use of diesel generators and thus removing 184.95 TCO_2 equivalent from the environment. The spill over benefits because of implementing this project will reach to over 2 million community members indirectly. This impact will be attained using solar power for productive use, via extracting ground water for potable and livestock use and irrigation purposes while providing clean electricity to the local community, helping achieve several Sustainable Development Goals (SDGs).
2. Ethiopia is considered as the "Water Tower" of North-Eastern Africa for irrigation, drinking water supply and fishery development[1]. Despite the above fact, only a significant portion of this potential is being utilized. The problem of food security had long been a sticking issue in Ethiopia. The problems of land degradation, population pressure, low productivity in agriculture, improper utilization of resources, poor infrastructure, absence or poor level of adoption of technological innovations, have been identified as the main factors attributing to the ever-decreasing resilience capacity of the small holder farmers and the pastoralists. Attaining food security using green technologies has been given a priority by the Prime Minister's office, thus the establishment of the Ministry of Irrigation and Lowlands (MILLs) to ensure that the policy drive at the top is met with practical implementation on the ground. Agriculture remains to be the backbone of the economy and small holder farmers inability to become food insecure has put the drive to initiate agricultural commercialization programs. These national programs are designed after a series of successful project outcomes in clustering small holder farmers into commercial scale. Furthermore, the overarching national plan of Ethiopia is cognizant of the fact that large scale land investments (LSLIs) is a vital tool for developing the pastoral areas, also substantiated by studies[2]. The government of Ethiopia plans for the modernization of Agriculture, that is grounded in transforming agriculture largely from subsistence to commercializing. This plan is reflected in the Home Grown Economic Reform (HGER) where development will be undertaken through privatization and market based economic policy with particular focus on increasing agricultural production.
3. This project thus builds on the government of Ethiopia's policy of increasing agricultural productivity using renewable energy. This project will be implemented in the Northern parts of Ethiopia of the Amhara Region targeting the Kobo Girana valley, a long stretch valley covering an area of over 3,000 square kilometers that has been frequently affected by climate change since the early 1974's. The other project area is situated in the Southern parts of Ethiopia of the Oromia region targeting the Borena Zone, predominantly inhabited by pastoralists who breed and trade livestock in Ethiopia and Kenya. This area is also known to have been hit by cyclical climate induced shocks. Recently in 2021, the Borena have again been hit by drought loosing almost 75percent of their livestock's due to lack of rain fall in the region. This project will target these poor communities and will build their adaptive capacity towards climate change. This will be attained by tapping on existing infrastructures and knowledge but refined to accommodate novice technology and lessons learned to ensure their lives is changed sustainably.

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[1] *Ethiopian Water Technology Institute, Public Relations and Communication Affairs Directorate, August 2019*

[2] *Keeley 2014*

4. The Kobo Girana valley is known for its fertile ground and rich ground water potential. The Kobo Girana River Valley Development Project (KGVDP) Office was established in the early 1980's to develop the valley to its full potential. It is against this backdrop that extensive studies were conducted in the area and 236 highly productive boreholes were identified and drilled for irrigation purposes. At a later stage and mainly due to lack of finance, only 50 of these boreholes were fitted with submersible pumps that were powered by diesel generators. Currently, only 32 boreholes powered by diesel generators remain operational serving 15,000 large scale farmers and irrigating 1,500 hectares of land. However, these generators have become expensive to run, not reliable, frequently fail, discounting the carbon that has been generated thus far.
5. The Borena area is also known for its vibrant pastoralists community who owned and bred in average of over 50 livestock per household as recent as 2020. The Borena Zone is also known for its fertile ground and rich ground water potential in its heavily fractured aquifers. Extensive studies have also been conducted in this area and 113 boreholes have been drilled and constructed of which, only 13 powered by diesel generators are operational to date. Climate change and its resulting effect of enormous land degradation and significant depletion of pasture in Borena zone is currently pushing pastoralist communities to the brink. The situation in Borena when this proposal is developed was dire, where over 9,900 households have completely lost their herd[3] and average livestock number per household has shrunk by over 75percent. Men with the remaining cattle's have been displaced in search of pasture and water, with women, children, elderly people and the weak cattle remain in the villages. According to the FEW-NET 2022 report, households are likely to have limited amounts of credit to purchase food. Across these areas, households are anticipated to increasingly employ severe coping strategies such as excessive livestock sales, including female animals, begging, and relying on what credit is available. Some populations, specifically those who face the complete loss of their herds, are expected to be in Catastrophe IPC – Phase 5 (Integrated Phase Classification)[4].
6. This project is thus anchored on extensive knowledge of the target areas both indigenous and scientific, initiatives and projects that have been implemented and planned to be implemented. It captures the degree to which climate change has continuously debilitated the resilience capacity of the community to the point where it is very dire especially in Borena. Previous attempts that have been implemented in the Kobo Girana valley have been able to reverse the effects of climate change to a certain extent, but due to inherent design flaws, the outcome of these projects has not been sustainable. Learnings from other similar initiatives funded by the GCF, Adaptation Fund, the World Bank and various Foundations have also been incorporated into the design of this project proposal. Extensive stakeholder engagement has been conducted both at the federal and project implementation area to understand the gaps and needs of the community. In addition, bottle necks on policies and regulations have been identified including the need for a lean and streamlined implementation arrangement are highlighted as paramount in ensuring a successful exit strategy.
7. The scope of this project will center in using solar energy to sustainably extract ground water for potable and livestock use and for productive purposes, i.e. irrigating farm land to grow crops and fodder. Essentially, this project will remove 13 existing diesel generators and avoid the installation of 87 planned diesel generators, all to be replaced by solar powered submersible pumps in the targeted 100 boreholes. This project picks up on a planned Government of Ethiopia initiative to irrigate highly productive areas that have been identified by the then Ministry of Water, Irrigation and Energy,

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[3] *The Famine Early Warning Systems Network (FEWS-NET), 2022, USAID*

[4] *Households have an extreme lack of food and/or other basic needs even after full employment of coping strategies. Starvation, death, destitution, and extremely critical acute malnutrition levels are evident.*

Agricultural Transformation Energy, Water Works Design and Construction Enterprise, Oromia Engineering Corporation and the Kobo Girana River Valley Development Office in close collaboration with their regional counterparts in the various parts of Ethiopia. Studies conducted by the same institutions and national and international academia also attest that in both target areas, the amount of natural recharge is more than the abstraction. Due to lack of capital funding to equip these boreholes with diesel powered submersible pumps and due to increasing operational cost of some of the boreholes that were equipped with the necessary assets, the plan by the Government of Ethiopia to build the resilient capacity of the communities did not materialize.

8. This project proposal thus is anchored on a low hanging fruit where interventions proposed will address critical bottle necks, layout the foundation towards streamlining the implementation, operation and management of the project and capture lessons along the way. This project will essentially pick the effort of the government of Ethiopia to build the resilience capacity of the community and carry it forward in a greener and sustainable manner. It will also carve the way for the Government and or financiers to develop other boreholes and easily turn the curve in building the resilience capacity of the community. This project is designed to be replicable. Renewables as an energy solution proposed in this proposal can also be adopted into the other sectors vis a vis transportation, industry and the urban space and builds on the NDC.
9. In most countries of Africa, agriculture is one of the primary sectors that contributes towards the national GDP, employs significant amount of work force but still is much dependent on rain, the patterns of which have become increasingly unpredictable due to climate change. Ensuring that subsistent farmers have access to sustainable water for their farms that is generated from green energy solutions will directly contribute towards their food security, social wellbeing, increased income, better livelihood at the farm level and reduced GHG, better environment, reduced FOREX needed to import fossil fuels and increased national Gross Domestic Product (GDP). The implementation of this project and its impact thereof could potentially become the tipping point to scale the use of solar energy to irrigate middle to large scale farmlands on the African continent.

Abbreviation

ACC	Agricultural Commercialization Clusters
AcFTA	African Continental Free Trade Area
ADELE	Access to Distributed Electricity & Lighting in Ethiopia
ADLI	Agricultural Development Led Industry
AGN	African Group of Negotiators
AfDB	African Development Bank
AGNPS	Agricultural Nonpoint Source Pollution
AISCO	Agricultural Inputs Supply Corporation
ANSWERS	The Agricultural Nonpoint Watershed Environment Response Simulation
AT	Ambient Temperature
ATA	Agricultural Transformation Agency
AR	Assessment Report (IPCC)
BDU	Basic Distribution Unit
BHs	Bore Holes
BIDP	Borena Irrigation Development and Pastoral Office
BOQ	Bill of Quantity
BoFED	Bureau of Finance and Economic Development
^{0}C	Degree Centigrade
CAPEX	Capital Expenditure
CFM	Cubic Feet Meter
CN	Curve Number
Co-SAERAR	Commission for Sustainable Agriculture and Environmental Rehabilitation in Amhara Region
CPS	Center Pivot System
CR	Climate Resilient
CRGE	Ethiopian Climate Resilient Green Economy
CSA	Central Statistics Agency
Ea	Application Efficiency
EC	Conveyance Efficiency
ECDSWC	Ethiopian Construction Design & Supervision Corporation
ECX	Ethiopian Commodity Exchange
Ed	Field Canal Efficiency
EE	Executing Entity
EEU	Ethiopian Electric Utility
EPA	Environmental Protection Agency
EIA	Environmental Impact Assessment
ESMP	Environment and Social Management Plan
ETCrop	Crop Water Requirement
ETc	Crop Evapotranspiration
ETo	Reference crop evapotranspiration
DEM	Digital Elevation Model
DFID	Department for International Development
DREAM	Distributed Renewable Energy -Agricultural Modalities
FAO	Food and Agriculture Organization of the United Nations

FC	Field Capacity
FDRE	The Federal Democratic Republic of Ethiopia
FOREX	Foreign Exchange
FSS	Ethiopia's Food Security Strategy
FTI	Fast Track Investment
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Green House Gas
GIS	Geographic Information System
GoE	Government of Ethiopia
GTP	Growth & Transformation Plan
GW	Gigawatt
GWh	Gigawatt hours
Ha	Hectare
HDPE	High Density Polyethylene
HDWs	Hand Dug Wells
HERA	Homegrown Economic Reform Agenda
HRUs	Hydrologic Response Unit
HSPF	Hydrologic Simulation Program Simulation FORTRAN
IE	Irrigation Efficiency
IFRPI	International Food Policy Research Institute
IMF	International Monetary Fund
ID	Inner Diameter
IDC	Irrigation Development Commission
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IRn	Net Irrigation Requirement
IRg	Gross Irrigation Requirement
IWMI	International Water Management Institute
IUA	Irrigation Users Association
Kc	Crop Coefficient
KGVDP	Kobo Girana Valley Development Project
l/s	Liters per second
l/h	Liters per hour
LLDPE	Linear Low Density Polythelyne
M	Meter (or Metre)
m.a.s.l	Mean above sea level
MCE	Mefteria Consulting Engineering
MCM	Million Cubic Meters
MDGs	The United Nations Millennium Development Goals
MEFCC	Ministry of Environment, Forest & Climate Change
MFAN	Ministry of Foreign Affairs of the Netherlands
MILLs	Ministry of Irrigation and Low Lands
MoA	Ministry of Agriculture
MOF	Ministry of Finance
MoWE	Ministry of Water Energy
MSE	Micro and Small Enterprise

ND	Nominal Diameter
NDC	Nationally Determined Contribution
NEP	National Electrification Program
NIE	National Implementing Entity
NIR	Net irrigation requirement
O&M	Operations and Maintenance
OD	Outer Diameter
OFAG	Office of Federal Auditor General
ORAG	Office of Regional Auditor General
OPEX	Operational Cost
OWWDSE	Oromia Water Works Design and Supervision Enterprise
P_{month}	Total rainfall in a month
P_{eff}	Effective Rainfall
PAD	Project Appraisal Document
PADETS	Participatory Demonstration and Training Extension System
PPP	Public Private Partnership
PPPA	Public Procurement and Property Authority
PUE	Productive Use of Energy
PSNP	Productive Safety Net Program
RKWAO	Raya Kobo Woreda Agricultural Office
SDGs	Sustainable Development Goals
SEDA	Solar Energy Development Association
SPs	Springs
SSA	Sub Saharan Africa
SWL	Static Water Level
SWM	Surface Water Modeling
SWAT	Solid Water Assessment Tool
TDH	Total Dynamic Head
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
UNESCO	The United Nations Educational, Scientific & Cultural Organization
UNICEF	United Nations Children's Fund
uPVC	Unplasticized Polyvinyl Chloride
USAID	United States Agency for International Development
WASH	Water Sanitation and Hygiene
WB	World Bank
WFP	World Food Program
WHO	World Health Organization
WOFED	Woreda Office of Finance and Economic Development
WTO	World Trade Organization
WWDSE	Water Works Development and Supervision Enterprise

A – Country Context, Policy and Regulatory Environment

1. BACKGROUND

1.1 Climate and Development Challenges

10. The IPCC Working Group I Sixth Assessment Report (AR6) provides an assessment of the current evidence on the physical science of climate change, knowledge evaluation gained from observations, reanalyses, paleoclimate archives and climate model simulations, as well as physical, chemical and biological climate processes. New climate model simulations, new analyses, and methods combining multiple lines of evidence have lead to improved understanding of human influence on a wider range of climate variables, including weather and climate extremes. According to AR6, it is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Since 2011 (measurements reported in AR6), concentrations have continued to increase in the atmosphere. Each of the last four decades has been successively warmer than any decade that preceded it since 1850 (Figure 1 & 2).

Figure 2 Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850–2020)

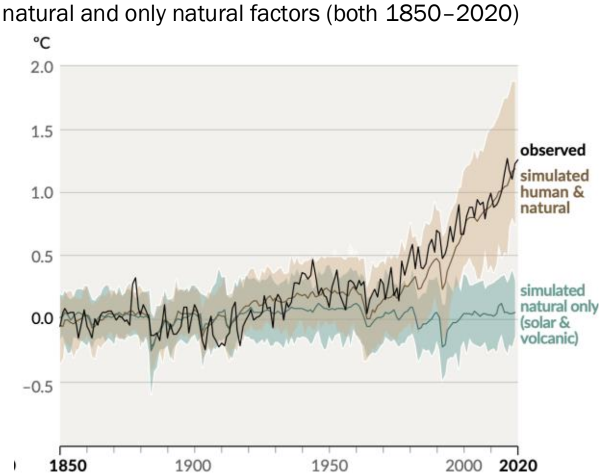
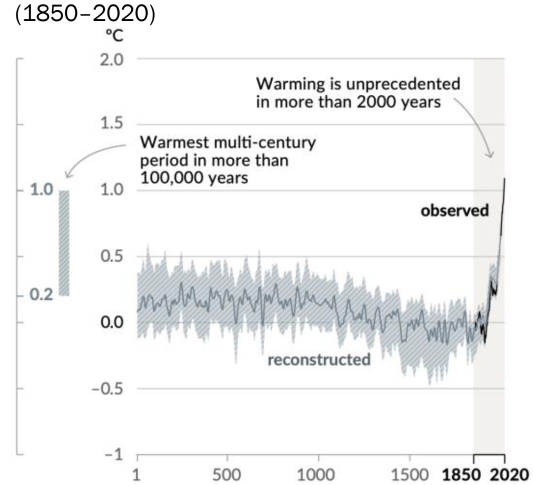
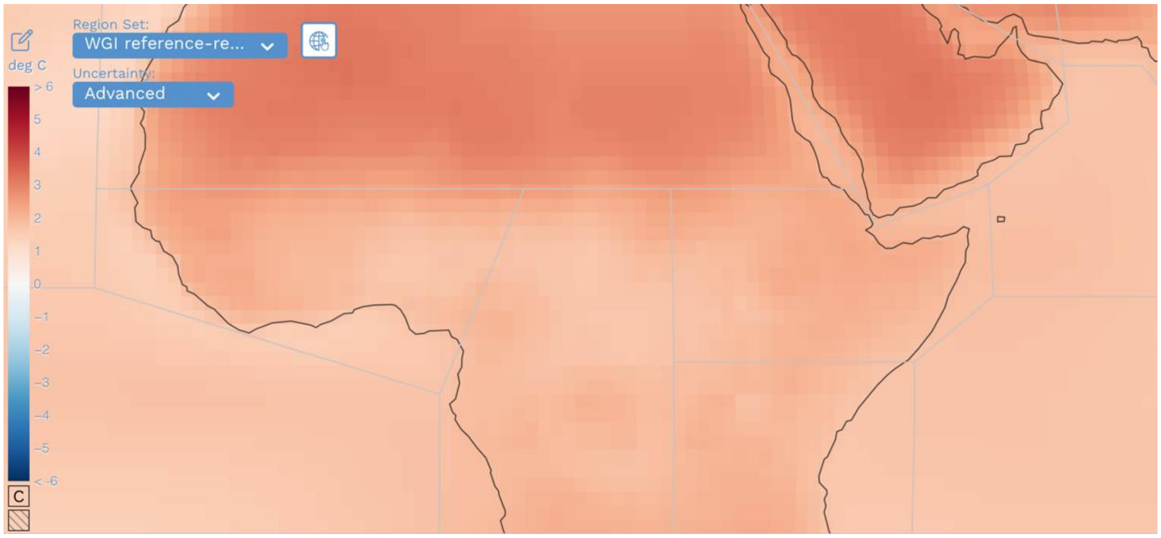


Figure 1 Change in global surface temperature (decadal average) as reconstructed (1–2000) and observed (1850–2020)



11. The African Region and particularly the sub Saharan Africa (SSA) region has observed a mean temperature increase of 2ºC in relation to the period 1850 – 1990, the effects of which are being felt in both natural and human systems. Climate change projections for this region point to a warming trend (Figure 3), particularly in the inland sub-tropics; frequent occurrence of extreme heat events; increasing aridity; and changes in rainfall—with a particularly pronounced increase in East Africa. Particularly vulnerable to these climatic changes are the rain-fed agricultural systems on which the livelihoods of a large proportion of the region's population currently depend. As agricultural livelihoods become more precarious, the rate of rural–urban migration will grow, adding to the already significant urbanization trend in the region.

Figure 3 CMIP6 - Mean temperature (T) Change deg C - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - Annual (34 models)



* IPCC WGI Interactive Atlas: Regional information

1.2 Ethiopia Country Context

12. Ethiopia is one of the world's most drought-prone countries[5, 6, 7, 8, 9]. The agricultural systems in Ethiopia mainly depend on rain-fed agriculture for food production and livelihoods, making them very sensitive to the negative impacts of climate variability and change. Climate change poses a huge challenge to Ethiopia and its people. Ethiopia is faced with increasingly unpredictable rains, and in some years the complete failure of seasonal rains occurrences which is directly attributed to climate change. It is a country with large differences across its regions, which is reflected in the country's climate vulnerability, (Figures 4 – 8).

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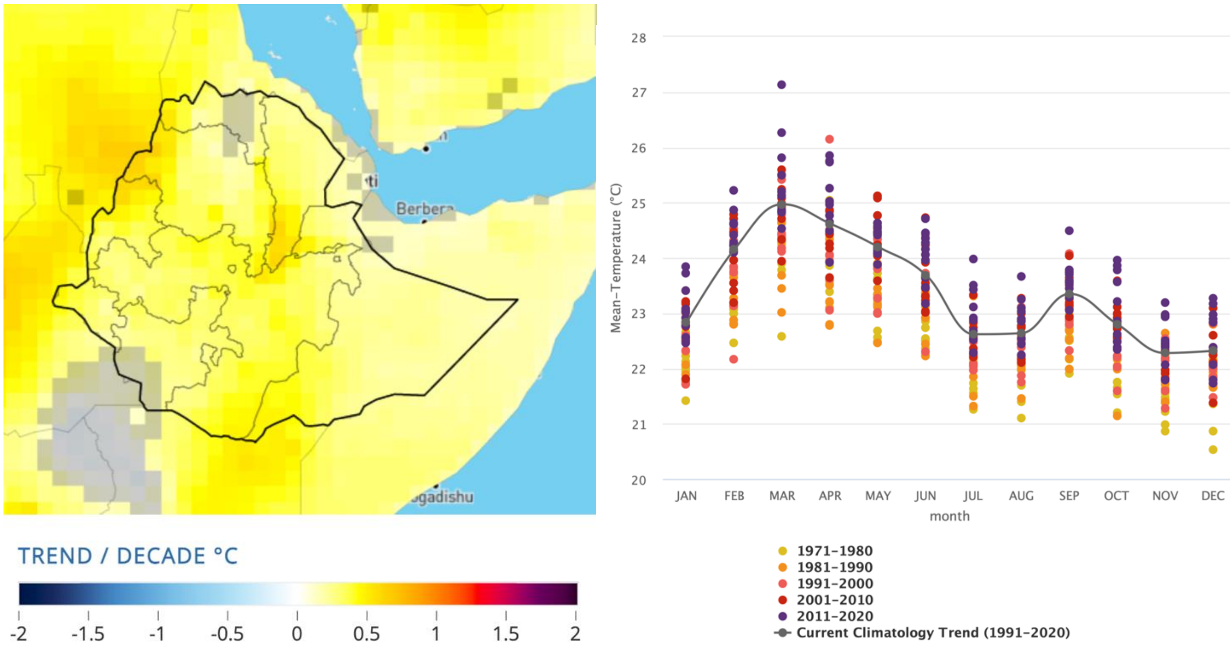
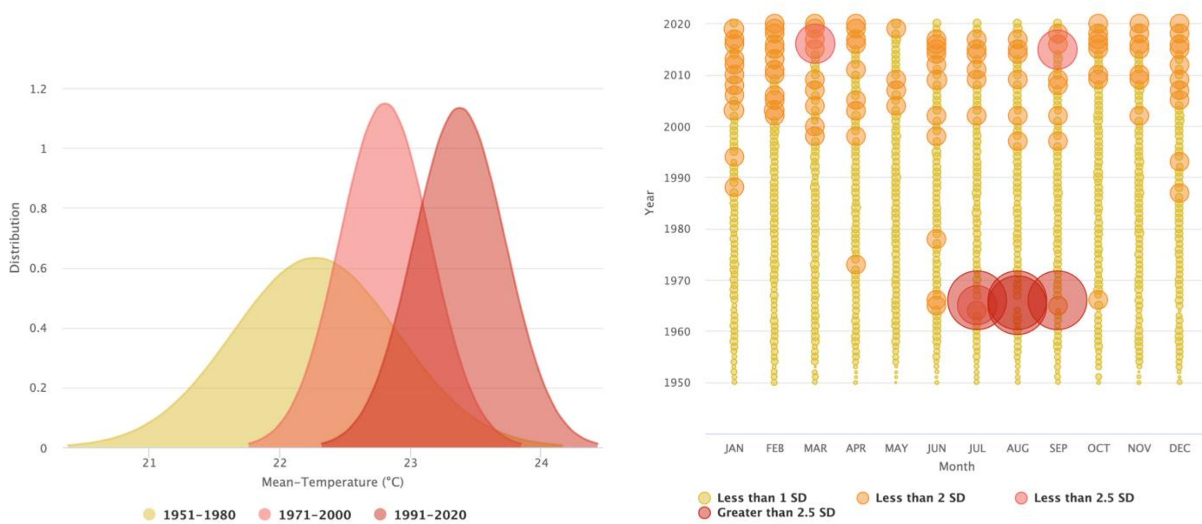
[5] Mekonen, A.A., Berlie, A.B. & Ferede, M.B. Spatial and temporal drought incidence analysis in the northeastern highlands of Ethiopia. Geoenviron Disasters 7, 10 (2020). https://doi.org/10.1186/s40677-020-0146-4
[6] Bayisa Negasa Wolteji, Sintayehu Teka Bedhadha, Sintayehu Legese Gebre, Esayas Alemayehu, Dessalegn Obsi Gemeda, Multiple Indices Based Agricultural Drought Assessment in the Rift Valley Region of Ethiopia, Environmental Challenges, Volume 7, 2022, 100488, ISSN 2667-0100, https://doi.org/10.1016/j.envc.2022.100488 (https://www.sciencedirect.com/science/article/pii/S2667010022000488)
[7] Eze, E., Girma, A., Zenebe, A. et al. Predictors of drought-induced crop yield/losses in two agroecologies of southern Tigray, Northern Ethiopia. Sci Rep 12, 6284 (2022). https://doi.org/10.1038/s41598-022-09862
[8] Causes, indicators and impacts of climate change: understanding the public discourse in Goat based agro-pastoral livelihood zone, Ethiopia, Ademe Mihiretu, Eric Ndemo Okoyo, Tesfaye Lemma, Heliyon. 2021 Mar; 7(3): e06529. Published online 2021 Mar 16. doi: 10.1016/j.heliyon.2021.e06529
[9] Groundwater and resilience to drought in the Ethiopian highlands, A M MacDonald7,1, R A Bell2, S Kebede3, T Azagegn3, T Yehualaeshet3, F Pichon4, M Young5, A A McKenzie6, D J Lapworth6, E Black5 and R C Calow4

Figure 4 Mean temperature trend per decade (left) & Variability and trends of mean – temperature across seasonal cycle (right), 1971 - 2020; Ethiopia



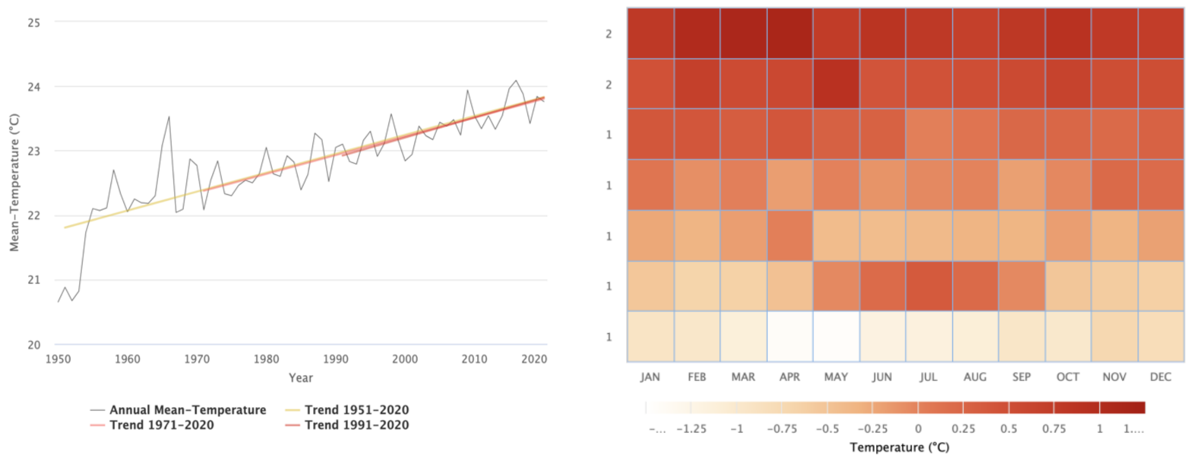
*Climate Change Knowledge Portal, World Bank

Figure 5 Change in distribution of temperature (left) & Change in event intensity of temperature (right), 1971 - 2020; Ethiopia



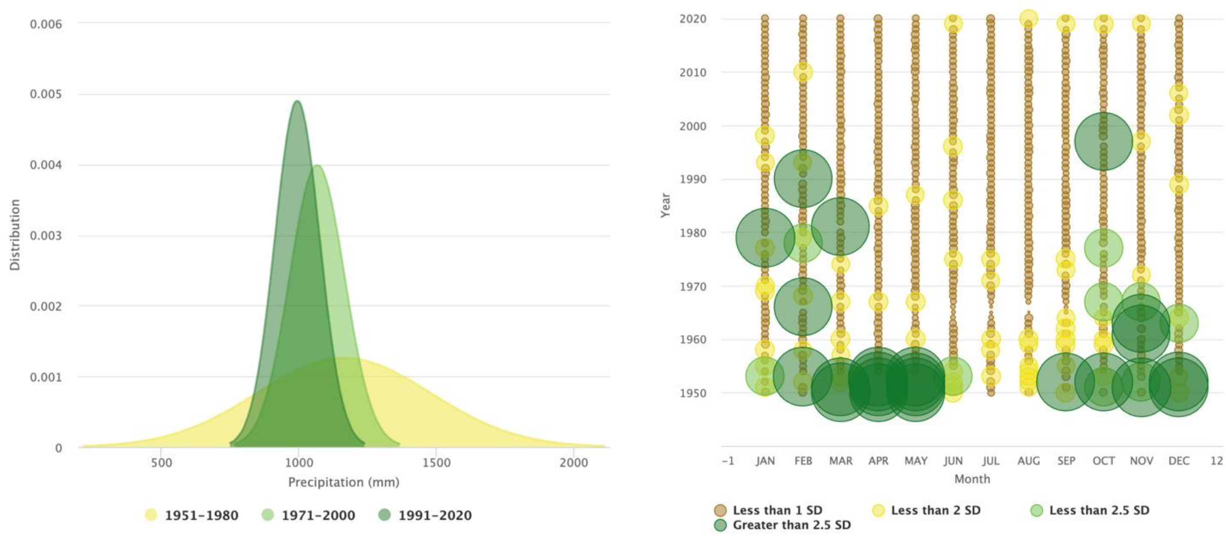
*Climate Change Knowledge Portal, World Bank

Figure 6 Temperature annual trends with significance of trend per decade (left) & Temperature monthly trends (right), 1971 - 2020; Ethiopia



*Climate Change Knowledge Portal, World Bank

Figure 7 Change in distribution of precipitation (left) & Change in event intensity of precipitation (right), 1951 - 2020; Ethiopia



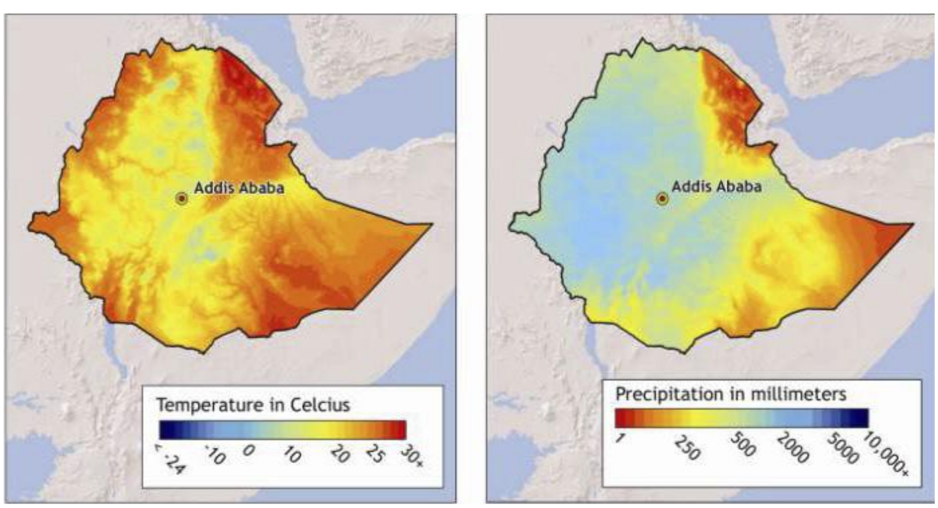
*Climate Change Knowledge Portal, World Bank

Figure 8 Precipitation annual trends with significance of trend per decade (left) & Precipitation monthly trends (right), 1951 - 2020; Ethiopia

*Climate Change Knowledge Portal, World Bank

13. Due to lack of weather information for the short, medium, and long-term and limited knowledge of adaptation measures, land users follow unsustainable livelihood practices. As it currently stands, generating, interpreting, packaging, and disseminating credible and timely weather and climate forecasts is challenging and faced with capacity limitations. Lack of access to timely and credible weather and climate forecasts has left land users with no option except to rely on traditional methods of weather prediction, which has proved ineffective in the context of a changing climate[10].
14. Ethiopia is faced with increasingly unpredictable rains, and in some years the complete failure of seasonal rains – occurrences that are linked to climate change. It is a country with large differences across its regions, which is reflected in the country's climate vulnerability. In general, the lowlands of are vulnerable to increased temperatures and prolonged droughts that may affect livestock rearing. The highlands on the other hand suffer from more intense and irregular rainfall, leading to erosion, which together with higher temperatures may result in lower agricultural production[11], (Figure 9).

Figure 9 Current Climate: mean annual temperature (left) and total annual precipitation (right)*



World Bank, 2011

10 Climate change adaptation in the lowland ecosystems of Ethiopia, 2021; UNDP
11 Ministry of Foreign Affairs of the Netherlands (MFAN), 2018. Climate Change Profile of Ethiopia

15. Ethiopia's Environmental Policy addresses climate change through regulations and institutional and strategic mechanisms. The policy emphasizes the need for a climate monitoring program, as the country is highly sensitive to climatic variability. It recognizes Ethiopia's environmental, long-term economic and energy interests. In fact, it is important to mention that a promising development trend is emerging in the country in terms of minimizing atmospheric inputs of greenhouse gases. For example, the energy sector is committed to harnessing hydro, geothermal, and solar energy. None of these produces significant amounts of pollutant gases. The policy also emphasizes the need to actively protect the ozone layer. It recognizes the vulnerability of the Ethiopian highlands which already have a thin protective atmosphere.
16. Thus, the country is faced with numerous development challenges that exacerbate its vulnerability to climate change, not only with high levels of food insecurity but also with ongoing conflicts over natural resources. Chronic food insecurity affects 10 percent of the population (over 10 million people), even in years with sufficient rains[12]. Rainfed agriculture contributes nearly half of national GDP and is the mainstay of livelihoods for over 80 percent of the population. These rural livelihood systems – crop cultivation, pastoralism and agro-pastoralism – are highly sensitive to climate. Food insecurity patterns are linked to seasonal rainfall patterns, with hunger trends declining significantly after the rainy seasons. Climate variability already negatively impacts livelihoods and this is likely to continue. Drought is the single most destructive climate-related natural hazard in Ethiopia. Estimates suggest climate change may reduce Ethiopia's GDP up to 10 percent by 2045, primarily through impacts on agricultural productivity. These changes also hamper economic activity and aggravate existing social and economic problems[13]. The World Bank's analysis predicts that climate change will lower Ethiopia's gross domestic product (GDP) growth by 0.5–2.5 percent per annum, largely by increasing the variability in rainfall. Over the coming 25 years, this could halve Ethiopia's potential GDP unless reasonable resilience measures are embraced now[14].

1.3 Biophysical context including summary on 50 year temperature and 70 year precipitation climate baseline data and projections

17. Ethiopians' topography is characterized by large regional differences, which are reflected in its climate. The lowlands in the southeast and northeast are tropical with average temperatures of 25-30^{o}C, while the central highlands (over 1500 meters in elevation, covering about 45 percent of the country's surfaces) are much cooler with average temperatures around 15 - 20 ^{o}C[15].
18. Changes in temperature and rainfall increase the frequency and severity of extreme events. Warming has exacerbated droughts, and desertification in the lowlands of the country is expanding. In an analysis in 2011, Ethiopia was ranked 5th out of 184 countries in terms of its risk of drought[16]. Between 1900 and 2010, twelve extreme droughts were recorded (killing over 400,000 people and affecting

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12 Wasley, E., Hernick, Ch., Hurley, K., Dr. Neigh, A., and Fikadu Getachew, 2016. The Global Environmental Management Support Project (GEMS II), award AID-OAA-M-13-00018.). The Cadmus Group, Inc. 100 Fifth Avenue, Suite 100, Waltham, MA 02451, 617-673-7000 Fax 617-673-7001: www.cadmusgroup.com

13 USAID (2016). Climate Change Risk in Ethiopia: Country Fact Sheet

14 World Bank, 2008. World Development Report 2008: Agriculture for Development. World Bank, Washington, DC

15 McSweeney, C.; New, M.; Lizcano, G. (2008): UNDP Climate Change Country Profiles: Ethiopia. http://ncsp.undp.org/sites/default/files/ Ethiopia.oxford.report.pdf

16 Swarup, A.; Dankelman, I.; Ahluwalia, K.; Hawrylyshyn, K. (2011): Weathering the storm: Adolescent girls and climate change. Plan. http://www.plan-uk.org/resources/documents/35316/

over 54 million)[17], of which seven occurred since 1980[18]. The majority of these resulted in famines. The severe drought of 2015-2016 was exacerbated by the strongest El Nino in decades, caused successive harvest failures and widespread livestock deaths in some regions. Apart from these major or extreme droughts, there have been dozens of local droughts with equally devastating effects. The country has experienced even more major floods in different parts of the country, though with less people affected: 47 major floods since 1900 (of which six since 1980[19]) killed almost 2,000 people and affected 2.2 million[20]. Ethiopia ranked 34th out of 162 countries in terms of flooding risk, and 5th out of 162 in terms of landslide risk[21].

19. The increase in severity of short, heavy rains in the highlands leads to increased flooding in the lowlands, causing further soil degradation in already exposed areas (although it can also decrease fertility). As indicated in Climate Change Profile of Ethiopia, different climate models present roughly similar projections concerning temperature change, but different ones for precipitation. Temperatures are expected to increase in all seasons with on average 1°C by 2030, 2°C by 2050, and 3°C by 2080 (compared to 1975)[22]. Some models project maximum increases as high as 5.1°C by the 2090s. Most models indicate substantial increases in the frequency of hot days and nights, with up to 93 percent of days and 99 percent of nights considered 'hot' in the July-September season by the 2090s (compared to 10 percent of days and nights in the same season in the 1960s)[23].
20. Despite the current trends of rainfall decreases, for the long-term precipitation for Ethiopia as whole is projected to increase by 9 percent over 50 years (compared to 1975). Higher resolution analyses however show both increase and decrease in different parts of the country. Even on a more local scale there can be large differences: a study on different districts in the Central Rift Valley projected rainfall decreases of over 11 percent for some, and increases of almost 9 percent for other, relatively nearby districts. An increase in rainfall variability for predicted for the whole country, making the rainfall less predictable. Moreover, a large share of total precipitation will fall during heavy precipitation events-specially from July to December. This is expected to lead to increased incidence of extreme events-with severe droughts in one year, and heavy flooding with erosion and landslides in the next year[24].
21. Climate trends differ for the various regions and seasons known in Ethiopia for rainfall temperature in different seasons/regions). The largest precipitation decrease during the driest quarter of the year will be in regions that are already very dry. Others concluded that rainfall reductions will be concentrated in areas of great significance for food production: the area suitable for cultivation during the Belg season (February - May) may be reduced by another 16 percent, while the areas benefiting from Kiremt rains will also contract further (Figure 10).

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17 You, G.J.Y; and Ringler, C. (2010): Hydro-Economic Modelling of Climate Change Impacts in Ethiopia. IFPRI Discussion Paper 00960. http://www.ifpri.org/sites/default/files/publications/ifpridp00960.pdf

18 World Bank (2010): Economics of Adaptation to Climate Change: Ethiopia. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/05/22/000425970_20120522100235/Rendered/ PDF/686500ESW0P1130UBLIC00EACC0Ethiopia.pdf

19 World Bank (2010)

20 You and Ringler (2010)

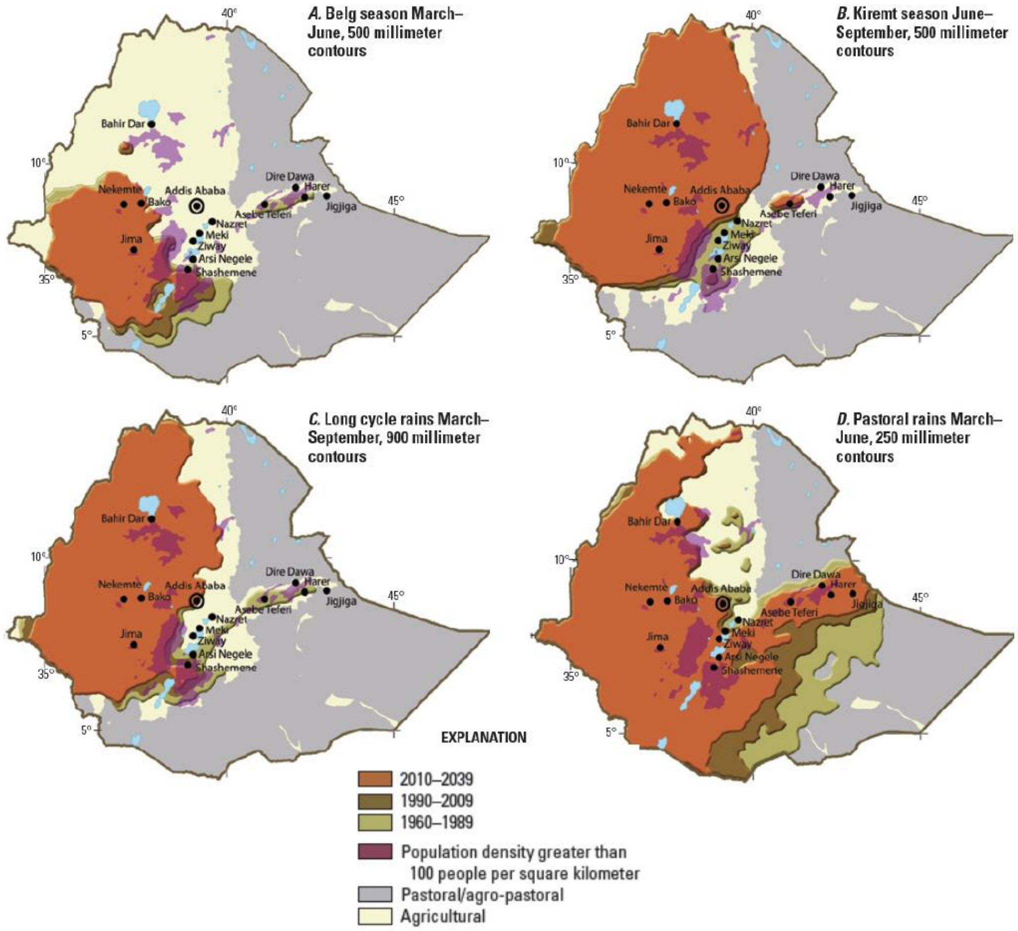
21 Swarup et al. (2011)

22 Climate Change Profile of Ethiopia, 2018, Ministry of Foreign Affairs of the Netherlands (MFAN)

23 Ministry of Foreign Affairs of the Netherlands (MFAN), 2018. Climate Change Profile of Ethiopia

24 Ministry of Foreign Affairs of the Netherlands (MFAN), 2018. Climate Change Profile of Ethiopia

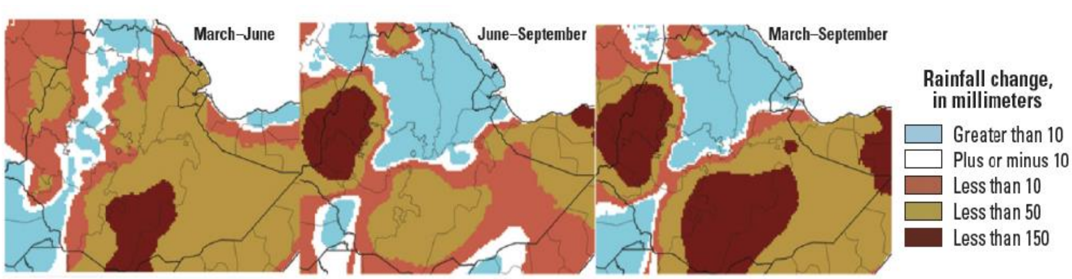
Figure 10 Changing Production Areas (past, present and future)



*Source: USGS et al. (2012)

22. To deal with the high uncertainty of climate change projections and the differences between models, the Ethiopian government has decided to use an average of projections from nineteen different models to estimate changes in temperature and rainfall for 2030, 2050 and 2080[25].

Figure 11 Projected Seasonal Changes in Rainfall Extrapolation of Current Trends (1960-2009) Per Season for the Years 2010-2039



25 Ministry of Foreign Affairs of the Netherlands (MFAN), 2018. Climate Change Profile of Ethiopia

*Source: USGS et al. (2012)

23. A decrease in Belg rains (February - May), as projected by one study (although contradicted by others), could have significant effects on both crop production and livestock rearing due to their important role in Ethiopian food production. If Belg rains reduce, the following effects can be expected:

- Central, south and east Ethiopia loses one of their two main growing seasons;
- the preparation of seedbeds for Kiremt (June-September) crops will be difficult or impossible;
- Long-cycle crops (maize, sorghum, millet) will have to be planted later and may not mature;
- Coffee plants will lack essential water for inflorescence;
- Pastures and drinking water places for livestock will lack not be replenished after the dry season.

24. Water supply will be affected throughout the country, but most severely in areas that are already water-scarce, such as densely populated parts of the Rift Valley and eastern pastoralist zones.
25. Future projections of temperature and rainfall patterns in Ethiopia exhibit a high degree of uncertainty, but most projections agree that mean annual temperature is projected to increase by between 1–2°C by 2050. The frequency of hot days and nights will substantially increase. About 15–29 percent of days will be considered hot by 2060. It is uncertain whether rainfall will increase or decrease; projections range from -25 percent to +30 percent by the 2050s[26]. There is an increase in the proportion of total rainfall that falls in "heavy" events with annual increases of up to 18 percent.

[26] World Bank, 2008. World Bank, 2008. World Development Report 2008: Agriculture for Development. World Bank, Washington, DC.

A2- Climate Change-Related Vulnerabilities at National Level

2.1 Socioeconomic Vulnerability

26. Ethiopia is highly vulnerable to climate change due to its low level of economic and social development, low levels of income per capita, limited disaster risk management and weak institutional capacities. According to Climate Change Profile of Ethiopia[27], Ethiopia is not only biophysically but also socio-economically vulnerable to climate change. Rapid population growth and expansion of agriculture in a potentially drier and certainly warmer climate could dramatically increase the number of people at risk. Rural livelihoods systems, crop cultivation, pastoralism and agro-pastoralism, are highly sensitive to climatic conditions. The increase in drought and in desertification from land use pressures have resulted in significant losses of arable land and increased dependency on food aid. Just as the country is heterogeneous in topography and climate zones, it is also heterogeneous in social, cultural and economic characteristics. The degree of vulnerability of different localities and their livelihoods varies accordingly. Several densely populated areas of the country–especially in southern Oromia – are expected to experience the strongest declines in rainfall during crucial cropping seasons. In these areas, all arable land is already being cultivated and landholdings are continuously being reduced in size: there is no possibility to further expand land under agricultural production. These areas may become hotspots of food insecurity due to climate change. Limited water storage capacity further increases vulnerability to climate risks.
27. Climate change will have significant economic effects on the Ethiopian economy, and on the agricultural sector in particular due to factors such as the loss of arable land due to shifting agro-ecological zones, altered growing cycles that delay planting, and increased incidence of pests and diseases. Ethiopia's livestock sector will be increasingly affected by drought and degradation of land. It has been estimated that climate change will affect the country's GDP growth by 0.5 - 2.5 percent per year in the near future with the potential reduction of GDP up to 10 percent by 2045 primarily through impact on agricultural productivity[28]. Another study found that about US $ 2 billion will be lost in the agricultural sector in the next few years due to rainfall variability alone – equal to 32.5 percent of current Real Agricultural GDP[29]. An integrated vulnerability assessment on climate change effects in Ethiopia's regional states found that the top five vulnerable states are Afar, Amhara, Oromia, Somali, and Tigray[30]. These regional states are all heavily agriculture-dependent and belong to the poorest ones in the country: 90 percent of people living in Tigray and Afar and 60-70 percent of those living in Oromia and Somali support their life on less than US $ 2 per day (Figure 12).

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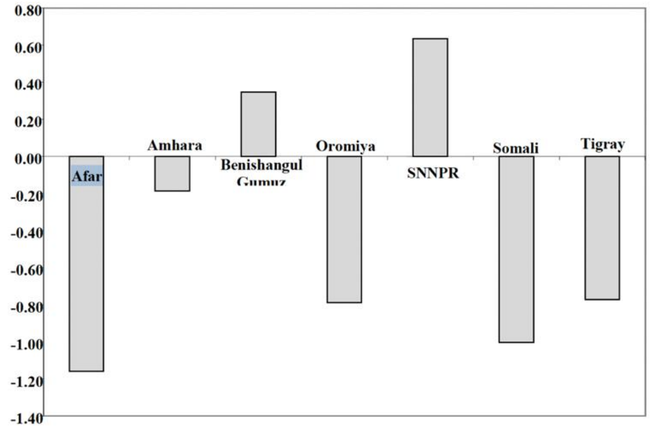
[27] MFAN, 2018. Climate Change Profile of Ethiopia
[28] Ministry of Foreign Affairs of the Netherlands (MFAN), 2018. Climate Change Profile of Ethiopia
[29] World Bank, 2008. World Development Report 2008: Agriculture for Development. World Bank, Washington, DC.
[30] Deressa, Temesgen & Hassan, Rashid & Ringler, Claudia. (2008). Measuring Ethiopian farmers' vulnerability to climate change across regional states [in Amharic]:. International Food Policy Research Institute (IFPRI), Research briefs

Figure 12 Vulnerability indices of the seven regional states of Ethiopia



28. A factor of specific importance in climate change vulnerability is gender. In poor areas, women often have more household responsibilities (25 percent of poor smallholder farm households were identified as female headed in some Ethiopian districts, compared to only 5 – 7 percent of other households). They are often disproportionately affected by climate change impacts on some of their primary responsibilities, including the collection of water for drinking, cooking and washing, the collection of fuel wood, and the small-scale cultivation of subsistence crops. An additional (indirect) effect of climate change is that women and girls have been found to be more vulnerable to sexual abuse since they have to travel to more remote sources of water. Despite the strong effects of climate change on their lives, the abilities of women and girls to cope with climate change effects are often significantly lower than men's. This is because of their reduced access to information, markets, mobility, alternative income sources, and decision-making mechanisms.
29. Climate change also has a determinantal impact on labour productivity and health. According to a UNFCCC/WHO report, considering a high emissions scenario, i.e. increase in temperatures of +4°C will bring about a project loss of 2 percent annual daily work hours for workers carrying out heavy labour (e.g., agriculture and construction) and an increase in heat related deaths among elderly people (65+) to over 65 deaths per 100,000 by 2080, compared to the estimated baseline of 3 deaths per 100,000 in 1990.

2.2. Vulnerability of the Agricultural System

30. Ethiopia's economy is dependent on agriculture, which accounts for 40 percent of the GDP, 80 percent of exports, and an estimated 75 percent of the country's workforce[31]. Yet, Ethiopia's rural communities predominantly depend on rain-fed subsistence agriculture, rendering them highly vulnerable to biophysical climate impacts. It is also the major source of food for the population and, hence, the prime contributor to food security[32]. Regional climate change has begun to accelerate drought cycles. Climate impact modelling shows increasing occurrence of extreme weather events and rainfall variability ranging from -25 to +30 percent by 2050. Droughts alone can reduce total GDP by 1 to 4 percent while soil erosion reduces agricultural GDP further (2 – 3 percent) without adaptation by 2045 (World Bank 2010). Just 5 percent of land is irrigated and crop yields from small farms are below regional averages. Moreover, pastoralists' livelihoods center on livestock, which is highly vulnerable to drought, leading to

[31] National Electrification Program (NEP) 2.), 2019, Ministry of Water, Irrigation and Energy (MoWIE)
[32] CEEPA, 2006

existential risks, but also transformative economic potential through climate-resilient water access. Furthermore, climate stresses and resulting water shortages have already resulted in a critical decline in quantity and quality of feed leading to decreased productivity and increased mortality of animals.

31. Food insecurity is not a recent occurrence. Ethiopia has historically been vulnerable for food insecurity and has often relied on food aid. Production of key crops is not increasing fast enough to keep up with the country's high population growth: per capita cereal production has been estimated to decline by 28 percent between 2009 and 2025. Correlations have been found between rainfall and temperature variations and variations in stunting and underweight in Ethiopia, suggesting that climate change will exacerbate the current situation. Ethiopia has established a Productive Safety Net Program (PSNP) through which millions of people, often in the south and east, receive assistance – but this may not be sufficient if productivity is further limited in the future. Food insecurity is highest in the east of the country or in parts of central Ethiopia, depending on the method used to measure it. Food insecurity is most pronounced before harvesting, when food stocks have finished. While most of the country has one hunger season per year (June - September), the eastern pastoralist has two (February - April and September - October).
32. If irrigation is being practiced, energy is generated from emission-intensive diesel generators[33], as large tracts of the rural population do not have access to the electricity grid. Solar water pumping has so far not been widely used due to access to finance and lack of experience (IWMI 2018). Solar PV pump irrigation could transform 18 percent of rainfed land in Ethiopia[34]. Moreover, access to irrigation enables farmers to diversify crop production, thereby enhancing their climate resilience (EFAC 2019, 3).

2.3 Vulnerability of the Water Supply System

33. Climate impacts on water supply negatively affect agricultural productivity and food security, drinking water, nutrition, health, while disproportionately affecting women and children. 76 percent of rural women and girls in Ethiopia are responsible in collecting water for their household; whereas only 12 percent men and boys participate. Moreover, the rural population often does not have access to safe water for drinking and sanitation (UNICEF 2018). People continue to rely heavily on surface water sources, which are vulnerable to climate impacts. Climate impacts on water supply therefore negatively affect agricultural productivity and food security, drinking water, nutrition, and health, while disproportionately affecting women and children.
34. 31 percent of rural population (>26 million people) travel more than 30 minutes to collect drinking water; 28 and 11 percent use unimproved and surface water respectively. 43 million people do not have hand washing facilities[35], and 60 to 80 percent of communicable diseases in Ethiopia are caused by inadequate access to safe water and sanitation[36]. Hand washing is particularly relevant for preventing the spread of COVID19 and other diseases. People continue to rely heavily on surface water sources, which are vulnerable to climate impacts. Water sources are often contaminated with human and animal waste and related diseases are the leading cause of death in children under five[37]. While Ethiopia achieved significant progress towards girls' education (enrolment rates increased from 51 percent in 2003/04 to 95 percent in 2016/17), only 53 percent finish primary school as e.g., helping in the household. UNICEF 2017 reported that in some places girls in Ethiopia invest up to 8 hours a

[33] USAID 2020, IMWI 2018
[34] Schmitter et al. 2018
[35] UNICEF and WHO 2019
[36] UNICEF 2018
[37] Usman et al. 2016

day in collecting water, thereby preventing them from using this time for education or productive purposes.

35. Development of water supply and sanitation is the responsibility of MOWE in cooperation with regional Bureaus and other relevant ministries. MOWIE is also responsible for rural electrification. Consistent with Ethiopia's decentralized federal government structure, regions, woredas, towns and communities are responsible for planning and managing their own water supply and sanitation services. Ethiopia has a long history of community-led measures across sectors and has established water user associations in other water access schemes.

2.4 Livestock

36. Just 5 percent of land is irrigated and crop yields from small farms are below regional averages. Moreover, pastoralists' livelihoods center on livestock, which is highly vulnerable to drought, leading to existential risks, but also transformative economic potential through climate-resilient water access. Furthermore, climate stresses and resulting water shortages have already resulted in a critical decline in quantity and quality of feed leading to decreased productivity and increased mortality of animals. Recent studies show that resilience and indigenous adaptive capacity of pastoralists in the Borena Zone have severely deteriorated, mainly due to extended dry seasons and shortage of rainfall[38]. If irrigation is being practiced, energy is generated from emissions-intensive diesel generators[39].
37. Of particular concern with respect to climate change impacts in Ethiopia are the implications for communities that depend on crop agriculture, agro-pastoralism, and pastoralism for their livelihoods[40],[41],[42]. Agro-pastoral and pastoral communities, dependent on rangelands or mixed livestock–crop systems[43], face climate impacts such as degradation in rangelands, invasive species that affect grazing lands, reduction in water availability for human and animal consumption, and livestock diseases[44]. It is estimated that there are 10 million pastoralists in Ethiopia, the largest pastoral population in Africa[45].
38. From a regional point of view, vulnerability to drought is highest in the pastoral areas in the lowlands[46]. Within the arid and semi-arid areas of the country, the regions of Oromia, Amhara and Tigray are among the most vulnerable to climate change, given their low levels of service provision and infrastructure development, and the frequency of droughts and floods[47]. In the social structure within the pastoral communities, women take care of the productive and reproductive work, such as cooking, cleaning, feeding family members, caring for cattle, and farming, yet have lower decision-making power than men[48]. The situation is similar in farming households. This creates barriers in access to resources and information and reduces adaptation potential[49]. Children, particularly girls; the elderly; and disabled people are among the most vulnerable to climate risk due to limitations in mobility, limitations in access

[38] Birhanu et al. 2017; Mengistu 2016
[39] USAID 2020, IMWI 2018
[40] Adenew, 2010
[41] IFAD, 2014
[42] Naess et al., 2010
[43] Few et al., 2015)
[44] World Bank, 2010b
[45] Few et al., 2015)
[46] MoARD, 2010
[47] Deressa et al., 2008).
[48] MoA, 2014)
49 Berga, H., Bryan, E., di Falco, 2014. Gender, risk, and climate information: Relevance for climate change adaptation in Ethiopia. International Food Policy Research Institute (IFPRI), Addis Ababa, Ethiopia.

to economic opportunities and social services, and dependency on close relatives, among other factors [50].

2.5 Access to Energy

39. According to the World Bank, Ethiopia has the second-highest installed available capacity for electricity generation in Sub-Saharan Africa, at 4.5 GW. It has a well-developed transmission and distribution network, with nearly 80 percent of the population living within proximity of medium-voltage transmission lines. It has abundant sources of renewable energy waiting to be tapped (including wind, solar and geothermal) – enough to easily supply the power needs of the country. And it is one of the few countries in the world where the electric grid is nearly 100 percent supplied by renewable sources.
40. Against this potential however, 70 percent of the population in Ethiopia live without electricity. The lack of power also impacts basic services – only 24 percent of primary schools and 30 percent of health clinics have access to electricity. Ethiopia's power generation is predominantly hydropower, the infrastructure of which is not resilient the shocks of climate change. While there is a beginning awareness for the potential benefits of using solar energy for lighting and productive use, access to finance and lack of experience with the technologies have so far constrained their use in Ethiopia[51] and other countries[52].
41. In order to meet with this energy deficit, the Government of Ethiopia launched the National Electrification Program (NEP) in 2017, a comprehensive plan to reach universal access to electricity by 2025. To achieve this, the NEP has taken a coordinated approach combining both grid and off-grid solutions, with a focus on last-mile service delivery to consumers. The NEP is for 65 percent of the population to have electricity through the grid, and the other 35 percent through off-grid technologies - stand-alone solar systems and mini-grids by 2025. Another priority will be providing reliable electricity to schools and health centers. A state-of-the-art geographic information system (GIS) will be used to optimize the planning for both the grid- and off-grid infrastructure, and act as a monitoring and evaluation platform for the program. The NEP plan gives due recognition to the effects of climate change on existing hydropower assets has the potential to decrease base energy generation thus paves pathways to diversify the energy generation mix with a least cost to power. Furthermore, the NEP also embeds the Energy-Water Nexus and builds on the Agricultural Transformation Agency (ATA) Agricultural Commercialization Clusters (ACC) initiative.

[50] MoA, 2014
[51] IWMI 2018
[52] EFAC 2019

A3- National Policy and Regulatory Environment

3. OVERVIEW

42. Over the past 15 years, the Ethiopian economy registered a remarkable double-digit real GDP growth and over a six-fold increase in per capita GDP to about US$ 865 in 2018. This has been accompanied with a significant poverty reduction from 44.2 percent in 2000 to 23.5 percent in 2015, and improvements in access to education, health, and infrastructure[53]. This economic development was fuelled through high public investments in infrastructure and human capital that addressed gaps in transport and energy infrastructure and human capital developments, there by laying the foundation for a sustained growth.
43. While significant strides were achieved through both GTP I and GTP II, there were noticeable shortcomings to achieve the required structural transformation and stimulate exports. The private sector development was yet to be achieved and directly affected job creation and gaps remain in ensuring quality universal access to basic services. Furthermore, the efforts to finance ambitious public investment programs through directing domestic financial resources and significant external borrowing, coupled with poor project execution, resulted in serious macro-economic imbalances—foreign exchange shortages, increased risk of external debt distress, growing financial sector vulnerabilities, limited access to finance for the private sector, high inflation, and potential misallocation of resources. Against these challenges, the Government of Ethiopia developed the Home Grown Economic Reform Agenda (HERA 2020 – 2030) to correct these macro-economic imbalances that will directly hamper the national ambition to become a middle-income economy by 2025.

3.1 The Homegrown Economic Reform (HERA)

44. The government of Ethiopia has launched the Homegrown Economic Reform (HERA) agenda (2020 – 2030), which aims to transform Ethiopia from a largely agrarian low-income country to an industrialised lower-middle-income country by 2030. The HERA is designed to eliminate macroeconomic imbalances and lay the foundation for sustainable and inclusive growth, which will require the private sector to take charge of growth amid waning public sector financing capacity. Against this backdrop, the IMF has approved a program for Ethiopia of almost US$3 billion to support the implementation of the HERA. Since the launch of the HERA, the Government of Ethiopia has given more emphasis on trade and regional integration as demonstrated in Ethiopia's signing and subsequent ratification of the African Continental Free Trade Area (AfCFTA).
45. Within the remit of this proposal, the HERA agricultural sector reform aims to improve the role and participation of the private sector, expansion of small- to large-scale irrigation development, improving supply of inputs and finance, enhancing the productivity of livestock, protecting the environment and natural resources, improving agricultural production methods, reducing post-harvest loss, promoting research-based food security systems,and promoting import substituting major agricultural crop production.

3.2 Agricultural Transformation Policy

46. Although Ethiopia is diversifying its economic base, the HERA outlines that agricultural growth will remain an important driver of economic growth and poverty reduction. Agricultural productivity has

[53] A Homegrown Economic Reform Agenda: A Pathway to Prosperity, FRDE, 2020

grown rapidly in the past decade due to intensification of modern seeds, fertilizer use, and farm management techniques. Productivity improvements in the past few years were limited on key crops, with limited investments and productivity improvements in a range of subsectors. Furthermore, yield growth remains insufficient to meet domestic food security and industrial needs, and underdeveloped markets continue to prevent farmers from realizing returns on their investments on inputs.

47. Some of the major constraints in the agriculture sector revolve around land use and administration system, access to high-quality inputs and finance, efficient market systems, and research and extension services. The agricultural sector reform thus focuses on addressing specific issues prioritized under each of the major constraints. Increasing market-driven agricultural production and productivity and enhancing agricultural value addition and access to domestic and international markets will be required for agriculture to contribute to the structural transformation of the economy.
48. To support this, the government has underlined that it will closely work with smallholder farmers, cooperatives and private actors. Key reform measures include the following.

1) Develop legal frameworks to enhance land use and administration and allow farmers to lease land use rights.
2) Enhance productivity of small-holder farmers and pastoralists through provision of modern inputs and services.
3) Modernize livestock production through improving veterinary infrastructure and establishing linkages with other industries.
4) Establish effective linkage between agriculture producers and commodity markets as well as the commercial value chain.
5) Accelerated growth in agricultural production with a focus on strategic crops for import substitution and exports.
6) Develop a legal framework for agriculture focused financial services

49. The agri sector reforms aim to address market failures and sectoral regulatory and investments constraints to promote investment. The macro-financial reforms are complemented with broad structural and sectoral reforms to unleash the potential of the private sector in the agricultural sector and enhance the productivity growth and job creation.

3.3 The CRGE Strategy

50. In 2011, the Ethiopian Climate Resilient Green Economy (CRGE) strategy was launched, laying the foundation for integrated planning for climate-resilient development. Ethiopia’s CRGE initiative aims to "climate-proof" its National Development Plan goals. The strategy was realized to stabilize the country’s net greenhouse gas emissions while building resilience to current climate risks and future climate change. Over time, Ethiopia went from climate-proofing its development plans to fully align its green growth and climate-resilience objectives with its national development plans the Growth and Transformation Plan (GTP) and currently the Homegrown Economic Reform Agenda (HERA – 2020 - 2030). To achieve this, the government has developed resilient strategies built on four pillars:

1) Improved crop and livestock production practices for greater food security and higher farmer income;
2) Protecting and re-establishing forests for their economic and ecosystem services, while sequestering significant amounts of carbon dioxide and increasing the carbon stocks in landscapes;

3) Expanding electric power generation from renewable energy; and
4) Leapfrogging to modern and energy efficient technologies in transport, industry and building sectors.

51. The CRGE strategy in particular focuses on four pillars that will support Ethiopia's overarching national policy (HERA) through:

    1) Adoption of agricultural and land use efficiency measures.
    2) Increased GHG sequestration in forestry (including protecting and re-establishing forests for their economic and ecosystem services including as carbon stocks);
    3) Deployment of renewable and clean power generation; and
    4) Use of appropriate advanced technologies in industry, transport, and buildings.

52. The CRGE initiative has led to establishment of new institutions, new efforts in capacity building and financial resource mobilisation, and has triggered comprehensive climate risk and vulnerability analyses. Ethiopia's decision to develop a strategic, national-level response to climate change has been triggered by a strong awareness of climate risks and strong political leadership. The historically high exposure to climate variability has created strong awareness about current and future climate impacts in Ethiopia. In its national development plan, the Ethiopian Government explicitly identified climate variability and climate change as a threat to its development goals, and hence called for a plan of action, strategies, laws, standards, and guidelines to lessen the effect of forecasted climate change. To fully mainstream climate resilience and green growth into development planning, the CRGE explicitly feeds into the overarching national development plan – HERA 2020 – 2030.
53. Ethiopia is already making substantive climate change relevant investments across its sectors. Climate change-relevant spending from the national treasury between 2008 and 2012 was estimated at an average of US$ 440 million per year, or 15 percent of total Government expenditure over these four years[54]. Additionally, while these investments are resulting in substantive benefits, which in the Ethiopian context are referred to as "unsupported' actions, the country has also been proactive in attracting and channelling finance from other sources, with a view to fast-tracking CRGE implementation. To this end, the then Ministry of Environment, Forest and Climate Change (MEFCC) and the then Ministry of Finance (MOF) together established the CRGE Facility with a clear mandate for climate-related resource mobilisation and management. To date the Facility has attracted US$ 20.8 m of climate finance from development partners. This funding has been allocated to support several Fast Track Investments (FTIs) in 35 Woredas (Districts) across all regions of Ethiopia. However, lack of finance has been identified as one of the three constraints (in addition to technology and capacity) that pose a major challenge to effective implementation of the CRGE strategy. Preliminary estimates indicate that building the green economy will alone require total expenditure of around US$ 150 billion over the next 20 years, with around US$ 80 billions of required funding estimated to be capital investment and the remaining US$ 70 billion assessed as being necessary to cover operating and programme expenses. This therefore underscores the need to mobilize significant amounts of new and additional finance from international, domestic, public and private sources in order to fully implement the CRGE strategy on the ground.
54. The CRGE strategy follows a sectoral approach and has so far identified and prioritised more than 60 initiatives, which could help the country achieve its development goals while limiting 2030 GHG emissions to around today's 150 Mt CO_2e (of which more than 85 percent came from the agricultural

[54] ODI, 2004

and forestry sectors) – around 250 Mt CO2e less than what is estimated under a conventional development path. The introduction of lower-emitting techniques for agriculture offers an opportunity to check this increase of emission, while maintaining production levels. The CRGE initiative has prioritised initiatives to limit the soil-based emissions from agriculture and limit the pressure on forests from the expansion of land under cultivation by intensifying agriculture through usage of improved inputs and better residue management. This will result in a decreased requirement for additional agricultural land that would primarily be taken from forests, while creating new agricultural land in degraded areas through small-, medium-, and large-scale irrigation. It will reduce the pressure on forests if expansion of the cultivated area becomes necessary and introduce into cultivated areas lower-emission agricultural techniques, ranging from the use of carbon- and nitrogen-efficient crop cultivars to the promotion of organic fertilizers to increase productivity.

55. In agriculture, GHG emissions are attributable to livestock and crops in that order. Emissions from crops are set to grow rapidly over the next 20 years due to increased use of fertilizer (~10 Mt CO2e) as well as the emission of N2O from crop residues reintroduced into the ground (~3 Mt CO2e). The proposed project, while focused on adaptation and building the resilience of vulnerable communities, will help address such challenges, by including improved agronomic practices that increase soil carbon storage, nutrient management to use carbon/nitrogen, improved tillage and soil management more efficiently, integrated systems (mixed crop-livestock agri-forest), and water management (irrigation, terracing, and other water harvesting techniques). This initiative would complement the existing government plans to strengthen the agriculture extension system.
56. Against this backdrop, the Government of Ethiopia has developed sector specific Climate Resilient (CR) Strategies for the 1) Water and Energy & 2) Agriculture and Forestry sector. The CR Strategies carves out interventions that can reduce this vulnerability and further shows that a lot of work is already being undertaken to reduce the vulnerability in the focus sectors, yet more needs to be done to ensure the future resilience of the national economy and its people, and more financing is required. The Strategy also recognizes combatting the negative impacts of climate change and building resilience requires collective responsibility of all stakeholders at different levels. The sectors must assume the leadership at the national level while working together with international efforts. To ensure success, it requires the involvement of local communities in the overall process. Further, the private sector is identified to play an important role in investments to build community resilience. Similarly, the CR Strategies acknowledge development partners could contribute significantly to ensure climate resilience by providing technical assistance, building capacity, and supporting implementation.

3.4 Climate Resilience (CR) Strategy for Water and Energy

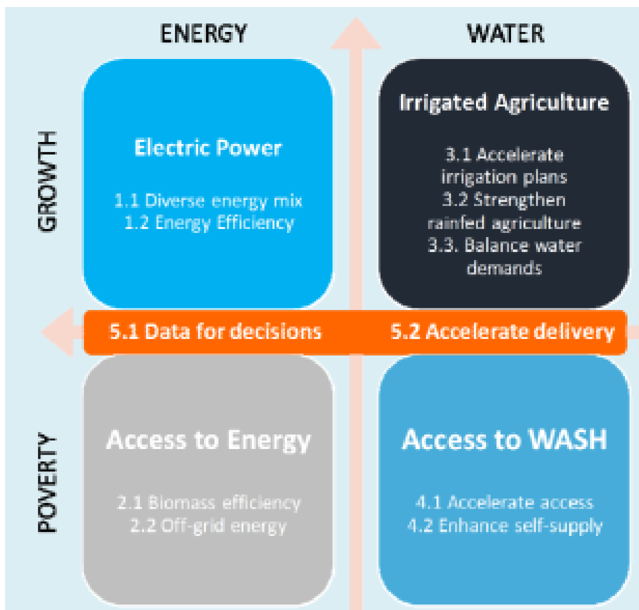
57. The water and energy climate resilience strategy has three objectives: a) to identify economic and social impacts of current climate variability and future climate change on water and energy, b) identify priorities for the water and energy sectors to build climate resilience and reduce impact of current climate variability and climate change, and c) map the necessary steps to finance and implement measures in the water and energy sectors to build climate resilience[55].
58. The strategy sets out 11 strategic priorities as set out below for climate resilience in the water and energy sector. Acceleration of irrigation investments and increasing access to off-grid energy are two of the priority areas. The climate resilience strategy for agriculture also identified irrigated agriculture as a key strategy for resilience (for both small- and large-scale irrigation).

[55] FDRE, 2015

59. The strategy points out that output and growth in the agriculture sector is exposed to rainfall variability (which is expected to increase in the future) and irrigation will play an important role in reducing this risk to agriculture (livelihoods and lives) – (Figure 13).

- The strategy estimates that growth potential of US$ 1.4 billion may be feasible in areas with insufficient water supply (these are lowland areas with very low rainfall).
- For the period 2015 to 2020 (GTP 2 period) a total of 176 medium and large-scale irrigation projects (over 5 million ha of irrigable land) is identified for assessment and implementation.
- The climate resilience strategy for water and energy points out that only 10 percent of the potential irrigation projects had reached detailed feasibility and design stage (from a total of nearly 3 million ha of irrigation area studied so far). Three quarter of the area identified is at reconnaissance or early stage of assessment.

Figure 13 Priority areas for implementation for Climate Resilience in the water and energy sector



I. Power Generation

- Strategic Priority 1.1 Diverse energy mix – hydropower production is dependent on rainfall, so we aim to diversify our energy mix to minimise the generation uncertainty. This requires some key strategic decisions to ensure that we can deliver a diverse and stable energy mix. Recent sector reforms need to be fully implemented.
- Strategic Priority 1.2 Improve energy efficiency – increasing energy efficiency will reduce the demand for electricity. Efficient lighting and motors could reduce energy demand by 7,930GWh in 2030 (12 percent of total energy sales) and peak power demand by 1,474MW in 2030 (12 percent of total peak demand).

II. Energy Access

- Strategic Priority 2.1 Improve efficiency of biomass use – reducing the demand for biomass by increasing fuel efficiency. The National Improved Cookstoves Program can contribute significantly to reducing demand.
- Strategic Priority 2.2 Accelerate non-grid energy access – the Rural Electrification Fund needs to be enhanced to deliver at scale. Pilot micro-generation projects need to be funded to demonstrate the potential for mini- and micro-grid solutions.

III. Irrigation

- Strategic Priority 3.1 Accelerate irrigation plans – feasibility and design work needs to be completed to fully understand the irrigation potential.
- Strategy Priority 3.3 Support the resilience of rainfed agriculture
- Strategic Priority 3.3 Balance water demands – Growing water demands need to be managed and allocated according to the water that is available.

IV. Access to WASH

- Strategic Priority 4.1 Accelerate universal access to WASH
- Strategic Priority 4.2 Enhance the climate resilience of self-supply – additional approaches and interventions to supplement self-supply, for example: improving local water storage facilities or participatory water resource management.

V. Cross-cutting issues

- Strategic Priority 5.1 Data systems for decision support – strengthening data systems so that they provide timely, reliable and usable data to decision makers at all level.
- Strategic Priority 5.2 Accelerate delivery of existing plans – a common theme across the CR Strategy is that most of our existing plans already support CRGE, but we need to accelerate delivery and implementation. Key bottlenecks are: co-ordination and streamlining of plans; performance feedback (monitoring implementation); monitoring gender impacts.

60. This proposal is thus designed to be coherent and aligned with GoE's national policies and will be an instrument to support the implementation of the CRGE strategy on the ground. The principal aim of the project is to build the resilience of vulnerable communities whose livelihood depends on rainfed agriculture and livestock rearing in an adverse environment. The project is designed to address Strategic Priority points 1.1; 2.2; 3.1; 4.1 and 5.2 outlined in the CR strategy of Ethiopia.

3.5 Climate Resilient (CR) Strategy for Agriculture and Forest

61. Launched in 2011, the Climate Resilient Green Economy (CRGE) strategy sets that by 2025 Ethiopia will be a middle-income country, resilient to climate change impacts and with no net increase in greenhouse gas emissions from 2010 levels. This resilience strategy for agriculture and forestry has been developed as part of the CRGE strategy. It shows that economic growth must be protected against the impacts of current and future climate change. The agriculture and forestry sectors are key to both national income and household livelihoods. Combined, the sectors make up over two-fifths of the national economy (43percent of our Gross Domestic Product (GDP)) and employ the vast majority (around 80percent) of the country's population. Due to reliance on rain-fed techniques, agriculture is

highly vulnerable to weather and thus to future impacts of climate change. Also, future climate change is expected to pose significant impacts on the productivity of our forests.

62. The food security strategy addresses both the supply and the demand side of the food equation – that is, availability and entitlement respectively from both a national and household level perspective. Within this, particular attention is focused on the diversity of food production zones in Ethiopia (i.e. areas with adequate moisture, moisture deficit and pastoral) to tailor options and strategies accordingly. The three basic pillars on which the strategy rests are: to increase the availability of food through increased domestic production, to ensure access to food for food deficit households; and to strengthen emergency response capabilities. The HER puts particular emphasis on the private sector's indispensable role in creating job opportunities, the government is determined to put the necessary policies and administrative structures in place to assist the private sector development in priority sectors suchas agriculture, manufacturing, mining, tourism and ICT sectors.

3.6 Ethiopia's First and Updated Nationally Determined Contribution (NDC)

63. Ethiopia submitted its first NDC to the United Nations Framework Convention on Climate Change (UNFCCC) in September 2017 with a revised version submitted in 2021. In its updated NDC, Ethiopia commits to reducing Greenhouse gas (GHG) emissions by 2030 to 125.8 Mt CO_2e. This means a 68.8 percent reduction of emissions compared to a Business-as-Usual (BAU) scenario in 2030[56]. A very ambitious target, which if reached, will enable Ethiopia achieve carbon neutrality by 2030. Full implementation of the updated NDC is contingent upon international support and a stimulating environment for enabling private investments in climate action.
64. Ethiopia based its NDC in its Climate Resilience Green Economy (CRGE) Strategy, focusing on (i) reducing GHG emissions and (ii) reducing the vulnerability of the Ethiopian population to the adverse effects of climate change.
65. Mitigation measures are built on four pillars that target agriculture (livestock and soil), forestry, transport, electric power, industry (including mining) and buildings (including waste and green cities): improving crop and livestock production practices for higher food security and farmer incomes, whilst reducing carbon emissions; protecting and re-establishing forests for their economic and ecosystem services (including as carbon stocks); expanding electricity generation from renewable sources of energy for domestic and regional markets; leapfrogging to modern and energy-efficient technologies in transport, industry and construction.
66. Ethiopia's food crops and livestock upon which the livelihoods of millions depend are underpinned by its natural resources – land, water and forests. In the face of growing climate change threats, such as temperature rise, frequent droughts and flooding, Ethiopia is working to address vulnerability and food insecurity to build the resilience capacity of its community. The resilience strategy for agriculture and forestry was developed as part of the CRGE strategy and shows that economic growth must be protected against the impacts of current and future climate change. The agriculture and forestry sectors are key to both national income and household livelihoods. Due to reliance on rain-fed techniques, agriculture is highly vulnerable to weather and thus to future impacts of climate change. The analysis exhibited in the CR Strategy for Agriculture and Forest shows the gravity of the challenge. Agriculture and the livelihoods that depend on it are vulnerable, and future climate change poses an even greater threat (for example, with increased incidences of droughts, the negative impacts on GDP could be 10 percent or more by 2050).

56 https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Ethiopia%20First/Ethiopia%27s%20updated%20NDC%20JULY%202021%20Submission_.pdf

67. Furthermore, the Government of Ethiopia recognizes that water and energy are both key for the country to meet with its CRGE ambition and the national goal for economic growth and poverty eradication. In total, sustainable water and energy supply plays a key role in around US$ 7.2bn of planned overarching national growth plan and the achievement of the MDGs through freeing up productive time and through improved health.
68. To assess the impact of climate change on building the resilience capacity of the community and consider uncertainty, based on available data, the Government of Ethiopia has defined a set of planning assumptions about how climate may change in future.

- Continued temperature increases of 0.8 to 2.7°C. Mean temperatures have been increasing and are likely to continue to do so with climate change.
- Year-to-year rainfall variability is the most significant climate variable and rainfall is likely to be less predictable with more frequent extremes in future.
- Parts of the country could see changes in key seasonal rainfall. The pattern of the belg and gu rains could change, which would have major implications for rural livelihoods and food security, particularly in Somali, South Oromia and parts of SNNPR.

69. These trends have several key implications for the water and energy sectors' contribution to Ethiopia's development.

- Cross-government partnership required to address key CRGE challenges. Several key areas lie outside of MoWIE's sole responsibility and require partnership with other Ministries.
- Current hydropower plans provide sufficient reserve generation to cope with climate change impacts, but this has an opportunity cost of US $208m/year in 2030. Extreme events would severely strain the grid – under the driest scenarios, a 1 in 50-year event could require 86 percent of reserve generation.
- Wood-fuel availability could be impacted by increases in temperature and changes in rainfall patterns, which reduces access to energy. By 2030, up to 8.5 million people will be living in high-risk areas where they are unable to meet their household energy needs
- Our planned growth in agriculture is also highly exposed to rainfall variability. Irrigation plays a role in reducing this exposure but is also at risk from changing rainfall. Up to US $16.8m of agricultural growth is at risk under driest scenarios due to insufficient irrigation. A further US $1.4bn of targeted growth has not yet undergone feasibility study but appears to be in areas where there is insufficient water supply.
- Universal water and sanitation increase climate resilience by shifting people from using exposed surface water sources to more resilient sources. However, climate risk interacts with technology and hydrogeology risks to create 'pinch points' for access to water. Up to 7.3m people in Tigray, Afar and Somali face the highest risk to water access as they are exposed to multiple 'pinch points.

3.7 The Agricultural Policy

70. Several strategies and policies refer and support the need for development of natural resources, community participation and diversified agriculture. The focus of agricultural policy has been to:

1) Increase food security,
2) Increase the supply of agricultural raw materials to the local industry,
3) Expand the local manufacturing industries to supply the rural areas and

4) Increase foreign exchange earnings

71. The policy is developed to bring about agricultural growth to broadly address three main areas, namely: price, institutional and technology development policies. The price policy has made it possible for traders to purchase grain from surplus areas and transport to deficit areas. The Institutional policy involves the restructuring of public enterprises, devolving agricultural activities to the regional governments, restructuring the national agricultural research system, and privatisation of state farms and the technology development policy focuses on the adoption of the new agricultural extension system, "Participatory Demonstration and Training Extension System" SWps, has accelerated the diffusion of productivity enhancing technological packages.
72. As part of the agricultural development policy, Ethiopia's Food Security Strategy (FSS) was first issued in 1996 and updated in 2002 (Teshome, 2006)[57]. It has been observed that food insecurity is one of the defining features of rural poverty affecting millions of people, particularly in moisture deficit areas. Both chronic and transitory problems of food insecurity exist. The government is tackling food deficit problem through the introduction of:

1) Small, medium and large-scale irrigation.
2) Drought resistant and early maturing varieties and with water harvesting technology.
3) Soil conservation and environmental protection.
4) Improved harvesting, handling, and storage facilities.

73. Food security is manifested directly in three security components: adequacy of supply (production, reduction of post-harvest loses), stability of supply (production and price stability), and access to supply (increase purchasing power of households and access to employment). World Food Summit (1996) also stated that Food security exists when all people, always, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"[58]. The consequences of food insecurity are reflected in the high level of malnutrition.
74. The basic principles that govern agricultural development policies and strategies in Ethiopia are adoption of labour-intensive strategy, development path compatible with different agro-ecological zones, proper utilization of agricultural land and coordinated development path.
75. The Agricultural policy puts due recognition in developing drought-prone regions where millions of people are becoming increasingly vulnerable to hunger and where desertification is posing a danger to agricultural livelihoods. A major feature of climate change driven drought-prone regions in Ethiopia is the intermittent and inadequate rainfall. These regions are also constrained by considerable soil depletion due to years of imprudent land use that has caused soil erosion over an extended period. In addition, land shortage is chronic and food insecurity is experienced in practically all drought-prone parts of Ethiopia.
76. According to National Planning Commission[59], in growth and transformation plan, the agricultural sector would continue to be the main source of economic growth. During the growth and transformation plan (GTP) period, a key strategic direction was to ensure small holder agriculture becomes the main source of agricultural growth by scaling up intervention based on the experience gained, and

[57] Teshome, A., 2006, March. Agriculture, growth and poverty reduction in Ethiopia: policy processes around the new PRSP (PASDEP). In a paper for the Future Agricultures Consortium Workshop, Institute of Development Studies, University of Sussex, UK (pp. 20-22).

[58] World Food Summit 1996, Rome Declaration on World Food Security. https://www.fao.org/3/w3613e/w3613e00.htm
[59] National Planning Commission. (2016). Federal Democratic Republic of Ethiopia: Growth and Transformation Plan II (GTP II). Vol. I.[Google Scholar].

identification of success achieved in the previous plan period. Experience to date has shown that it is possible to increase the productivity of small holder farmers within short period of time by better utilizing small holders labor, land and by using improved, but less capital-intensive agricultural practices and technologies.

3.8 Ethiopian Irrigation Policy

77. According to the Ethiopian Water Resources Management Policy, the general objective of the national irrigation policy is to develop the irrigation agriculture by the Regions for potential production of food crops and raw materials needed for agro industries, on efficient and sustainable basis and without degrading the fertility of the production fields, water resources base and irrigation water. Furthermore, the focus of the specific objectives of the policy is briefly outlined as below.

1) Ensure the full integration of irrigation with the overall framework of the country's socio-economic development plans, and more particularly with the Agricultural Development Led Industrialization (ADLI) Strategy,
    - Promote the development of irrigation on two- pronged approaches of: -
    - Strategic planning for achieving socio-economic goals and
2) Participatory- driven approach for promoting efficiency and sustainability,
3) Recognize that irrigation is an integral part of the water sector and consequently develop irrigation within the domain and framework of overall water resources management,
4) Earmark a reasonable percentage of the GDP as committed resource towards the development of irrigated agriculture, especially in capacity building and infrastructures,
5) Promote decentralization and users-based-management of irrigation systems taking account of the special needs of rural women in particular,
6) Develop a hierarchy of priority schemes based on food requirements, needs of the national economy and requirements of raw materials and other needs,
7) Support and enhance traditional irrigation schemes by improving water abstraction, transport systems and water use efficiency,
8) Ensure the prevention and mitigation of degradation of irrigated water and maintain acceptable water quality standards for irrigation,
9) Establish water allocation and priority setting criteria based on harmonization of social equity, economic efficiency and environmental sustainability requirements,
10) Integrate the provision of appropriate drainage facilities in all irrigated agriculture schemes,
11) Enhance greater participation by the Regional and Federal Governments in the development of large-scale irrigated farms in high water potential basins but with low population density Ethiopian Water Sector Policy,[60].

78. According to the Irrigation policies, strategies, and institutional support conditions in Ethiopia[61], the Irrigation Development Strategy was developed to increase the agricultural production potential of the country to achieve food self-sufficiency at the national level, including export earnings, and to satisfy the raw material demand of local industries without degrading the productivity of the land and water

[60] Ministry of Water Resources (MoWR) (2001). The Federal Democratic Republic of Ethiopia: Ethiopian Water Resources Management Policy, Addis Ababa, Ethiopia.

[61] Solomon Cherre, 2006, March. Irrigation policies, strategies and institutional support conditions in Ethiopia. In Best practices and technologies for small scale agricultural water management in Ethiopia. Proceedings of a MoARD/MoWR/USAID/IWMI Symposium and Exhibition held at Ghion Hotel, Addis Ababa, Ethiopia, and (p. 113).

resources base. The specific objective of the strategy is to expand irrigated agriculture, improve irrigation water-use efficiency and thus the agricultural production efficiency, develop irrigation systems that are technically and financially sustainable, and address water logging problems in irrigated areas.

3.9 Energy Policy

79. A national energy policy draft was prepared by MOWIE in 2020; the document has been submitted to the Committee reviewing national policies under the Council of Ministers; it is yet to be approved. The vision of the energy policy is to see equitable, sustainable, economically competitive, and clean energy supply to all by 2030.

Key considerations for the policy include:

1) The role of energy as enabler in the economic and social sectors
2) Accelerate the development of Ethiopia's large potential for renewable energy development for domestic uses and for export
3) Reduction of dependence on petroleum products, which is the source of greenhouse gas emission from Ethiopia, and to promote use of systems that rely on renewable energy sources (such as electric vehicles and electric rail)
4) Achieving the UN Sustainable Development Goals (SDGs) by 2030 and to meet Ethiopia's commitment to the Paris Climate agreement
5) Environmental sustainability of energy production and distribution, as well as to promote energy conservation
6) To increase the domestic component of energy inputs (infrastructure, equipment, knowledge and skills); and to increase the role of the domestic private companies in the sector

80. One of the strategies for energy supply is the promotion of development of off grid energy sources for electricity production. Another strategy for energy use is promotion of alternative energy sources for the agriculture sector including solar PV water pumping for irrigation.

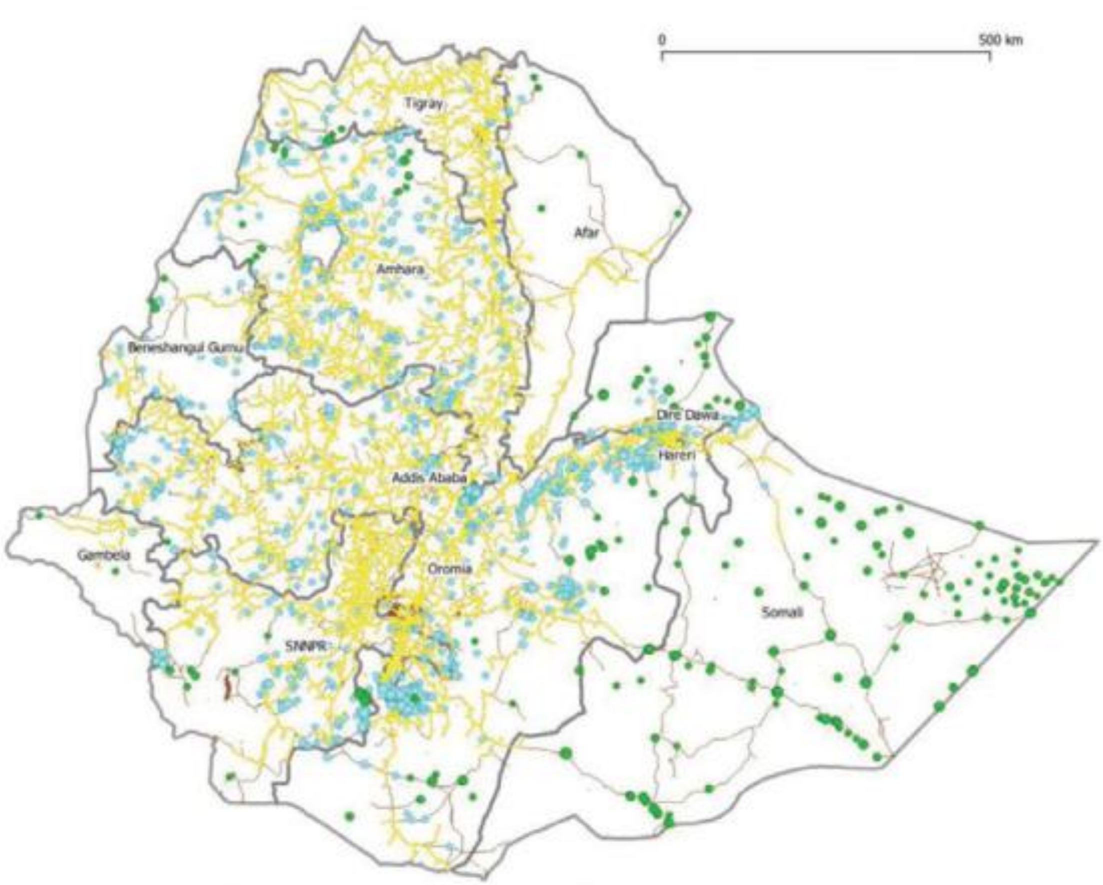
3.10 National Electrification Program (NEP) 2.0, FDRE, 2019

81. The NEP is a program for universal electrification of Ethiopia by 2025. The program envisions achieving universal electrification by 2025 through extension of the national power grid (65 percent of the electrification target) and off-grid electrification technologies (35 percent of the target). The plan envisages increasing connections to the national power grid to 15 million households (from 6.9 million in 2019); to enable up to 6 million households with off-grid technologies (mainly standalone solar systems); and support for universal electrification of all health and educational facilities (Table 1).
82. Development of mini grids is given emphasis in the off-grid electrification component of the NEP because mini grids are expected to provide higher quality of service to consumers including application of electricity for productive and social services. Mini grid development sites are also expected to become commercial centers for rural communities around them. The mini grid component of the program will have a public (implemented through the EEU) and PPP modalities of implementation.

Table 1 Investment for the Grid and Off-Grid Components of the Program

	Investment (US$ million)	GoE contribution (US$million)	Syndication (US$million)
A. Grid program			
Grid total investments*	3,200		
Customer contribution (—)	(1,100)		
Total	**2,100**	**480**	**1,620**
B. Off-grid program			
Access to finance (with a revolving fund)	1,760	530	1,240
End-user subsidy	72	72	-
Social institutions	230	70	160
MST off-grid solar	133	41	92
Mini-grids (MST and EPC)[a]	300	280	20
Off-grid total investment syndication	**~2,500**	**~1,000**	**~1,500**
C. Program implementation support (grid and off-grid)	**50**	20	30
Total Investment syndication (A + B + C)	**4,650**	**~1,500**	**~3,150**

Figure 14 Mini Grid Development Sites Identified by the NEP (light blue)



3.11 Access to Distributed Electricity and Lighting in Ethiopia (ADELE) Project

Programme Appraisal Document, PAD, March 2021

83. The ADELE project is a support facility under the NEP 2.0, mainly for off-grid electrification but also supports improvement of reliability of electricity supply in urban areas. The project will provide support for off-grid electricity access to 750,000 households with solar home systems; support the development of solar powered mini grids to serve 240,000 households and 11,500 businesses; and installation of standalone solar systems for 1,400 off-grid health facilities and schools (Table 2 & Figure 14).
84. A key consideration of the ADELE project is support for productive use of energy (PUE) in rural, peri-urban and urban areas. PUEs are to be promoted under the mini-grid component, component 2 and through standalone solar systems component 3 (Figure 15).

Table 2 ADELE Project Components and Financing, Million US $

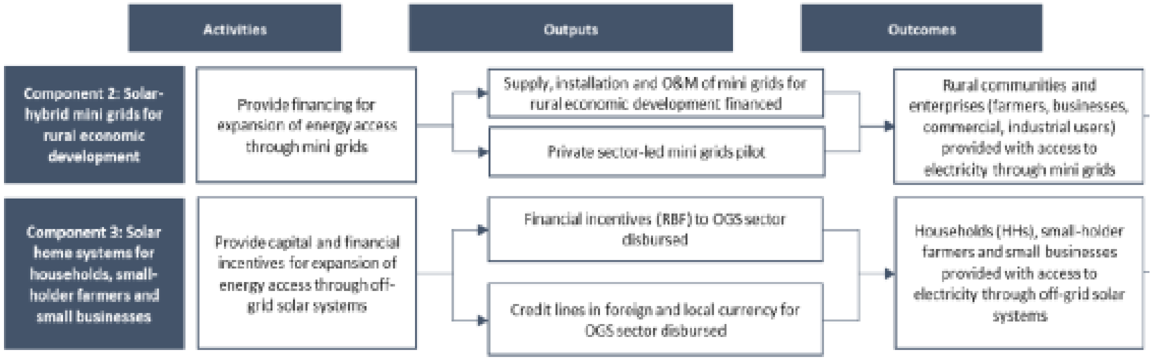
Components and Subcomponents	IDA Financing
Component 1: Network strengthening for improved reliability of supply in urban areas	**100**
Component 2: Solar-hybrid mini grids for rural economic development	**270**
Subcomponent 2.1: EEU-led mini-grids	217
Subcomponent 2.2: Private sector-led mini-grid pilot	53
Component 3: Solar home systems for households (HHs), small-holder farmers and small businesses	**50.5**
Subcomponent 3.1: Incentivizing market expansion into deep-rural areas innovation	10
Subcomponent 3.2: Access to finance to increase off-grid solar penetration	40.5
Component 4: Standalone solar systems for health and education facilities	**55**
Component 5: Capacity building, technical assistance, and implementation support[14]	**24.5**
Subcomponent 5.1: Enhancing EEU's institutional, technical and planning capacity	12
Subcomponent 5.2: Enhancing MoWIE's monitoring and technical capacity	11
Subcomponent 5.3: Enhancing the financial sector's capacity to provide financing to the off-grid energy sector	1.5
Total	**500**

85. PUE support is given high priority under the mini grid component because these will make investment in mini grids more viable (because they provide day time loads that complement evening loads from residential consumers). The mini grid ecosystem in Ethiopia is underdeveloped (ADELE, PAD, 2021):

"The mini grid ecosystem in Ethiopia remains nascent with few private players and limited success with business models. Local companies struggle with sufficient access to finance, companies that have demonstrated rapid scale in other markets are restricted from entering the Ethiopian market, and productive use of electricity solutions such as water pumping, and irrigation have not yet found inroads into the market. "

86. Solar powered irrigation is an important element in PUE development under both component 2 (solar hybrid mini grids) and component 3 (standalone solar systems). The ADELE project will increase access to electricity to households, enterprises, and social institutions through financing investments and providing support for institutional development (including support for market enabling environment to increase participation of the private sector in the off-grid electrification space).

Figure 15-The Theory of Change for the ADELE (for components 2 and 3)



3.12 Water Policy

87. The Water Resource Management Policy is intended to promote comprehensive and integrated water resources management and optimal utilization of available water resources for sustainable socio-economic development. Inter alia, the policy calls for conservation and protection of water resources as an integral feature of the water resources planning and development process, and therefore mandatory EIAs of all water resource development projects. The policy entrusts the Ministry of Water Resources with broad powers to plan, manage, use, administer and protect water resources, including the promotion and implementation of irrigation projects. The sub-sectoral policies include Irrigation, Hydropower, and Water Supply and Sanitation, each with an associated Strategy[62].
88. The Policy was elaborated in the Ethiopian Water Sector Strategy[63] , also known as the National Water Strategy. The purpose of the Strategy is to translate the Policy into action, with the following specific objectives: Improving the living standard and general socio-economic well-being of the Ethiopian people. The Strategy is a comprehensive document, covering all aspects of water resources development and management. Inter alia, it calls for mandatory EIAs for all water projects, and promotes gender mainstreaming[64].

[62] MoANR, 2016)
[63] Ministry of water resources, 2001, Ethiopian Water Sector Strategy
[64] MoANR, 2016)

Part B - Selection of The Target Regions Kobo Raya and Borena and Overall Project Rationale

89. Rationale for the selection of the target areas of Kobo Girana valley and Borena zone is mainly attributed towards existing build infrastructure that provides an opportunity to revise the delivery of it in a climate compatible manner. This project picks up from the ongoing implementation of the DREAM project, currently financed by the Rockefeller Foundation, AfDB and focuses in the productive use of energy. This project thus is scale up of the DREAM project and targets boreholes that have been drilled and capped in the target areas of Kobo Girana valley and Borena zone due to lack to funding resources but were planned to be equipped with diesel powered generators to abstract ground water. This proposal thus picks up on this low hanging fruit to use GCF funding to replace the planned diesel generators by solar power at the project site level for irrigation purposes in both areas, and also for potable water supply for humans and livestock. At the regional and federal level, this project will be a learning ground to scale the same project in the same regions where there are boreholes that are not targeted by this project or replicate the same in other regions.

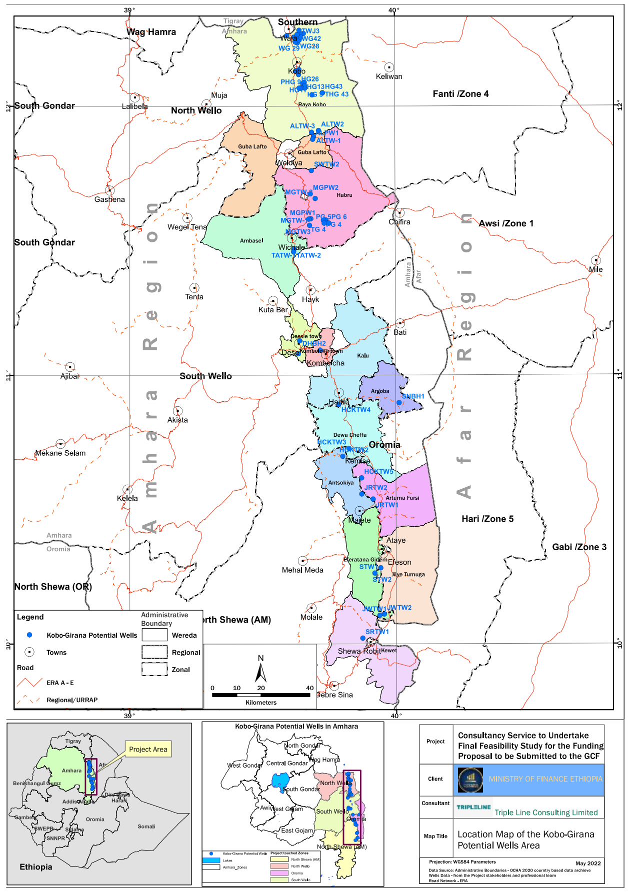
4. BASELINE OF TARGET LOCATIONS TO VULNERABILITY AGAINST CLIMATE CHANGE

4.1 Kobo-Girana Valley – Amhara Region

90. Kobo Woreda is one of the eight rural districts in North Wollo Zone in the North Eastern part of Amhara National Regional State of Ethiopia (Figure 16). The Woreda lies about 54 km north of the zonal town Woldia, 189 km south of Mekele and 570 km from Addis Ababa. Kobo Girana is bordered in the north by Tigray Region, in the south by Gubalafto and Habru woreda, in the east by Afar Region and in the west by Gidan woreda[65].

[65] Getachew Belay, 2018. Determinants of Households' Willingness to Pay for Soil Conservation on Communal Lands in Raya Kobo Woreda, North Wollo Zone, Ethiopia. MSc Thesis, Haramaya University pp 114.

Figure 16 Location map - Kobo-Girana, Amhara Region



91. Altitude ranges are from 1,350 to 1,500 both in Kobo and Girana sub-basins. These areas are mostly cultivated, growing cereals, pulses and vegetables as dominant crops. These major units include Vertisols, Fluvisols and Cambisols[66]. There are 43 rural and six urban kebele administrations.

4.1.1. Socio Economic Vulnerability

92. The conflict that erupted in 2020 at the backdrop of the devastating impact of COVID- 19 and locust infestation crisis in the Kobo Girana Valley has reduced the coping capacity and challenged the resilience of the local communities. To make matters worse, the conflict erupted in the middle of the harvest season, effectively halting attempts to gather the remains of already-depleted crops. Woreda authorities responsible for registering movement of Internally Displaced People (IDP's) into the region have reported that the outflux has now doubled and in some instances tripled since the conflict started. Woreda officials also reported that the desert locust infestation has damaged on average 50percent of the last Meher harvest (2020).
93. Although there are no official records that show deaths due to COVID 19, social distancing, conflict, movement restriction and market blockage has impacted the communities, particularly those within the lower income bracket.

[66] Amhara National Regional State, Bureau of Agriculture. (2014). Crop Development and Protection Package for Drought Prone Areas. Bahir Dar, Ethiopia.

94. The conflict has been attributed to have crushed livelihood base in the target region and put lives at greatest risk as it resulted in complete or partial loss of their household assets including food, seed reserves and livestock through widespread looting and or being caught up on fire in the midst of fighting. A number of people have been reported to have been killed in Kobo Girana valley though it is difficult to validate the numbers at this stage.
95. In most woredas of Kobo Girna, there is no functional public service except the health services that are also semi-functional in some of the woredas effectively halting the provision of reproductive health service for women. Destruction and/or damage of the energy infrastructure has resulted in lack of household electric power, grinding mills, and shutting down of the water supply system. Thus, the community is forced to use unprotected water sources without any treatment, traveling long distances to fetch water, creating extra workloads for girls and women to meet with their family needs which has directly exposed young girls to abduction. The situation in Kobo Girana currently is dire and appalling where women and children are the primary victims of the crises followed by elderly and people living with disabilities (Table 3).

Table 3 Population of North & South Wello and Borena Zone (Amhara Region)

#	Region	Zone	Wereda	Population*
1	Amhara	North Shewa	Antsokiya	79,091
2	Amhara	North Shewa	Eferatana Gidem	110,493
3	Amhara	North Shewa	Kewet	100,806
4	Amhara	North Wello	Guba Lafto	134,939
5	Amhara	North Wello	Habru	171,142
6	Amhara	North Wello	Raya Kobo	188,122
7	Amhara	Oromia (Amhara Region)**	Artuma Fursi	76,901
8	Amhara	Oromia (Amhara Region) **	Dewa Cheffa	130,512
9	Amhara	Oromia (Amhara Region) **	Jilye Tumuga	67,807
10	Amhara	South Wello	Ambasel	116,017
11	Amhara	South Wello	Argoba	34,998
12	Amhara	South Wello	Dessie town	120,095
13	Amhara	South Wello	Kalu	166,371
14	Amhara	South Wello	Kombolcha town	111,870
				1,609,164
***Population data projected is based on 2007 CSA census data**				
**** Oromia is a special zone within the Amhara region**				

4.1.2. Agriculture

96. The Kobo-Girana valley is characterized by mixed farming agricultural practice: i.e., the farming society produces crops and rears animals and almost all farmers practice this activity[67]. In general, the economy of the region is highly dependent on mixed farming system. The sector is notably characterized by traditional rainfed subsistence farming using basic (traditional) farm implements, traditional agricultural techniques and very low inputs. Furthermore, bad weather (climate change in high

[67] ADSWE, 2013. Irrigation Agronomy Feasibility Study and Detail Design Draft Report of Alewuha_Kobo Ground Water Irrigation Project: Amhara National Regional State, Bahir Dar, Ethiopia.

temperature and variation in onset and end of rainfall) conditions coupled with crop pests attack, lack of modern technologies, severe soil erosion resulted in low production of the project area.

97. Unreliable and low rainfall condition brought about as a result of climate change added with severe soil erosion and poor management practice, crop pest occurrence and insufficient controlling mechanisms, low agricultural input use, lack of improved farm implement, poor cropping system, inadequate extension service, and back ward irrigation development have been identified as the main factors affecting the livelihood of the community in the Kobo-Girana area. The socio-economic condition of the project area is characterized by high population growth and pressure, subsistence agricultural economy, low diversification of income and employment, high degree of poverty incidence and food insecurity, degradation and deteriorating livelihoods. In recent years, though many efforts have been made to improve livelihoods, however significant number of the rural population still suffers from multiple socio-economic problems.
98. In addition to erratic and unpredictable rainfall pattern affecting the vulnerability of the population, population increase has also resulted in land fragmentation and shortage of arable land. As a result, the majority of the households own very small plots of land. The agricultural sector suffers from critical shortage of arable land, degradation and soil fertility decline, unrewarding traditional farm practices, and low level of input utilization. Over 98 percent of the agricultural production depends of rainfall and less than 8percent of the agricultural land is under fertilizer. Irrigation, though currently increasing, has benefited only small proportion of the households. Furthermore, crop pests, weeds and various diseases devastated significant volume of production each year. Lack of diversification of cropping pattern also makes the cropping system more vulnerable to climate risks.

4.1.3 Livestock

99. Livestock production in the Kobo Girana valley is subsistence and used mainly for traction power, with limited milk and meat production. Rapidly declining individual and communal grazing land, animal diseases and pests, poor animal husbandry practices are some of the problems affecting the livestock sector. Non-farm activities are also not well developed to support the livelihood of the poor. However, in recent years, with increasing poverty and destitution, a number of households started to engage in various non-agricultural activities. Yet, income from this sector is low due to lack of competitive power, access to credit, lack of technical support, and weak entrepreneurship. Due to vulnerability of the agricultural sector, farm income is also low and predominantly depended on the volume of annual production. Lack of affordable rural credit further crippled income and employment opportunities and diversification of livelihoods.

4.1.4 Ground Water Availability

100. The Kobo pressurized irrigation project was initiated in 1998 by the Commission for Sustainable Agriculture and Environmental Rehabilitation in Amhara Region (Co-SAERAR) to tackle the food insecurity in the valley. Then after, Kobo Girana Valley Development Program (KGVDP) Office was established as a project office 1999 by the Amhara National Regional State with the aim of enhancing food security through irrigation development in the Kobo-Girana valleys. Subsequently studies and drilling was conducted (mostly at the western part of the valley) by German Consult, Kobo-Alamata Agricultural Development Program (1977), Relief Society of Tigray (1998), Water Well Drilling Enterprise (1998), Ethiopian Institute of Geological Survey (1998), Water Works Design and Supervision Enterprise (2005), and Tekeze Deep Water Wells Drilling Plc (2006).

101. The alluvial deposits found in the Kobo-Valley are composed of intercalating layers of gravel, sand, silt and clay. Both geophysical investigation and drilled well logs indicate thickness of the sediment aquifer ranges from a few meters to 170 meters. The thickness is minimal on both western and eastern flanks whereas the maximum of 250 m, occurs towards the central part. Depth of groundwater table in the valley varies according to local hydrogeological and morphological conditions. In the western and central part it varies from 20 to 5 m and it gets shallower towards southeast. It is greater than 50 meters along volcanic ridge of Mendefera, western flank and near to the inselberg hills. Shallower groundwater depth condition is expected along the proximity of dry rivers.

102. The groundwater of the basin unconsolidated deposit aquifers has a groundwater divide along the Mendefera volcanic ridge and is divided into two parts: Hormat- Golina and Waja-Golesha groundwater systems.

- Hormat-Golina Well field: The well field is located southwest of Kobo town. It includes Horamt, Golina and Aramo areas. It has an approximate area of above 50 sq. km. and the sediments comprise sand and gravel.
- Waja-Golesha Well Field: Occupies the plain located between Waja and Golesha within Kobo sub-basin. The well fields start from the alluvial fan at the bottom of the Lasta Mountain to the edge of Zobel ridge. In the south it is bordered with Mendfra Insberg hill. It has an approximate area of about 45 sq. km. The geology is mainly composed of coarser materials, sand and gravel. According to the report of Kobo Girana Development Project Office report (2011), the Kobo sub-basin groundwater resource safe yield was estimated using analytical method. It is found to be around 309,942 m^3/day (186,514 m^3/day for Hormat Golina well field and 123,428 m^3/day for Waja Golesha Well field).

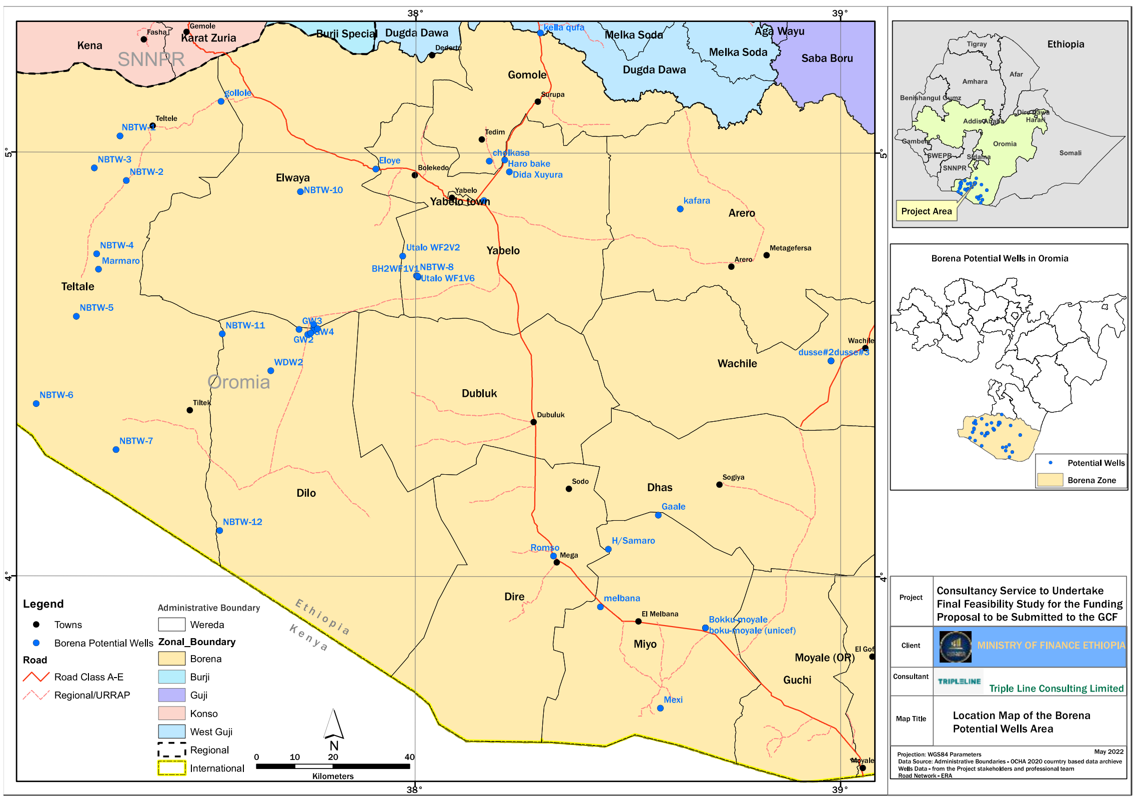
103. In order to understand the ground water abstraction rate limits, the annual production of a well in the basin is calculated based on the assumption of pumping for 20 hours/day for 250 days per year at a rate of 30 l/s. Accordingly, a total of 246 high-capacity irrigation were identified to be developed in Kobo-Waja, Kobo- Robit, Alawuha and Gelana sub-basins[68]. The total number of proposed boreholes to be drilled in the first stage of development of the project was 160 which is about 65percent of the total boreholes planned to be drilled by the project. According to the Feasibility Study Report for the Kobo-Girana Valley Development Program (1999), 70 wells in Waja-Golesha, 76 wells between Hormat and Golina, 10 wells in Alawuha and 4 wells east of Mersa town were successfully completed during the first phase of the drilling program.

[68] Feasibility Study Report for the Kobo-Girana Valley Development Program, 1999

4.2 Borena – Oromia Region

104.The project location is targeted in Teltele and Dillo Woreda of the Borena Zone (Figure 17) in the Oromia Region. The community is largely pastoralists that depend on livestock production for their livelihoods, with limited crop-livestock mixed farming system. Goats, sheep, cattle, donkeys and camels are the dominant sources of income and basis for livelihoods of the pastoralists. Dillo Woreda is one of the project Woreda where some pastoralists cultivate cereal and pulse crops with both meher and belg season rainfall – but, due to shortages of rainfall, not all cultivated land is currently productive.

Figure 17 Location map – Borena, Oromia Region



4.2.1 Socio Economic Vulnerability

105.Pastoral production remains the dominant land use in Ethiopian lowlands, which occur below an elevation of 1500m and constitute between 54 and 61 percent of the country's surface area[69]. Pastoralists are defined variously in the literature as those who obtain more than half their income from livestock and livestock products and who characteristically practise mobility to avoid risk, respond to variable climatic conditions and ensure healthy livestock and rangelands (Figure 18).

106.According to the OCHA report 2021, drought and insecurity in the Borena Zone is affecting the continuity of essential health services, increased school dropouts, crop production losses, price increase and lack of water continue to be an issue. The USGS/USAID/FEWS NET revealed that rainfall

[69] Coppock, 1994

performance as of November 2021 was well below normal. The rainfall in Borena was 51 percent of average, the driest season on record since 1981.

107. According to the FAO rapid assessment report released in November 2021, approximately 68,000 animals have died and over 1 million animals were in poor condition due to the impact of consecutive droughts in the previous years. The poor outlook of the current rainfall will result in more loss of animals and livelihoods. Zonal authorities estimate about 443,000 people in Borena to be facing critical lack of potable water. Water trucking intervention is ongoing in both but insufficient due to resource constraints. Purchasing power has also deteriorated due to falling livestock prices (to poor body conditions) against increasing prices of food items. A mature goat is now worth 40-45 percent of the food it was worth last year, whereas it could fetch 148 kg of maize in October 2020, it is now worth 60 kg. The situation is the same for teff (115 kg then, now 45 kg) and haricot beans (124 kg vs 58 kg). Only 211 of the 411 schools in Borena have water reservoirs, implying water storage remains a challenge in other schools even in the presence of water trucking interventions.

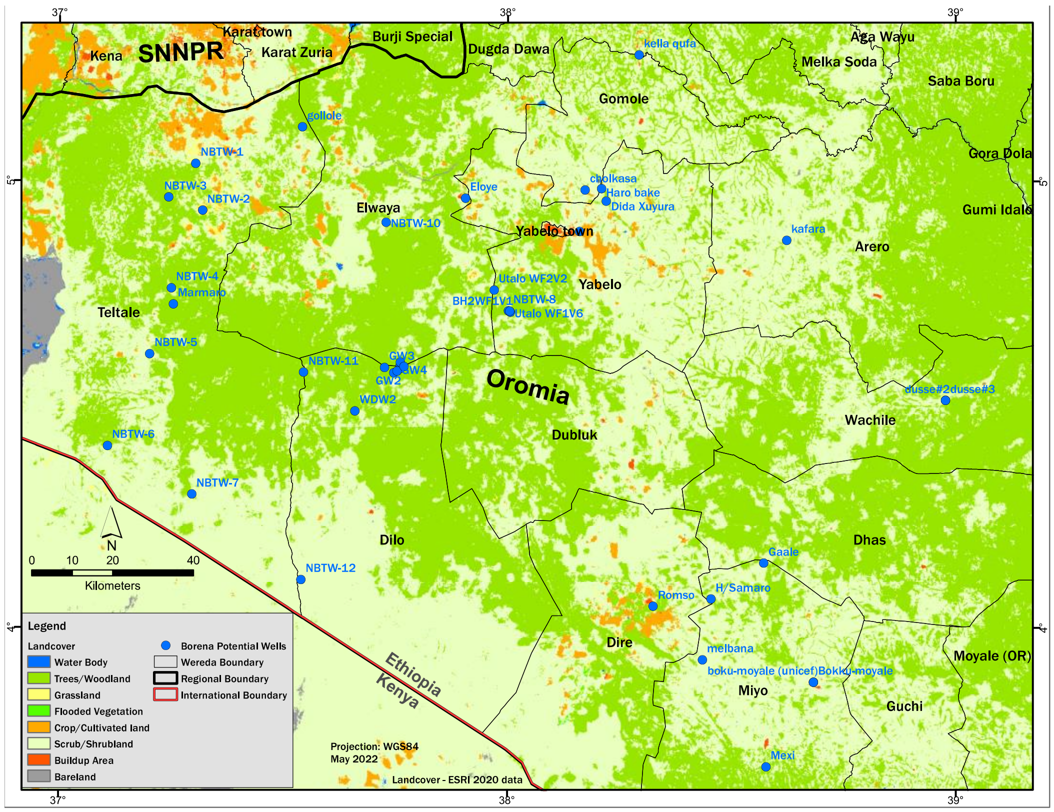
108. The situation is expected to worsen, as the current rainfall season is approaching its end, with no signs of substantial improvement. Water and pasture situation will start to improve with the onset of the next season, by March 2022. During this lean period, more animals are expected to die. Priority interventions include livestock feed, water and animal health services.

109. According to ECDSWC, a total of over 30,000 households in Mermero kebele and Elkune kebele (Teltele Woreda) are supported by Productive Safety Net Program (PSNP) due to food insecurity caused by climate change[77]. Cash and food items (255 birr per head and 15 kg grain per head per month) is extended to the poor pastoralists, elders and individuals who are unable to work. Similarly, data from Dillo Woreda Agriculture and Natural Resource Development Office shows about 13,000 households are supported by PSNP and World Food Program (56 respecttively.

110. It is widely recognized that poor communities' particularly pastoralists of Borena are politically and economically marginalized and their livelihoods are highly dependent on natural resources with weak local adaptation mechanisms making highly vulnerable to the impact of climate change[70]. The high dependence on natural resources and climate sensitive livelihoods coupled with the existence of rampant poverty, weakening of local adaptive mechanisms and variable weather events has put the pastoralists in a most vulnerable position[71].

[70] Macchi, M., 2008. Indigenous and Traditional Peoples and Climate Change. Issue Paper. IUCN - Danièle Perrot-Maître
[71] Akililu and Alebachew (2009)

Figure 18 Land cover map – Borena, Oromia Region



4.2.2 Livestock

111. Pastoralists in the Borana lowlands will continue to depend on rainfed agriculture as a primary source of livelihood for which they face considerable uncertainty due to prevalent climate perturbations and eroded ability to adapt[72, 73, 74]. The dependency presents the need to urgently and successfully deal with multiple internal and external pressures to significantly reduce vulnerability to changing climate manifesting itself through increased temperature and more frequent/intense droughts already felt by the community. The study reports also found that for the pastoralists of the Borena:

1) Climate change adaptation is intrinsically resilient or transitional,
2) Indigenous knowledge and resources play a crucial role in adaptation, and
3) There exist a wide range of barriers to adaptation and these barriers are limiting adaptive capacity and shape routes for adaptation.

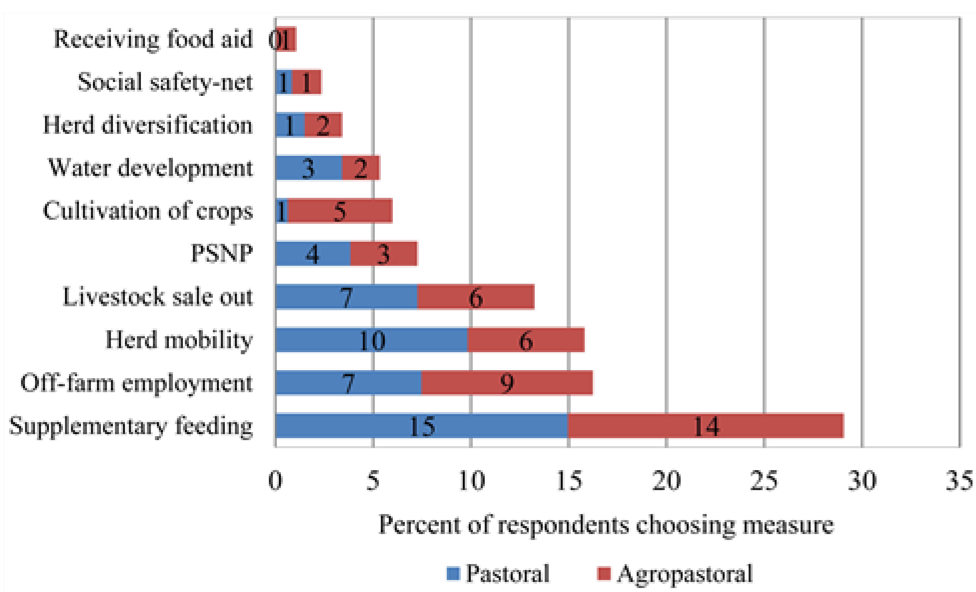
112. The study has shown that pastoralists in the Borana farming systems adopted a wide range of adaptation measures and tried to remain flexible to overcome what they perceived as changing climatic conditions. Supplementary feeding, off-farm employment and herd mobility to remote areas are the

[72] Debela, N., McNeil, D., Bridle, K. and Mohammed, C., 2019. Adaptation to climate change in the pastoral and agropastoral systems of Borana, South Ethiopia: Options and barriers. American Journal of Climate Change, 8(1), pp.40-60.
[73] Ayele, Tariku & Dedecha, Diba & Duba, Daniel. (2021). The Impact of Climate Change on Pastoralist Livelihoods in Ethiopia: A Review. 63. 8-14. 10.7176/JRDM/63-02.
[74] Boru, D., Schwartz, M., Kam, M., & Degen, A. A. (2014). Cattle Reduction and Livestock Diversification Among Borana Pastoralists In Southern Ethiopia. Nomadic Peoples, 18(1), 115–145. http://www.jstor.org/stable/43124164

three most commonly used adaptive strategies pastoralists and their communities pursued as responses to climate change. Declining seasonal rainfall with often below average extreme lows, its uneven seasonal distribution and increased temperature are key features of perceived climate change they responded to. Particularly, increasingly frequent as well as intense drought conditions continue resulting in scarcity of pasture and water resources challenging the sustainability of traditional pastoralism.

113. Considering the most commonly used adaptation options between pastoral and agropastoral systems, they are similar but with noticeable differences. Households in the Agro-Pastoral system are engaged in cultivation of food crops (e.g., maize and sorghum) and off-farm employment (e.g. petty trade) as compared to pastoral ones (Figure 19). Agropastoral households obtain more percentage of non-farm income and less of farm income as compared to pastoral households. Whereas herd mobility to remote areas and supplementary feeding of animals are identified as the most commonly used option by more households in pastoral systems than agropastoral counterparts. The variation can be attributed to the fact that livestock rearing is a primary source of livelihood for pastoral community which makes an important source of income. Subsequently, average livestock holding is relatively larger among pastoral households than their agropastoral counterparts.

Figure 19 Percentage of pastoral (n = 240) and agropastoral (n = 240) household interviewees identifying the most common adaptive measures adopted across production systems. (PSNP = Productive Safety Net Programs.)

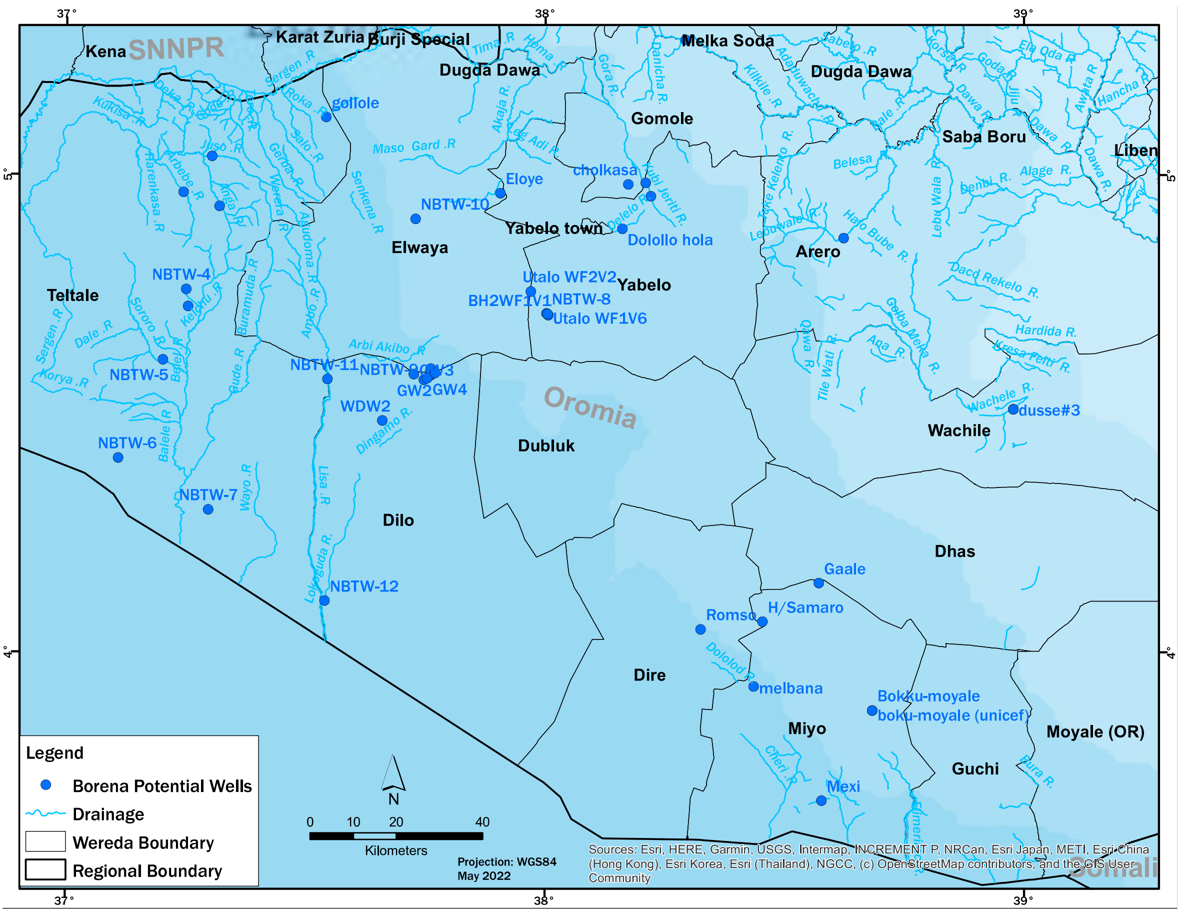


4.2.3 Ground Water Availability

114. The Borena basin is located in southern Ethiopia, a semi-arid climate, on the eastern shoulder of the south Main Ethiopian Rift (MER) and bordered with Kenya. The study area covers 18,000km^2 and is characterized by a lack of perennial surface waters that can be used for domestic and agricultural purpose. As a result, groundwater, which occurs in complex volcanic settings, is the only source for water supply in the study area. Rainfall is erratic and variable and is reflected in the vegetation type. Unable to depend on annual cropping, the Borana have developed one of the most elaborate water control and management systems and an efficient and extensive livestock production system that includes mixed herds of cattle, camels, sheep and goats, and equines.

115. The water management systems employed by the Borena community ensures equitable access for the livestock to all households. Water sources can be divided into surface and groundwater, with people and livestock typically transitioning from seasonal surface water sources in the wet season, to permanent groundwater sources in the long dry season. Surface water sources include seasonal runoff that is harvested in shallow depressions and water courses, small and large ponds and rainwater harvesting systems (Figure 20). While widely used in season, surface water from ground catchments carries risks of faecal contamination and associated illnesses. Such risks are much reduced when households switch to accessing water from groundwater sources in the dry season, including traditional shallow and deep wells, handpumps and shallow boreholes and motorized and deep boreholes.

Figure 20 Drainage map with topographic relief – Borena



116. Management of different water sources varies with the most complex systems associated with traditional wells, in particular the nine ela tula or deep well complexes found on the central plains. The management of these traditional wells is well documented in various literature sources [75, 76, 77]. Each well is owned and managed by a clan representative responsible for day-to-day management including

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75 Boku Tache and B Irwin. "Traditional, Institution, multiple stake holders and modern perspectives in common property: Accompanying change within Borana pastoral system." Food and Agriculture Organization of the United Nations (2003).

76 Beshah et al. "Indigenous Practices of Water Management for Sustainable Services: Case of Borana and Konso Ethiopia." Traditional Wisdom: Before It's Too Late (2016).

77 Helland, J. "Social organization and water control among the Borana of Southern Ethiopia. Nairobi, Kenya: International Livestock center for Africa." International Livestock Research Institute (ILRI) (1980).

use, routine cleaning, maintenance and coordinating labour for more major repairs. While women collect water on a daily basis, cattle are watered on a strict three-day rotation, in order that all are watered equitably. This requires high levels of cooperation and organisation that researchers suggest provides the foundation for the Borana's complex social systems. Study conducted by Care Ethiopia in 2021 confirmed that communities continue to mobilise significant local resources of up to US$ 7,000/ month for the development of new and repair of old ela adadi or shallow wells.

117. In recent formal and informal reports on the situation in the lowlands of Borena, drinking water appears as the main concern. Drinking water is becoming more-scarce for livestock and domestic use as all the available ponds are drying and more and more hand-dug wells are also running dry due to regressing ground water levels[78]. According to University of Pennsylvania – African Studies Center (Ibid), climate change has brought wide challenges on the pastoralist society of Borena Zone in general and the project area in particular. The major ones are 18 months of drought and near drought conditions have inflicted a heavy toll; extremely scarce drinking water for humans and livestock and absence or lowering of remaining surface water and levels in the traditional deep water cisterns (locally called Ellas), creating poor quality drinking water and a health hazard; diarrhoea and arising of other intestinal disorders; livestock (in Borana society, mainly cattle) suffer from scarce water resources and lack of pasture, cattle have started to perish and there is little doubt that more livestock will be lost before the next rainy season sets in. The most negative effect of the poor condition of the cattle herds is the lack of milk for human consumption; malnutrition among children (especially up to 5 years) appears to be increasing as there is a scarcity of milk. Malnutrition usually goes together with heavy infestation of parasites/worms. Bloody diarrhoea, malaria and gastritis are common among the adult population (Figure 21).

Figure 21-Sample Pictures Demonstrating the Severity of Climate Change on Borena Zone Cattles

118. Women in Borena are negatively impacted as they are required to walk between 5-10 km every day and spend on average 3-5 hours collecting water. Even though water points that were fitted with diesel generators have recently been made functional as they have been fitted with new submersible pumps, generators and fittings, installation and/or sizing and matching of components was not done correctly. According to USAID study, access to safe water, compared to routinely collecting water from remote areas, has improved health outcomes; and time-saving that could be invested in other livelihood

[78] Eggenberger, W., 2000. Relief Assistance Alleviates Crisis but More Help Needed. A Field Mission Report, University of Pennsylvania - African Studies Center, UNDP-EU. Borena Zone of Oromia, Ethiopia

activities. The study concluded that there is a huge change in living standards for those people who benefit and 'its importance cannot be stressed enough'. The study did however highlight concerns regarding sustainability and the impact of the water- related investment on socio-cultural habits[79]. This is further substantiated by a study conducted by CARE Ethiopia[80] that reveals that while the community recognized the multiple benefits that emerge from water resources development, they were however inclined to choose traditional ground water resources. The main reason behind this decision is mainly attributed to boreholes fitted with motorized schemes frequently break down and are not sustainable. This has directly affected the predictability of water availability and has brought about a detrimental impact on the seasonal grazing, land management, rangeland and livestock productivity

119. The Zonal and Woreda Water Bureaus stated that they do not have the capacity to support the maintenance and/or repairs of all schemes. The high degree of failure of assets in the Borena Region has been attributed to unavailability and/or shortage of spare parts, lack of regular maintenance of generators which has led to pushing an increased number of women collect water from cattle troughs. The government and local development partners have now resorted to mobile tankers to provide emergency water.

120. As a result, many pastoralists in Borena zone have now shifted from customary pastoralism into smaller-scale commercialized livestock-keeping, notably of goats and sheep. Higher temperatures during peak drought periods raises the demand for more livestock water to substitute for loss due to dehydration and puts increased evaporative demand on plants[81] (Table 4).

Table 4 Population of Borena Zone (Oromia Region)

#	Wereda	Zone	Region	Population*
1	Arero	Borena	Oromia	67,716.00
2	Dilo	Borena	Oromia	43,565.00
3	Dire	Borena	Oromia	55,140.00
4	Elwaya	Borena	Oromia	44,976.00
5	Gomole	Borena	Oromia	17,185.00
6	Miyo	Borena	Oromia	62,676.00
7	Teltale	Borena	Oromia	69,699.00
8	Wachile	Borena	Oromia	31,941.00
9	Yabelo	Borena	Oromia	110,475.00
				503,373.00

* CSA Census data and Oromia Engineering Corporation Study Feb. 2022

5. GAPS ASSESSMENT

5.1 Kobo-Girana Valley – Amhara Region

5.1.1 Baseline - Agricultural Irrigation Practices and Cropping Pattern

79 USAID, 2014, Iimpact of lowland water projects in Ethiopia

80 Cullis, A., with Ali, D. B. and Irwin, B. (2019). Water in Borana, Ethiopia: A study of the development, use and maintenance of water sources in the rural areas of Borana Zone

81 Debela, N., McNeil D., Bridle K., Mohammed C., 2019. Adaptation to Climate Change in the Pastoral and Agropastoral Systems of Borena, South Ethiopia: Options and Barriers. American Journal of Climate Change, http://www.scirp.org/journal/ajcc ISSN Online: 2167-9509 ISSN Print: 2167-9495.

121. Kobo Girana area represents where the community practice mixed farming system with crop production as a primary way of livelihood earning followed by livestock rearing. The valley is characterized to have been cyclically affected by climate change since 1965[82] and manifested in the form of rainfall variability, reduction of soil fertility, occurrence of crop pests and diseases[83]. Even though the area has an enormous potential for crop production, agricultural productivity is generally low and subsistence oriented typically characterized as "low input – low output" productivity. Crop production is predominantly carried out under rain-fed condition and is frequently vulnerable to natural vagaries such as droughts and floods[84] .
122. Irrigated agricultural production is very minimal compared to the potential and extent of the area. It is practiced on a small scale mainly based on river diversions, and in the case of the project area, from deep wells. There is no large scale irrigation in the area[85]. Groundwater based irrigation was commenced by the regional government and run by Kobo-Girana Valley Development Project (KGVDP) since 2005[86]. In both areas of the valley, the irrigation scheme was implemented with the objective of increasing food security through reducing the dependency on rain fed agriculture. The Kobo District (Woreda) has a potential irrigable area of about 20,000 hectares, of which 1,100 Ha (5.5 percent of the potential) has been developed. There are over 236 boreholes that have been drilled in the valley, of which 92.2 percent were financed by the government and 7.8 percent by the private sector. All the wells that were drilled by the private sector are currently functional and provide water for irrigation purposes while only 28.8 percent of the government drilled wells are functional and irrigation structures constructed. Farmers are cultivating both cereal and vegetable crops using complimentary irrigation system have seen better income and improved livelihoods. The remaining 71.2 percent would require submersible pumps and irrigation systems to be installed before they are operational and provide ground water for irrigation purposes.
123. Despite the effort that has been made by regional government, stakeholders and the needs of the community, irrigated agriculture has been developed only to a limited extent. Except very limited number of schemes, the majority of the existing irrigation schemes deploy traditional methods. However, the newly studied and design irrigation projects recommend drip irrigation for saving scarce water[87]. Different high value crops such as onion, tomato, cabbage, and pepper crops are the common existing crops and recommended by the new studied projects in Kobo Girana valley. Also, major fruit banana, papaya and avocado are included in the recommended cropping pattern. Crops such as sorghum, teff, barley, wheat and maize crops are the existing major crops cultivated with rainfed in Kobo Girana and neighbouring areas, whereas common bean, field pea, sesame, lentil, finger millet, nigger seed, line seed and chickpea crops are growing on limited areas of land.
124. Irrigation practiced in the Kobo Girana Valley and almost all other parts of Ethiopia consider the use of medium to heavy-duty diesel-powered pumps to pump ground water at the design stage. This has resulted in directly inflating the initial investment cost and further inflates the operational cost of the whole project as the design is inherently not efficient. These inefficiencies in the operational cost mainly

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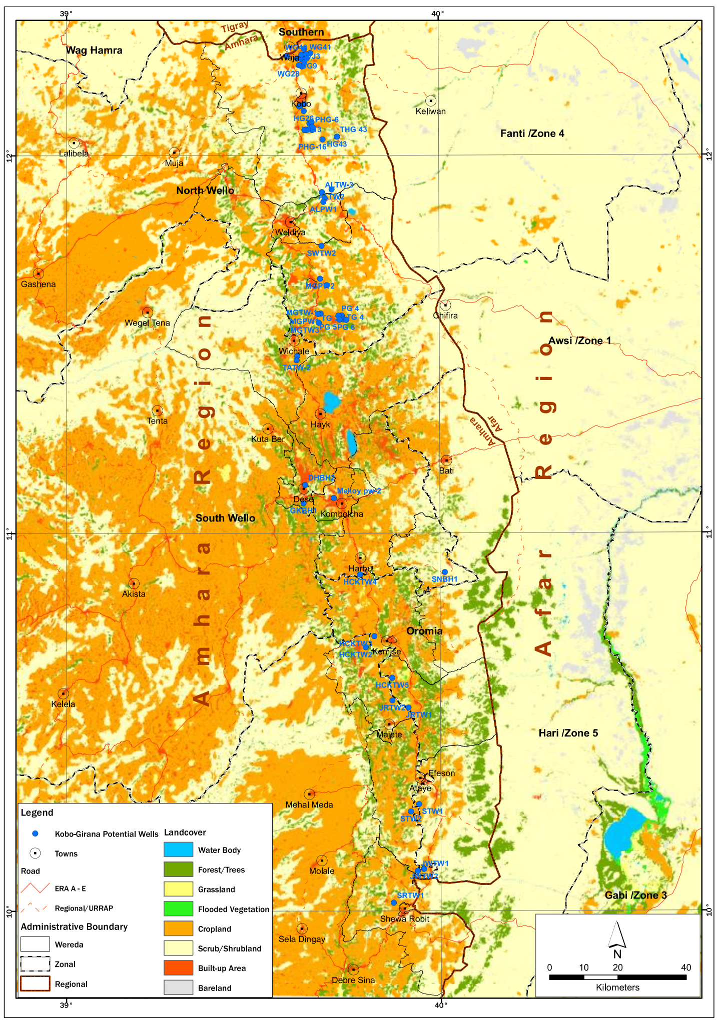
[82] Seleshi, Yilma & Camberlin, Pierre. (2006). Recent changes in dry spell and extreme rainfall events in Ethiopia. Theoretical and Applied Climatology. 83. 10.1007/s00704-005-0134-3.
[83] Amhara Bureau of Agriculture, 2014
[84] Metaferia Consulting Engineering PLC. (MCE), 2008. Girana Irrigation Agronomy Study report. Addis Ababa, Ethiopia.
[85] MCE, 2008. Girana Irrigation Agronomy Study report. Addis Ababa, Ethiopia.
[86] Abrham Melesse Endalamaw, "Optimum utilization of groundwater in Kobo valley, eastern Amhara, Ethiopia," A Thesis Presented to the faculty of the graduate School of Cornell University, in partial fulfillment of the requirements for the Degree of Master of Professional Studies (MPS), 2009.
[87] ECDSWC, 2021. The Federal Democratic Republic of Ethiopia: Irrigation Development Commission, Study and Design of Borena Groundwater Irrigation Development Project: Final Feasibility Report on Agricultural Planning and Irrigation Agronomy Studies. Addis Ababa, Ethiopia

emerge from the daily cost of purchasing 200 liters of fuel, which can only be transported using a pickup vehicle. The additional cost of transporting the fuel for the vehicle including operation and maintenance of both the diesel generator and the transporting truck is an additional cost, not to mention the carbon that is emitted by both engines. Age will further exasperate the issues as there will be frequent breakdown of the generators and the vehicle rendering them inoperable in a matter of 6-7 years after installation/purchase.

125. The private sector however has been able to run the irrigation scheme for a longer period as they are more efficient and regularly maintain their assets. Recently however, there has been an increased case that more and more of their machines require frequent maintenance and services due to age and has significantly increased their operational cost making the price of their products higher. This eventually will translate towards rendering them less competitive both in the national and the international market.

Figure 22 Land cover map - Kobo Girana



5.1.2 Baseline - Livestock and Challenges with Low Productivity

126. The Kobo Girana valley is known with crop livestock mixed farming, characterized by various constraints mainly moisture scarcity due to rainfall variability, reduction of soil fertility and low or absence of perennial rivers (Amhara Bureau of Agriculture, 2014). Moreover, the livestock are highly affected by shortage of pasture and water scarcity.
127. Livestock and its product contribute a significant proportion of cash income for households. The livestock population of the woreda is estimated as 242,621 cattle, 32,602 sheep, 118,375 goats, 13,863 camels, 21,611 donkeys, 674 mules, 44 horses and 156,126 poultry[88]. Major problems that affect livestock production and productivity includes shortage of livestock feed and water supply, encroachments of grazing land by cactus, and bushy plants, overstocking and shortage of grazing areas, and closing of hilly areas for forestation and animal diseases, competition of land for grazing and crop [89] (Figure 22).
128. The erratic nature of rainfall and higher ambient temperatures in Kobo Girana Woreda affect both accessibility and quality of feed to be offered for existing livestock, which is highly associated with shortage of water that can satisfy forage development activities in the target areas.
129. In addition to being a semi-arid environment, climate change negatively imposes livestock productivity by affecting the availability of water and feed in the required amount and quality. Thus, it increases the water requirement both for drinking and feed production. The increase in ambient temperature (AT) also aggravates the demand for water requirement. Increase in AT also lowers the feed utilization potential of available feed resources.
130. Changing climatic conditions towards global warming are projected to reduce forage quality. The effect of climatic region on digestibility of roughages was evident from a study by Nsahlai & Apaloo (2007). There are suggestions that increases in AT would affect the degradability of feeds in the rumen by increasing the lignin and NDF[90] and decreasing the CP content of feeds, thereby lowering the rate of degradation and PD of feeds[91]. According to (Moyo, and Nsahlai, 2021) increasing AT reduced digestibility parameters consequent upon higher lignification of plant material in turn reduce the amount of feed that can be potentially digested in a ruminants' stomach. Based on this study, a 1°C increase in ambient temperature decreased potential degradability (PD) of roughages by 0.39 percent, concentrates by 0.76 percent , and PD of mixed diets by 2.41 percent, with an overall decrease of 0.55 percent degradability for all feed types, while the fibre content of feeds was projected to increase by approximately 0.4 percent . Hence elevated levels of AT increase NDF but decrease the CP content of feeds that lowers the feed quality[92]. Consequently, it lowers the daily dry matter feed intake by promoting a wrong feedback of gut fill. As a result, the animal consumes less and in turn reduces the livestock productivity.

5.1.3 Baseline - Potable Water Supply

131. Many wells drilled in the basin are mainly for community water supplies. These wells are small in diameter and with partial penetration of the sediments. Some of the wells are on the slopes of the

[88] RKWAO (Raya Kobo Woreda Agricultural Office), 2018. Livestock population report of the woreda (unpublished).
[89] WWDSWE (Water Works Design and supervision Enterprise), 1998. Feasibility study report for the Raya valley Agricultural development project Volume III: Agriculture Annex K. Livestock
[90] Sanz-Saez et al, 2012
[91] Polley et al, 2013
[92] Rojas-Downing et al, 2017

basin on weathered volcanic rocks forming the mountains and ridges on both east and west sides of the plain area.

132. There are several wells at different locations (escarpment, plain, and plateau) for different uses. The different technologies employed in groundwater abstraction in the basin include dug wells, drilled boreholes and protected springs. The groundwater is used for domestic and cattle water supply as well as for small household farming in the areas located around Waja, Golesha and Elala Boku.

133. Drilling of water wells for water supply of community residing in the valley is common. Most of the wells are drilled on the slopes of the valley exploiting weathered basalt aquifers. These wells are very important for providing data on the geology of the valley, static water level and water quality.

5.1.4 Baseline - Boreholes for Irrigation Purposes

134. The large-scale groundwater abstraction wells in the plain area are those wells drilled by KGVDP in the Kobo sub-basin for irrigation. The Kobo valley pressurized irrigation project is run by Kobo-Girana Valley Development Project. Large diameter boreholes have been constructed by the project for the pressurized irrigation project in the four sub-basins where irrigation well fields have been identified: Waja-Golesha in Kobo-Waja sub-basin, Hormat-Golina in Kobo-Robit sub-basin, Alawuha in Alawuha sub-basin, and Mersa in the Gelana sub-basin.

135. In the valley, a total of 236 boreholes have been drilled for the pressurized irrigation system. Out of these, 32 boreholes are operational via diesel generators and 204 boreholes need to be equipped with the necessary assets to pump ground water for irrigation purposes. The area covered by irrigation using these numbers of boreholes is 333.5 ha is developed by the community and 1,446.65 ha by investors (Table 5).

Table 5 Operational Boreholes powered by diesel generator in Kobo Girana that are servicing the community

#	WELL ID	COORDINATE (X,Y)		Q (l/s)	Command area (Ha)	Household Benefeceries	Beneficiary population
1	*PHG-15*	571659	1332742	66.97	53.58	107.16	535.78
2	*PHG-16*	572165	1332742	65.47	52.37	104.75	523.74
3	*PHG-55*	574646	1334654	67.38	53.9	107.81	539.03
4	*PHG-35*	573793	1333437	66.94	53.55	107.11	535.54
5	*PHG-36*	573303	1333516	66.43	53.15	106.29	531.46
6	*PW-41*	569339	1350807	66	52.8	105.61	528.04
7	*ALPW1*	575116	1312965	53	42.4	84.8	424
8	*SWTW2*	574602	1300133	60	48	96	480
9	*MGPW1*	573583	1280146	72	57.6	115.2	576
10	*MGPW2*	574158	1290510	64	51.2	102.4	512
11	*TAPW1*	565492	1267426	58	46.4	92.8	464
12	*TAPW2*	566411	1267636	81.7	65.36	130.72	653.6
13	*TATW4*	575474	1262582	60	48	96	480
14	*ARPW1*	605928	1271973	53	42.4	84.8	424
15	*ARPW2*	606070	1272573	58	46.4	92.8	464
16	*HCKTW1*	582837	1207610	20	16	32	160
17	*HCKTW2*	587540	1182638	60	48	96	480
18	*HCKTW3*	590050	1185850	66	52.8	105.6	528

19	*HCKTW4*	585874	1203916	60.3	48.24	96.48	482.4
20	*Mekoy PW1*	588742	1178663	80	64	128	640
21	*Mekoy PW2*	588028	1181701	80	64	128	640
22	*JRTW1*	600042	1164989	62	49.6	99.2	496
23	*JRTW2*	595313	1167092	53	42.4	84.8	424
24	*AKTW1*	599826	1149466	18	14.4	28.8	144
25	*STW1*	603153	1136754	55	44	88	440
26	*STW2*	600793	1134590	33	26.4	52.8	264
27	*JWTW1*	602800	1117220	68	54.4	108.8	544
28	*JWTW2*	604659	1117744	40	32	64	320
29	*SRPW1*	595265	1107546	40	32	64	320
30	*SRPW2*	595249	1108085	40	32	64	320
31	*SRPW3*	594562	1102628	60	48	96	480
32	*DHTW1*	608911	1193509	56	44.8	89.6	448
					1,480.15	**2,960.33**	**14,801.59**

136. The utilization of groundwater by the farmers is set by the irrigation users committee, where each irrigation committee consists of five people elected by the farmers among themselves. The committee consists of chairperson, secretary, cashier, storekeeper and two members. This committee is the one that decides on the duration of the discharge and recharge of the borehole. The time of irrigation and duration of irrigation is also set by this committee. The members of the committee are not professionals but are assisted by agriculture extension workers which are assigned by the woreda agriculture office. Neither of the members of the committee receive incentives for being members of the committee.

Figure 23 Lesson being captured from private sector irrigated field in Kobo Girana

137. In addition to the IUA's, farmers union have also been established to handle the ground water management together with the KGVDP office. Numerous IUA's that are established in the valley coupled with the farmers union, working with the KGVDP office are not in sync and roles and functions of each stakeholder is not clear, adding to the blunder. This miscommunication has created a gap in effectively managing the water resources, efficiency in supplying water to the small holders, collecting fees and maintenance of the assets.

Figure 24 Tinbit, supported by the KGVDP office - Papaya produce for the local market - Kobo Girana Valley

5.2 Borena – Oromia Region

5.2.1 Existing Livestock and Challenges with Low Productivity

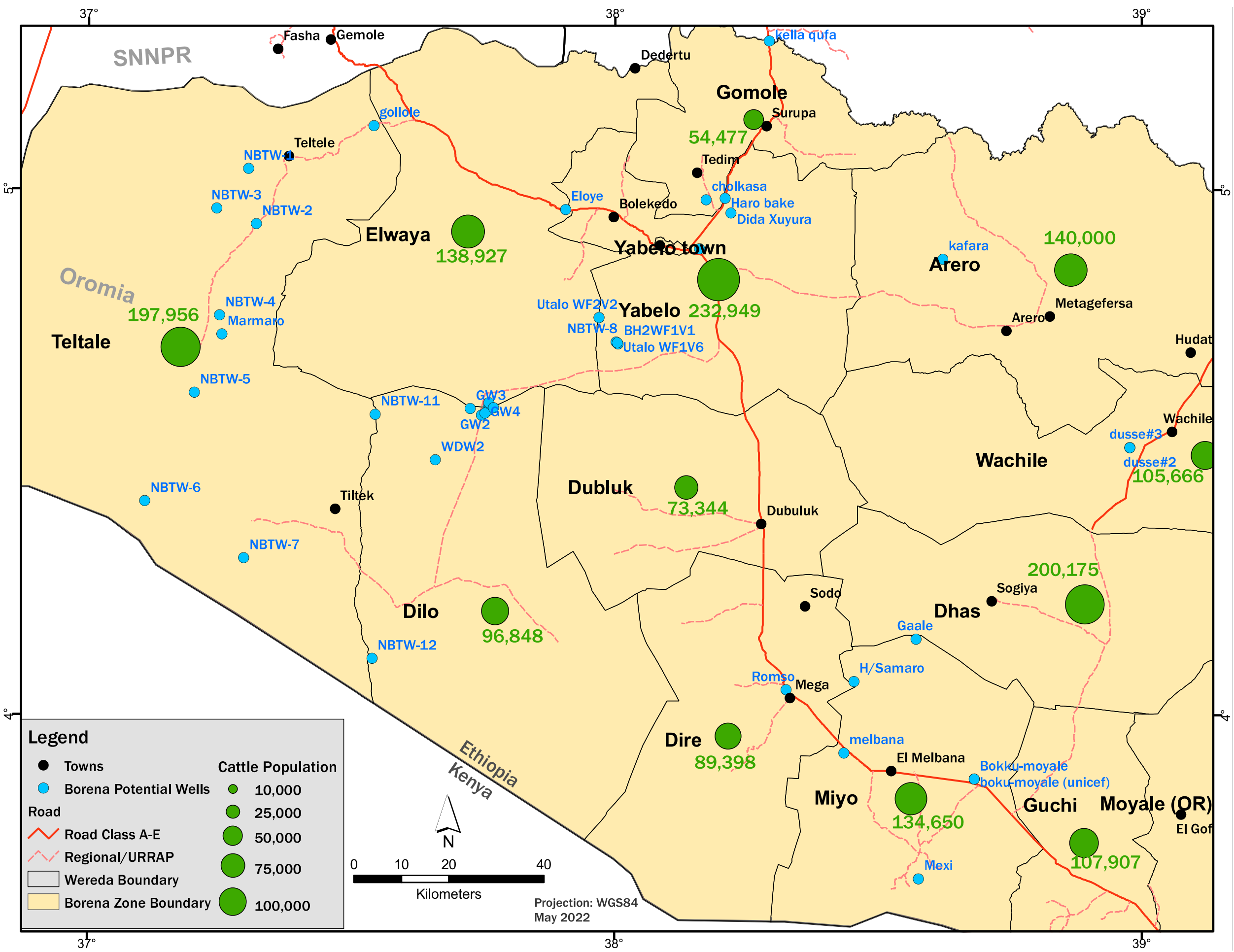
138. Livestock species such as sheep, goat, camel, cattle and donkey predominantly exist in the project command area, in that order of decreasing population size. The livestock are primarily of local origin selected naturally over time and the production is subsistent. However, the Borena cattle are diluted with the surrounding cattle coming from Southern Nations and Nationality Region during transhumance movement. Community consultation also revealed that cattle holding per household was very large but decreased later on mainly due to drought and the resulting feed and water shortage as a result of climate change. At the time of the survey that was conducted end of 2021, it was difficult to find large cattle herd owned by pastoralists. According to the community, this was mainly attributed to the pastoralists moving away from their village with their cattle in search of feed and water. During the time of the survey, a single household kept an average of 50 cattle, which is considerably lower than the previous holding per household. Pastoralists in the project area do not fatten cattle and shoats for marketing purposes. With respect to milk production, the average yield is about 2 litre/day/cow.

139. During the driest period of the year, pastoralists move to the mixed farming areas and they return during the rainy season. During the wet season, forage may be available throughout the districts and the communities used to settle in their original place for long time. However, the recurrent and prolonged drought occurring in this area is changing this practice and has forced both the pastoralists and agro-pastoralists to move frequently in search of feed up to one year with in the Borena zone or by crossing

to the Southern Nations Nationalities Peoples Regional State. Improving the availability of pasture and water throughout the year, and resettlement of pastoralists is thus highly recommended[93].

140. The huge livestock losses during recurrent drought periods results death of most livestock due to feed shortage and pastoralists remained with very small numbers of animals. As the result, most of the pastoralists shifted their stock to small ruminants because of the frequent drought that resulted in a decreased grass and browse cover.

Figure 25 Cattle population - Borena, Oromia Region



[93] ECDSWC, 2021. The Federal Democratic Republic of Ethiopia: Irrigation Development Commission, Study and Design of Borena Groundwater Irrigation Development Project: Final Feasibility Report on Agricultural Planning and Irrigation Agronomy Studies. Addis Ababa, Ethiopia).

5.2.2 Existing water supply and powering stations used

141. Water inventory data conducted revealed that there are 113 boreholes that have been drilled over various initiatives and no surface water availability in the study area. The collected water point data are from boreholes (BHs), springs (SPs) and hand dug wells (HDWs)[94] and for detail refer table 6 below.

Table 6 Types of water points inventoried

Types	Water points
BHs	89
SPs	11
HDWs	13
Total	**113**

142. The 17 exploratory wells developed by OWWDSE in 2017 and 2018 shows that there are bore holes with yields estimated of more than 15 l/s. Audit of borehole records found in the Kobo Girana valley has been provided below (Table 7)

Table 7 Status of the BHs Records out of 89 BHs in the study area

SN	Types BHs Records	# of BHs with no Records	# of BHs with Records	% of Total Records
1	Depth	29	60	78
2	SWL	48	41	53
3	Drawdown	65	26	34
4	Yield	56	35	45

143. The current status of boreholes that are functional and their locations with respect to the project area is as presented in table 8 below. The boreholes identified below are all powered via diesel generators and used for community and livestock water supply and one borehole NBTW -9 is used for forage development by the zonal pastoralists commission.

Table 8 Operational Boreholes powered by diesel generator in Borena Zone that are servicing the community

No	ID	Locality	x	y	Well Status
1	BTW4A	Megado	407203	416267	Serving Alabor-Magado local community for water supply (WS)
2	BTW4B	Megado	407336	416104	Has been serving for Megado town WS & currently Not working due to generator & switch board failure b/c of high flooding in the recent three years
3	BTW6B*	Sarite	346062	527765	Serving the local community for WS & currently functional
4	BTW7	Gelchet	361398	509856	Busiest well for Dugda-Dera local Community WS
5	WDW1	Dambala Dara	344066	491162	Serving Dambala Dara local community & their livestock for WS

[94] ECDSWC, 2021. The Federal Democratic Republic of Ethiopia: Irrigation Development Commission, Study and Design of Borena Groundwater Irrigation Development Project: Final Feasibility Report on Agricultural Planning and Irrigation Agronomy Studies. Addis Ababa, Ethiopia)

6	WDW2	Dillo	351378	496069	Serving Tadacha-Gotu local community & their livestock for WS
7	GW1	Gelchet	360919	505465	Serving Dillo town & surrounding community for WS (40km from source)
8	GW5	Gelchet/ Sabboko	358921	504802	Pump installed & not connected with system but has generator House with generator & guard house, not operational
9	NBTW-8	Utalo	389316	520638	Pump installed & serving temporarily Utalo area community for WS, but planned for Yabelo WS
10	NBTW-9	Gelchet	361038	505480	Pump installed & serving for forage development on 26 hectares by zonal pastoralist Dev't Commission
11	NBTW-10	Sarite	359028	542560	Serving the local community & their livestock for WS
12	NBTW-11	Liso/Ririba	338707	505655	Serving the local community & their livestock for WS due to damage of the nearby BTW10
13	NBTW-12	Melka Sedeka	338035	454326	Pump installed & serving Melka-Sadeka communities for WS in addition to the existing 6" well

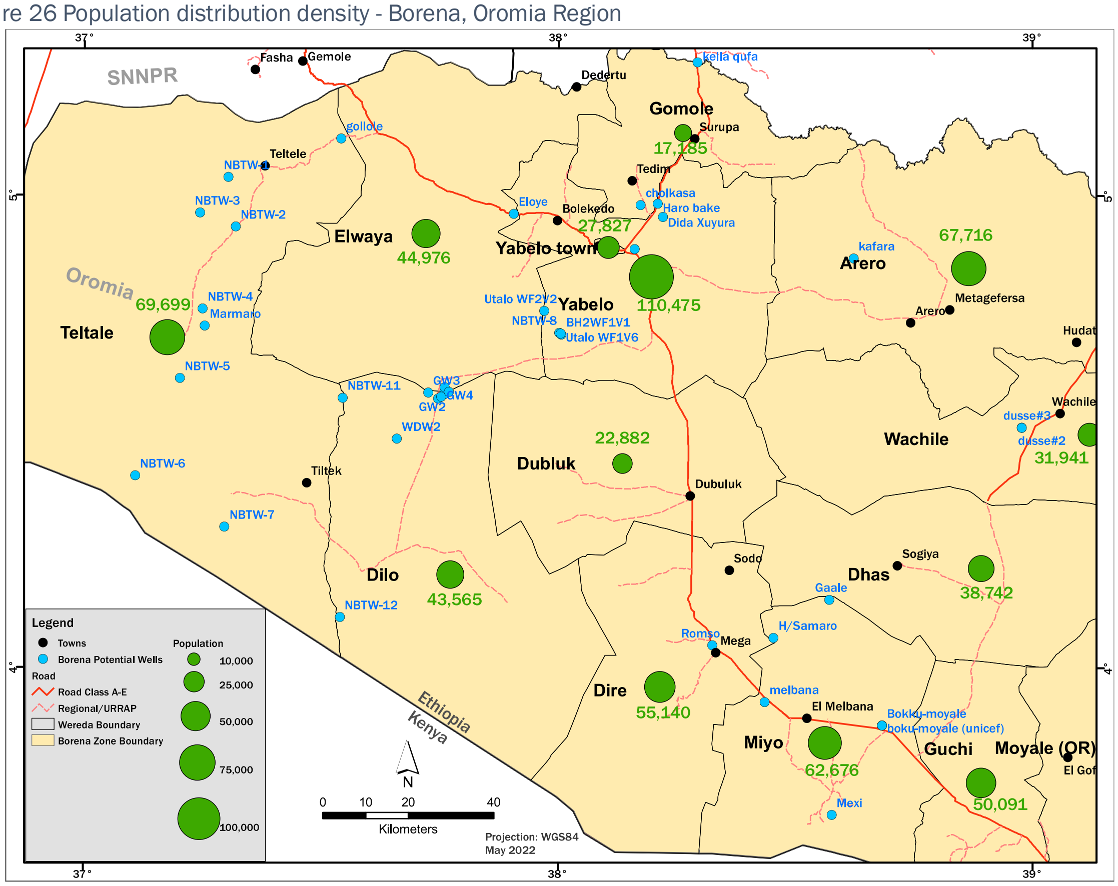
144. Key informant discussions conducted with the zonal water bureau attributed the high level of failure of water schemes to sub-standard construction materials, shortage of trained operators, inadequate recurrent budgets, lack of spare parts, delayed repairs and poor institutional arrangements. Poor institutional arrangements were linked to the lack of capacity of Water Management Committees, which while were able to effectively collect fees and manage day-to-day operations and routine maintenance, they were however dependent on the woreda administration and water office to effect major repairs. This has led to key water sources for human and livestock populations remain non-functional for weeks and months at a time, while local government offices respond to other maintenance and repair requests. Such delays result in hardship in dry and drought seasons when water sources are routinely used more intensively.
145. Key informant discussions with zonal representatives of the Water, Irrigation and Electricity office revealed that the office has limited funds and hence are unable to provide the quality service required. One representative suggested that at any one time, 17 – 20 percent of water points is either broken or only working partially. It was also noted that Zonal offices are dependent on their regional counterparts and development actors for funding through short-term projects, to be able to expand existing schemes, rehabilitate old and non-functional schemes, mobilise communities for maintenance, and train Water Management Committees.
146. Besides government, the principal external actors intervening in development in Borena Zone are NGOs and development agencies. These provide construction and rehabilitation of water points, develop small-scale irrigation and work on capacity- building and training. A broad distinction between interventions aiming at building the resilience capacity of the pastoral community and those of a humanitarian or emergency response nature persists. Given the short-term nature of humanitarian interventions in Borena, practitioners tend towards top-down, technical responses at the expense of planning, participation and sustainability. Limited communication or collaboration between emergency response and development donors and practitioners also frustrates ambitions to build the adaptive capacity of the pastoral community. Coordination and communication between development-oriented NGOs and development agencies can be improved.

5.3 Needs assessment

147. The baseline drawn for both Kobo Girana Valley and Borena area depicts the implicit socio-economic challenges faced by the communities directly caused by climate change. There has been numerous initiatives implemented by the government and the community themselves to increase their resilience capacity. Projects designed without giving due consideration to the inherent challenges has led to inefficient execution that has not brought the required change. As elaborated in the previous sections of this study, the unavailability of solar PV technology then, and lack of awareness and/or lack of confidence in the technology now has been the other factors that could be considered as a missed opportunity to better the lives of these communities. There are multiple studies conducted in the target areas confirming a rich and fertile valley that holds considerable amount of ground water that can be extracted saftely. Against this end, 349 boreholes have been drilled in both regions specific to the study area, and only 45 (13 percent) of the boreholes are functional and servicing the community and investors in the area.

148. The 45 boreholes that are functional are all powered by diesel generators. While these generator sets have been functional with minimal maintenance needs for the first five years, their operational cost has been increasing since then. Transporting diesel to individual borehole locations using pickup trucks themselves run by diesel, oil, lubricants, and spare parts, including the cost of transporting them has been constantly increasing. While this study has identified 45 functional boreholes during the survey, the woreda counterparts noted that there are twelve generators sets that have been decommissioned due to operational inefficiency i.e. cost of transporting fuel to a particular site or lack of spare parts being the main factors.

Figure 26 Population distribution density - Borena, Oromia Region



149. In addition to the technological challenges, the community have further applied indigenous knowledge to build their adaptive capacity and reverse the effects of climate change in their livelihoods. This has however been met by a harsher and more frequent changes in the weather and their eco-system that has severely debilitated them to the point the target areas are now labelled as drought prone areas. The target areas are now at a stage where the situation is dire and further neglecting these communities would only result in mass migration activities.

150. Going back to the drawing table and critically reviewing the variables that attributed in projects not being able to build the required resilience capacity of the community, the following points have been identified as the "Needs" that need to be considered/rectified before designing and executing a project.

1) Local regulatory frameworks that that are not climate adaptive and necessarily not aligned with the CRGE Strategy
2) Lack of a participatory approach in designing climate compatible project in close consultation with the communities and local officials.
3) Lack of knowledge on available green and efficient technologies and or lack of confidence to consider them in the project design.
4) Lack of finance to purchase sustainable and lasting green solutions.
5) Lack of capacity in project implementation leading to poorly executed projects;

151. Against this end, this project has captured lessons learned from previously implemented initiatives on the project sites (Annex 9), and widely available research studies outlined in the reference, that have been conducted in the target areas. This project also brings considerable insight from the design and implementation of the Responding to the increasing risk of drought: building gender-responsive resilience of the most vulnerable communities and Climate Smart Integrated Rural Development Program that were funded by the GCF and Adaptation fund respectively.

152. The DREAM project that is currently being financed by the Rockefeller Foundation, IKEA Foundation and the AfDB is currently being implemented by the Ministry of Water and Energy in collaboration with the Ministry of Irrigation and Low Lands. The project aims in developing medium - large scale irrigation schemes using mini-grids to power both the submersible pumps and also to provide electricity access to households, institutions, and small and medium enterprises.

153. This project was thus designed on the basis of considering best practices, efficiency and efficacy, replicability and sustainability of similar projects that have been implemented thus far and refining the design and methodological approach anchored on lessons learned to date. This project thus has proposed innovative ideas not only to be implemented under this project but to also inform the regulatory frameworks vis a vis access to finance, de-risking the technology, use of advanced technological products and green equipment's that have been tested. It will also tip the balance towards designing initiatives at the federal and regional level on the basis of efficacy and efficiency that will bring about a paradigm shift on enabling environment in creating job opportunities through the private sector at the heart of the initiative, increasing productivity, stirring local economy and offsetting diesel requirement to power generators now and into the future.

5.3.1 Target Beneficiaries (Direct and Indirect)

154. The average household size in Ethiopia is 4.6 and has remained the same for the period 2011 – 2016[95]. In this project, a total of 2,112,537 indirect beneficiaries disaggregated as 1,054,698 male

[95] Central Statistical Agency (CSA) [Ethiopia] and ICF. 2016. Ethiopia Demographic and Health Survey 2016.

and 1,057,839 female and 267,250 direct beneficiaries disaggregated as 130,952 and 136,297 male and female respectively have been targeted, the figures of which will be verified duing the M&E schedule. The gap and needs assessment made in the Kobo-Girana valley and the Borena Zone were the basis upon which this project initiative was primarily designed. Challenges at the grass roots were identified, relevant stakeholders engaged at the different level of governance, community and the private sector and identifying pertinent initiatives as outlined under sub-section (7.2.1. Project design: activities and sub-activities) was approved at the grass tops to be submitted to the GCF.

A. Kobo Girana

155. A total of 60 boreholes that have been constructed with a potential to serve 22,535 small holder farmers have been capped and are not functional. These boreholes are part of the 236 boreholes that have been drilled in the valley where only 32 are currently operational through diesel generators (Figure 27). In Kobo Girana, the main focus of the project is not replacing the existing diesel generators but, rather, to make the 60 boreholes that have been capped to become productive and be used for irrigation purposes. Table 9 below outlines the boreholes that will be constructed and utilized for productive use under this project, their location, hectares of land that will be irrigated and number of small holder farmers that will benefit from each borehole.

Figure 27 Small scale drip irrigation system - *Climate Smart Integrated Rural Development Project in the Pastoralist Areas of Ethiopia*

Table 9 Direct beneficiaries in the Kobo Girana valley

Kobo Girana Valley Borehole Data						Projections/Estimate (Irrigation)		
#	Well ID	Q (l/s)	Location (GPS) x	Location (GPS) y	Location (GPS)z, masl	Targeted ha (Coeff of 0.84 Ha/1 L/S)	Targeted HH (Coeff of 1.5 HH/1 L/S)	Targeted Pop (Coeff of 5 per HH)
1	WG9	30	567405	1354956	1446	25.20	45	225
2	WG23	47.78	569685	1354829	1403	40.14	71.67	358.35
3	WG28	60	568854	1352624	1425	50.40	90	450
4	WG 29	60	568000	1353000	1436	50.40	90	450
5	WG31	24.36	568574	1354821	1430	20.46	36.54	182.70
6	WG32	43.2	569683	1354829	1420	36.29	64.80	324
7	WG33	51	569408	1356020	1428	42.84	76.50	382.50
8	WG40	40.45	571293	1356513	1412	33.98	60.68	303.38
9	WG41	56	570153	1356181	1421	47.04	84	420
10	WG42	58	569574	1353799	1418	48.72	87	435
11	WG 43	75	570275	1355009	1418	63	112.50	562.50
12	WG 34	52	568670	1356024	1438	43.68	78	390
13	HG 5	50	571867	1334044		42	75	375
14	HG11	50	571055	1335915	1437	42	75	375
15	HG13	50	571683	1336365	1425	42	75	375
16	HG26	85	569380	1339575		71.40	127.50	637.50
17	HG 28	55	568066	1340931	1491	46.20	82.50	412.50
18	HG 29	80	568476	1341101	1488	67.20	120	600
19	HG 37 A	50	569485	1341610	1475	42	75	375
20	HG43	29	579090	1332043	1375	24.36	43.50	217.50
21	PHG-6	70	571823	1334961	1407	58.80	105	525
22	PHG 8	46.4	570553	1334124	1434.097	38.98	69.60	348
23	PHG 9	53.5	570085	1333953	1440.327	44.94	80.25	401.25
24	PHG 10	59.5	569560	1334010	1447.831	49.98	89.25	446.25
25	PHG-16	25	574874	1331241		21	37.50	187.50
26	ALTW-1	52	575506	1314095	1425	43.68	78	390
27	ALTW2	48	577550	1316613	1395	40.32	72	360
28	ALTW-3	50	574703	1315873	1422	42	75	375
29	ALPW1	53	575116	1312965		44.52	79.50	397.50
30	MGTW-1	62	574345	1280320	1524	52.08	93	465
31	MGTW-2	57	576148	1288640	1491	47.88	85.50	427.50
32	MGTW3	25	573821	1277578		21	37.50	187.50
33	MGPW1	72	573583	1280146		60.48	108	540
34	MGPW2	64	574158	1290510		53.76	96	480
35	SWTW2	60	574602	1300133		50.40	90	450
36	TG 3	52	580516	1279739	1394	43.68	78	390

37	TG 4	55	581014	1278563	1387	46.20	82.50	412.50
38	PG 4	30	579579	1279670	1409	25.20	45	225
39	PG 5	20	579838	1278511	1405	16.80	30	150
40	PG 6	43	581793	1278463	1377	36.12	64.50	322.50
41	TATW-1	56.9	567514	1267867	1588	47.80	85.35	426.75
42	TATW-2	62	567307	1266660	1571	52.08	93	465
43	HCKTW2	60	587540	1182638	1450	50.40	90	450
44	HCKTW3	66	590050	1185850	1423	55.44	99	495
45	HCKTW4	60.3	585874	1203916	1459	50.65	90.45	452.25
46	HCKTW5	19	595255	1173713	1406	15.96	28.50	142.50
47	Mekoy pw-1	41.3	564435	1355542	1484	34.69	61.95	309.75
48	Mekoy pw-2	30	578231	1226297	1470	25.20	45	225
49	JRTW1	62	600042	1164989	1461	52.08	93	465
50	JRTW2	50	595313	1167092	1490	42	75	375
51	STW1	55	603153	1136754	1421	46.20	82.50	412.50
52	STW2	33	600793	1134590		27.72	49.50	247.50
53	JWTW1	68	602800	1117220	1180	57.12	102	510
54	JWTW2	40	604659	1117744		33.60	60	300
55	SRTW1	50	595779	1107850	1346	42	75	375
56	DHBH2	41	569800	1230107	2446	34.44	61.50	307.50
57	SNBH1	42	610691	1204682	1192	35.28	63	315
58	GKBH1	35	569303	1224795	2257	29.40	52.50	262.50
59	THG 43	29	579090	1332043	1375	24.36	43.50	217.50
60	TWJ3	60	569491	1357769	1433	50.40	90	450
						2,523.94	**4,507**	**22,535**

156.The project design of this study has landed on 0.84 ha of land could be irrigated on one litres per second water discharge. This figure was arrived after having conducted detailed analysis of the type of irrigation system under consideration i.e. drip irrigation, types of crops to be grown in the area, the soil type and the amount of water that can be saftley discharged to the surface, see part C of this feasibility study for the design and annexes 1 & 2 for the engineering details. Accordingly, a total of 4,507 households or 22,535 small holder farmers will be directly benefiting from irrigation agriculture that will be fully powered by solar energy.

157.Furthermore, 1,609,164 communities will also be receiving indirect benefits that will be trickling from the implementation of this project (Table 10). Indirect benefits will include short- and long-term job creation from the private sector project developers i.e installation and commissioning of the solar PV's, drip irrigation systems, land preparation, excavation etc and employment opportunities with the service providers during the operation and maintenance of the assets. Spurring of the local economy, additional market systems on the agri value chain, increased private sector participation along the other segments of the agri-market chain, spurring the local economy, better regulatory environment and a step towards meeting with the NDC.

Table 10 Indirect Project beneficiaries in Kobo-Girana valley

#	Region	Zone	Wereda	Population*
1	Amhara	North Shewa	Antsokiya	79,091
2	Amhara	North Shewa	Eferatana Gidem	110,493
3	Amhara	North Shewa	Kewet	100,806
4	Amhara	North Wello	Guba Lafto	134,939
5	Amhara	North Wello	Habru	171,142
6	Amhara	North Wello	Raya Kobo	188,122
7	Amhara	Oromia (Amhara Region)	Artuma Fursi	76,901
8	Amhara	Oromia (Amhara Region)	Dewa Cheffa	130,512
9	Amhara	Oromia (Amhara Region)	Jilye Tumuga	67,807
10	Amhara	South Wello	Ambasel	116,017
11	Amhara	South Wello	Argoba	34,998
12	Amhara	South Wello	Dessie town	120,095
13	Amhara	South Wello	Kalu	166,371
14	Amhara	South Wello	Kombolcha town	111,870
				1,609,164
***Population data projected is based on 2007 CSA census data**				

B. Borena Zone

158.In Borena, a total of 40 boreholes have been targeted by this project to be powered by solar energy for potable water supply for the community & livestock and produce fodder for the livestock. Thirteen out of the forty targeted boreholes that are currently operational and powered by diesel generators will be decommissioned and replaced by solar power. Furthermore, the approach followed in allocating ground water in Borena is slightly different and has followed the ratio below for every litre of ground water pumped for every second (Table 11);

1) Boreholes with a discharge capacity of more than 10 litres per second have their water divided into the following ratio – Potable: Livestock: Irrigation (3:4:3).
2) Boreholes with a discharge capacity between 10 and 4 (inclusive) 10 litres per second have their water divided into the following ratio – Potable: Livestock (4:6).
3) Boreholes with a discharge capacity of less than 4 litres per second have their water allocated only for potable use - Potable (1).

Table 11 Direct beneficiaries in the Borena Area

Borena Borehole Data							Projection/Estimate (Potable Water)		Projection/Estimate (Livestock)		Projections/Estimate (Fodder)		
#	Well ID	Name of well location	Q (l/s)	Qp 30%	Ql 40%	Qf 30%	Projection/ Estimate (Potable use per head/day)*	Projection/ Estimate (Potable use per HH)**	Projection /Estimate (heads of Livestock) ***	Projection /Estimate (Livestock /HH)****	Targeted ha (Coeff of 4.64 Ha/1 L/S)	Targeted HH (Coeff of 1.5 HH/1 L/S)	Targeted Pop (Coeff of 5 per HH)
1	NBTW-6	El-Dima	71	21.3	28.4	21.3	24,537.60	4,907.52	20,448	409	99.05	31.95	159.75
2	NBTW-5	Mermero	50	15	20	15	17,280	3,456	14,400	288	69.75	22.50	112.50
3	NBTW-12	Malka Sadeka	46	13.8	18.4	13.8	15,897.60	3,179.52	13,248	265	64.17	20.70	103.50
4	NBTW-8	Utalo	41	12.3	16.4	12.3	14,169.60	2,833.92	11,808	236	57.20	18.45	92.25
5	NBTW-9	Gelchet	40	12	16	12	13,824	2,764.80	11,520	230	55.80	18	90
6	BH2WF1V1	Utalo	31.8	9.54	12.72	9.54	10,990.08	2,198.02	9,158	183	44.36	14.31	71.55
7	Utalo WF1V6	Yabelo	28	8.4	11.2	8.4	9,676.80	1,935.36	8,064	161	39.06	12.60	63
8	Utalo WF2V2	Yabelo	28	8.4	11.2	8.4	9,676.80	1,935.36	8,064	161	39.06	12.60	63
9	NBTW-11	Liso	27.2	8.16	10.88	8.16	9,400.32	1,880.06	7,834	157	37.94	12.24	61.20
10	NGW-2	Gelchet	22	6.6	8.8	6.6	7,603.20	1,520.64	6,336	127	30.69	9.90	49.50
11	NBTW-10	Sarite	18	5.4	7.2	5.4	6,220.80	1,244.16	5,184	104	25.11	8.10	40.50
12	NBTW-1	Taltalle	17.72	5.316	7.088	5.316	6,124.03	1,224.81	5,103	102	24.72	7.97	39.87
13	Bokku-moyale	miyo	16	4.8	6.4	4.8	5,529.60	1,105.92	4,608	92	22.32	7.20	36
14	kella qufa	Gomole	15	4.5	6	4.5	5,184	1,036.80	4,320	86	20.93	6.75	33.75
15	NBTW-7	Hobok	15	4.5	6	4.5	5,184	1,036.80	4,320	86	20.93	6.75	33.75
16	GW2	Gelchet	15	4.5	6	4.5	5,184	1,036.80	4,320	86	20.93	6.75	33.75
17	GW4	Gelchet	15	4.5	6	4.5	5,184	1,036.80	4,320	86	20.93	6.75	33.75
18	GW3	Gelchet	14	4.2	5.6	4.2	4,838.40	967.68	4,032	81	19.53	6.30	31.50
19	Mexi	Mi'o	14	4.2	5.6	4.2	4,838.40	967.68	4,032	81	19.53	6.30	31.50
20	dusse#2	wacile	13	3.9	5.2	3.9	4,492.80	898.56	3,744	75	18.14	5.85	29.25

21	boku-moyale (unicef)	Miro	13	3.9	5.2	3.9	4,492.80	898.56	3,744	75	18.14	5.85	29.25
22	NGW-1	Gelchet	13	3.9	5.2	3.9	4,492.80	898.56	3,744	75	18.14	5.85	29.25
23	NBTW-3	Taltalle	11.11	3.333	4.444	3.333	3,839.62	767.92	3,200	64	15.50	5	25
24	NBTW-4	Mermero	10.19	3.057	4.076	3.057	3,521.66	704.33	2,935	59	14.22	4.59	22.93
25	dusse#3	Wacile	8	3.2	4.8		3,686.40	737.28	3,456	69			
26	gollole	Taltale	8	3.2	4.8		3,686.40	737.28	3,456	69			
27	cholkasa	Yabelo	7	2.8	4.2		3,225.60	645.12	3,024	60			
28	H/Samaro	Dirre	6.3	2.52	3.78		2,903.04	580.61	2,722	54			
29	Gaale	Dubluk	6	2.4	3.6		2,764.80	552.96	2,592	52			
30	Marmaro	Taltale	6	2.4	3.6		2,764.80	552.96	2,592	52			
31	kafara	Arero	5.6	2.24	3.36		2,580.48	516.10	2,419	48			
32	Dida Xuyura	Yabelo	5	2	3		2,304	460.80	2,160	43			
33	Romso	Dirre	5	2	3		2,304	460.80	2,160	43			
34	NBTW-2	Taltalle	4.7	1.88	2.82		2,165.76	433.15	2,030	41			
35	WDW2	Wobok	4.2	1.68	2.52		1,935.36	387.07	1,814	36			
36	melbana	miyo	4	1.6	2.4		1,843.20	368.64	1,728	35			
37	Dolollo hola	Yabelo	4	1.6	2.4		1,843.20	368.64	1,728	35			
38	Eloye	Eloye	4	1.6	2.4		1,843.20	368.64	1,728	35			
39	Haro bake	Yabelo	3	3			3,456	691.20					
40	NGW-3	Gelchet	2.8	2.8			3,225.60	645.12					
							244,715	**48,943**	**202,095**	**4,042**	**816**	**263**	**1,316**

159.Part C – Project design of this study has landed on 4.64 ha of land could be irrigated for fodder on one litres per second water discharge. This figure was arrived after having conducted detailed analysis of the type of irrigation system under consideration i.e. centre pivot system, type of forage to be grown in the area, the soil type and the amount of water that can be safely discharged to the surface, see section C for the design and annexes 1 & 2 for the engineering details used. Accordingly, a total of 48,943 households or 244,715 communities will benefit from water supply for potable use and their livestock and producing fodder on 816 hectares of land.

160.The decommissioning of the thirteen generators and replacing them with solar power will create the required awareness on capacity of the technology but more importantly, the shear act of replacing the diesel generator by solar will create that confidence within the community and amongst all relevant stakeholders on the power of solar energy and its capability (Figures 28 – 30). Replacing the diesel generators that have capacity of over 75 kW by solar will create that ripple effect from the grass roots to the grass tops and will facilitate that much required enabling environment to streamline import duties around solar powered equipment's, knowledge around their deployment and ensuring that project designs at all levels consider using solar power for transport, urban, industries health care etc as opposed to diesel generators.

Figure 28 Diesel Generator used for borehole water extraction and replaced by Solar PV, Oromia Region; Ethiopia

Figure 29 Borehole powered by Solar Energy, Oromia Region Ethiopia

Figure 30 Solar PV that replaced the Diesel Generator, Oromia Region; Ethiopia

161.Furthermore, 503,373 communities will also be receiving indirect benefits that will be trickling from the implementation of this project (Table 12). Indirect benefits will include short- and long-term job creation from the private sector project developers i.e installation and commissioning of the solar PV's, centre pivot irrigation systems, land preparation, excavation etc and employment opportunities with the service providers during the operation and maintenance of the assets. Spurring of the local economy, additional market systems on the agri value chain, increased private sector participation along the other segments of the agri-market chain, spurring the local economy, better regulatory environment, and a step towards meeting with the NDC. Essentially, the Borena zone and the Kobo Girana valley areas will be receiving similar ripple effects in terms of indirect benefits mainly because of how this project is designed.

Figure 31 Elderly woman carrying potable water on her back, Amhara Region, Ethiopia

Table 12 Indirect Project beneficiaries in Borena Zone

#	Wereda	Zone	Region	Population*
1	Arero	Borena	Oromia	67,716
2	Dilo	Borena	Oromia	43,565
3	Dire	Borena	Oromia	55,140
4	Elwaya	Borena	Oromia	44,976
5	Gomole	Borena	Oromia	17,185
6	Miyo	Borena	Oromia	62,676
7	Teltale	Borena	Oromia	69,699
8	Wachile	Borena	Oromia	31,941
9	Yabelo	Borena	Oromia	110,475
				503,373

*** CSA Census data and Oromia Engineering Corporation Study Feb. 2022**

162.Successful implementation of this project will inform the grass tops to influence planners and engineers to consider the use of solar energy to sustainably extract ground water from the 173 and 73 boreholes in Kobo Girana and Borena valleys that are not targeted in this project. The volume of diesel avoided, GHG mitigated by just using solar energy for productive use in Kobo Girana and Borena zone will be in the tune of 0.7 MT CO2 eq if all the boreholes in the project target area are powered by solar energy. Numerous boreholes have been drilled in various areas of Ethiopia namely Becho Meda, Ada Plains amongst others that have been capped and waiting for a diesel generator. Replicating the same project at the national level will have a scale in the economy interms of forex saved for diesel, operation and maintenance, sustained increase on the agri-output, jobs created and GHG emissions that will be avoided.

Figure 32 Deforestation severely affecting agricultural productivity, Kobo Girana, Ethiopia

Part C – Project Feasibility

163. The Feasibility Study of “Climate resilient community access to safe water powered by renewable energy in drought vulnerable regions of Ethiopia” considers a broad component of civil and electro-mechanical works to be implemented on a turnkey basis. This Feasibility study constitutes the consultation, planning and design phase of the project and embedded within this section is the design blueprint, implementation arrangements and schedule and budget requirements to execute the project in a turnkey basis.
164. In this study, 100 boreholes spread out as 60 and 40 boreholes in Kobo-Girana Valley and Borena respectively have been identified to be developed specifically for productive use purposes using solar PV. The Feasibility section here under has anchored the blueprint of the design based on each borehole’s safe yield and has considered the following core elements into the project.

1) Identification of the pertinent submersible pump, its motor and energy requirements.
2) Design pipe and fitting layout, size and components.
3) Well hydraulic analysis.
4) Storage tanks, booster stations, valve room points on the network plotted.
5) Design the Solar PV to generate the required energy to power the system.
6) Generate a 3D wire mesh topomap for the irrigation infrastructure.
7) Design a drip and center pivot irrigation system in Kobo-Girana and Borena respectively
8) Generate bill of quantities

6.0 KOBO-GIRANA AND BORENA: DETAILED PROJECT DESIGN

6.0 Introduction

165. The Ethiopian economy is mostly based on agriculture, with industry and services slightly increasing recently. Agriculture is primarily rain fed and thus highly dependent on rainfall. However, the poor performance of the sector and insufficient and erratic rainfall condition of our country exacerbated by the rapid population growth (the rapidly increasing demand for food), result in problem of food security. The major factors behind the poor performance of subsistence farming of the Ethiopian agriculture diminishing farm size (High lands), severe soil degradation, and inadequate and variable rainfall combined with frequent droughts in lowlands.
166. Currently, the Ministry of finance Ethiopia and the Ministry of Irrigation and Lowland developed this project in Borena zone of Oromia National Regional State and Kobo-Girana of Amhara region primarily focusing on irrigation, fodder, livestock, and domestic water supply. GCF funding will be the catalytic finance used to transform the livelihoods of small holder farmers to become commercial irrigator farmers, including replicating the same project in the vicinity and also scaling the project by way of introducing cold chain/thresher/dryer and other productive use of energy assets post project completion.
167. Based on the hydrogeology studies and aquifer tests conducted in the project boreholes which has been provided in annex 3, a safe yield for 100 production wells has been determined, which is 40 in Borena zone and 60 in Amhara region Kobo-Girana site in North Wello. The safe yield of the wells varies between 13 to 85 l/s with exception of a few, where the safe yield is ≤ 10 l/s.
168. These were the analytical results of the groundwater potential and land resource studies carried out in 2021 in Borena zone of Oromia Regional state (OWWDSE) and Kobo Girana River Valley Development Project (KGVDP) of the Kobo Girana Amhara regional state. The study was conducted with the consent

of both Federal and Regional governments to utilize the zone's resource in an integrated and sustainable manner for the benefit of the community. Geological, geomorphologic, geophysical survey and hydrogeological field investigation studies were conducted to identify the potential aquifers and quality of water in a wider range of assessment.

169. As an output of the general zonal initial study and the actual site conditions of Borana and Kobo-Girana – detailed ground water study has been carried out in June 2020. This study has put into consideration the different irrigation application options such as surface water, drip irrigation, overhead sprinkler system application (fixed and drag hose type) and machine irrigation (center pivot irrigation (CPI) systems) – (Figure 33).

Figure 33 Center Pivot System (Ethiopia), Ethio-Agriceft (Private sector) farmland located in Oromia Regional State, and Bir-Sheleqo and Ayehu farms in Gojjam, Amhara Regional State

6.1 Scope of the feasibility study

170. This Feasibility Study is prepared by considering objectives of the ground water-based irrigation developments in both regions which would enable irrigation of farmland in Kobo Girana and forage feeds in Borena to increase the adaptive capacity of the local community and their livelihood by transitioning them to commercial farming. This study and detailed design of the project thus follows good practice standards of drought prone areas accepted both nationally and internationally.

171. The following activities (but not limited to) are properly addressed during the study, detail design and verification of the previous design:

- ✓ Reviewed and updated previous information, data and studies and design works of WWDCE, KGVDP & OWWDSE.
- ✓ Conducted topographic survey for the wells command area and validated filed data.
- ✓ Georeferenced borehole location and re-assessed the yield of production wells.
- ✓ Revised the irrigation agronomic study, propose commercial crops, and determined crop water requirement.

- ✓ Development of irrigation and drainage system design criteria.
- ✓ Evaluate the energy requirements of the project particularly for lift irrigation systems.
- ✓ Cost estimation for immediately implemented for Drip and Center Pivot Irrigation systems as well.
- ✓ Preparing technical specifications and bill of quantities

Figure 34 KGVDP Office team inspecting irrigation drainage systems powered by Diesel Generators, Kobo Girana, Ethiopia

6.2 Approach and methodology

172. Feasibility and preliminary design study phase forms a track for feasibility of the project by performing integrated disciplinary studies and also detail documents review and analysis that could assess the field situation and lead to the preparation of Feasibility Study. The Feasibility Study and Design is carried out based on available resources data at site level to irrigate 2,523.94 ha and 816.87 ha in Kobo Girana and Borena with drip and center pivot irrigation system respectively.
173. This study approach pays attention to attitudes preferences, skills and previous experiences of the local farmers in the course of the studies and designs through active and full participation of the end users of the schemes during all process. Review of findings of all previous studies and identified data gap, constraints, potentials and means of filling the gap including methodologies and detailed schedule of the remaining breakdown of activities are presented in the subsequent chapters. For immediate implementation of the irrigation systems, the details of the design including the draft design report and Engineering drawings for the proposed sites has been annexed as 1 & 2.

174. The methodology used in this study is aimed at plainly defining and describing the irrigation Engineering infrastructures situation of the project area and developing appropriate ones for the same. The methodologies followed in this section is described subsequently.

Figure 35 Asnaketch and her small scale drip irrigation system, Amhara Region, Ethiopia

6.3 Principles of Pressurized Irrigation

175. The use of pressurized irrigation method has brought improvements in the irrigation efficiency and land utilization due to its suitability to the application of irrigation water to farms with undulating topography, shallow soils, and higher slopes. Thus, application of improved irrigation methods and techniques on small farms is expanding rapidly because of the increasing demand for higher irrigation efficiency, improved utilization of water and intensification and diversification of production.
176. Experience gained locally and from many African countries has shown that piped irrigation techniques are successfully replacing the traditional open canal surface methods at farm level. This is due to its ability of irrigating undulating and higher slope fields, shallow and light soils, increased crop water use and simplified operation and maintenance.
177. A pressure piped irrigation system is a network installation consisting of pipes, fittings and other devices properly designed and installed to supply water under pressure from the source of the water to the irrigable area.

6.4 Objectives

178. The main objective of the project is to build the resilience capacity of the community in Kobo Girana and Borena zone through the productive use of renewable energy.
179. The feasibility design report consists of detailed design procedures, principles, and design criteria for drip irrigation (Kobo Girana Valley) and Center Pivot irrigation system (Borena Zone) development: where appropriate, design examples have been incorporated to clarify the design methods and equations used in the design and blueprint engineering drawings. This feasibility design study will thus frequently refer to the blueprint drawings and the equations drawn upon, which are provided in annex 1 & 2. Redacted versions of some of these drawings, representing typical cases, are provided in A4 or A3 size papers.

6.5 Baseline scenario considered to setup an Irrigation system for both regions

180. Selecting the irrigation systems for the project requires careful consideration of many factors. The main factors that have been considered for this study include optimization of irrigable area, crops to be grown, topography, soils, climate (wind speed. Rainfall and temperature), requirement and availability of energy.
181. The following are the basis used to select the water application that best suits the irrigation type.

- In some locations of Kobo-Girana, farmers are irrigating their pasture field by letting pipe system discharge the water in the field for grass growing.
- The accumulated surface water during the short rainy seasons causes frequent malaria outbreak.
- To grow forage, drip Irrigation technology is less efficient to evenly spray water in a larger land mass
- Overhead Sprinkler (Fixed type) is very efficient and less labour intensive but costly as that of Drip irrigation system.
- Overhead Sprinkler (Drag Hose) type is somewhat labour intensive than fixed type sprinkler system but cost effective as number of laterals as well as number of sprinklers are reduced by less than 50 percent.
- Drip irrigation is labour intensive as compared to fixed type sprinkler system but cost effective as number of laterals as well as number of sprinklers are reduced by less than 50 percent.

182. In line with the considerations of the community's needs, the Borena Zone is prominent for its communities to herd large number of livestock and the community Kobo Girana have experience in growing crops. It is against these baseline that this feasibility study was conducted to better understand their livelihood, the environment including the available natural resources and based on this understanding that this proposal was designed. The investments outlined here under are means to increase the adaptative capacity of the community by way of introducing productive use of energy to increase their resilience. Proposed irrigation methods follow and build on the existing livelihood and are anchored on effective and efficient way of drawing ground water using solar energy.

6.6 Kobo Girana Valley: Drip Irrigation versus sprinkler system

183. System design of the plots was prepared based on the location of the wells, assessment of topographical map and the availability of total discharge from each source. The hydraulic analysis of

pipes is carried out following the standard design procedure and the necessary data has been derived from field visits, KGVDP office and the WWDCE.

184. While sprinkler systems consist of tubing embedded in the ground with heads above that spray water on your plants, drip irrigation has tubing that runs low along the ground and slowly drips water into the soil around the crops. Each has its value and its issues, and it is against the following advantages that drip irrigation system was identified to be practical for the Kobo Girana valley (Table 13).

Table 13 Advantages of Drip irrigation vs Sprinkler irrigation system

Parameters	Advantages	Disadvantages
Water efficiency	Drip irrigation systems are low to the ground and have hole punches directly next to the plants, they send water directly to plant roots, minimizing water loss to runoff and evaporation.	
Cost effectiveness	Saves water as it pours in only the required amount of water to the crop and thus available water that can be safely discharged can be applied to a irrigate larger land mass.	
Disease prevention	Driping water directly to the soil gives drip irrigation the advantage of reducing powdery mildew and other diseases that can develop on wet leaves.	
Promotes fewer weeds	While weeds can sprout up from wide watering, when the water is meticulously dripped to the soil around each plant, there is less opportunity for weeds to steal water from your cultivated plants. This also decreases the need for additional investment for pesticides	
Vulnerability to damage		With the tubing for drip irrigation above ground, it is easier for farmers or animals to accidentally damage the tubing. Exposure to the sun's UV rays also can weaken the plastic and cause it to crack.
Easily blocked		Hole punches can become clogged with sediment in the water. If left unnoticed, these

		water drops will not be reaching a crop.

6.6.1 Design Principle and parameters used to design the irrigation infrastructure

185. The basic parameters used for the irrigation design include:

- ✓ To enable farmers/users use irrigation application methods (drip technology) to grow mixed crops in a Basic Distribution Unit (BDU).
- ✓ To use the safe yield of wells as efficient as possible,
- ✓ To achieve the desired emission uniformity, 90 percent for drip
- ✓ To apply the 20 percent rule in system design for all the plots, i.e. to keep the allowable variation of pressure head and discharge in the subunit and BDU within 20 and 10 percent, respectively. Excess pressure over 20 percent, if any, at inlet of the subunit is to be controlled by pressure regulators.
- ✓ To keep the system inlet pressure minimum (to reduce running cost) and to limit the pressure variation in the system to 20 percent maximum, hence the system is hydraulically self-adjusted.

6.6.2 Site specific design considerations

186. The following considerations are considered in this design report.

1) The smallest irrigation unit of the system (sub-unit) which is managed by one valve is fixed to be 0.25 ha.
2) The layout assumes that the irrigable area will be reallocated to farmers as per the manageable size, and the beneficiaries will be organized at tabia/queshet (sub-district/ least administrative unit) level accordingly.
3) Provision of drip irrigation system is made to facilitate irrigation of most types of crops to be grown, i.e. crops, fruits and vegetables
4) Since most of the proposed wells have not been operational since their construction, discharge of sand with water pumped is expected, at least in the initial stages of operation. Suitable Hydrocyclones (sand separators) are provided in the head control unit at each well delivery point.
5) Standardized head control units are suggested for different safe yields of wells. Hydrocyclone with screen filter (disc filter or stainless-steel wire mesh type), check valve and control valves are provided in the system design.
6) All pipes from Head Control Unit up to BDU level to be of 6 kg/cm^2 pressure rating. Piping work after distribution unit at BDU to be of 4 kg/cm^2. LLDPE tubes to be of Class 1 and 2.5 kg/cm^2.
7) Financial comparison has shown that comparative cost of HDPE pipes of diameters higher than 160 mm is very high when compared with uPVC pipes of same diameter and pressure rating. Therefore, HDPE pipes up to 160 mm and uPVC pipes above 160 mm diameters are recommended in the system design and BOQ.
8) Gate valves/isolating valves installed on underground main and submain pipes shall be made from cast iron and conform to ISO 9635-2:2006. Valve spindle shall be provided with a square key on top to open or close the same with a 'T' shape rod having a matching ingress to fit on to the square key. All gate / isolating valves on main and submain pipes shall be of same diameter as that of the pipeline on which it is installed. However, if gate valves of the recommended diameter are not

available then the contractor will supply and install the next higher available size with requisite fittings such as increaser and reducer connectors.

9) Vacuum and Air Release Valves are to be placed at various points on main, submains, Head Control Unit and Control Unit at BDUs, as per the standard code of practice and guidelines. VARV shall conform to ISO: 11419:1997.
10) One Fertilizer Applicator is provided for each BDU at the BDU Control Level. To eliminate shifting of Fertilizer Applicator from one plot to another, a separate manifold is provided at each BDU to connect Fertilizer Applicator to drip irrigation system in anyone (or more) plots.
11) Drawings showing typical Head Control Unit at well outlet and BDU level are submitted in annex 1.
12) Main head control unit at well (including pump set motor controls) is proposed to be housed in a pump house of suitable size with a door and window of prescribed sizes.
13) Efficiency of the drip system is 90 percent
14) Daily maximum pumping hours shall be set to a maximum of eight hours.
15) Farm leveling and preparation will totally be done by the farmers of beneficiaries themselves.

187. It is against these premise that the drip irrigation design lay out has been prepared and values extracted are shown in table 14 and sample design of Drip Irrigation system is plotted hereunder (Figure 36).

Table 14 Sample Design of Drip Irrigation System

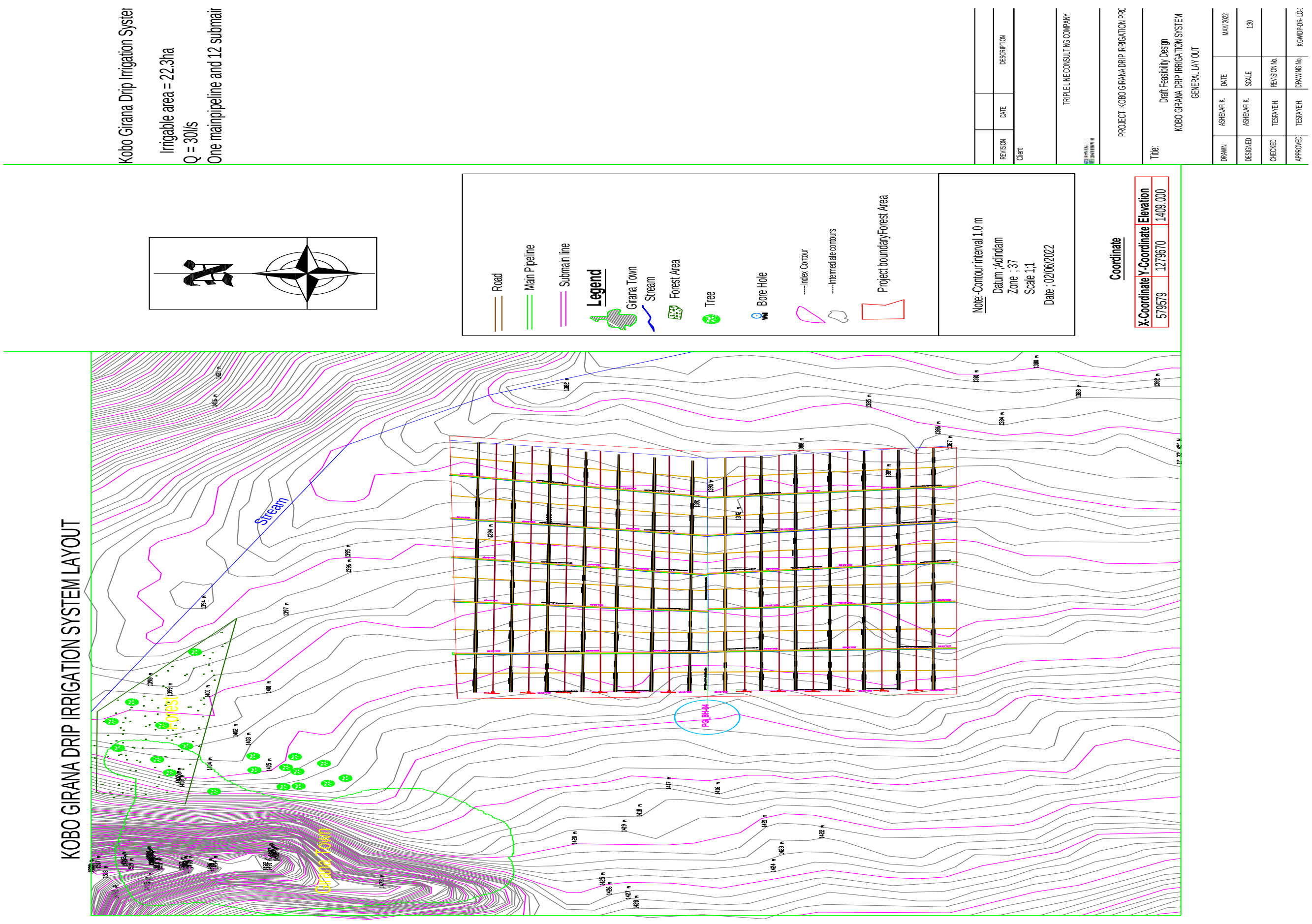
Basic data		
Description	Unit	Value
Maximum allowable Irrigable area (TIA)	ha	50.64
Available time of application (TD)	hrs	8
Crop water requirement (DA)	mm/day	5.9
efficiency of drip	%	0.85
% of area irrigated by drip	%	100
Type of crop to be irrigated by drip system: fruit/Crop		
Gross application depth	mm/day	6.94
Actual gross application depth	mm/day	6.94
Total daily volume of water	m3/day/ha	69.41
Total daily volume of water	m3/day	3515.01
Estimated discharge	m3/hr	439.38
Volume of water requirement per ha	m3/day/ha	69.41
Volume of water requirement per ha	m3/hr/ha	3.86
Actual discharge: Borehole yield = 60 lps	m3/hr	216
Smallest Irrigation unit width	m	60
Smallest Irrigation unit length	m	100
plot area area as defined by design unit	ha.	0.6
Actual plot area area as defined by design unit	ha.	0.6
Number of Actual plot area as defined by design unit	Nr.	84.4
Clustered Number of Actual plot area as defined by design unit	Nr.	10.55
Actual Clustered Number of Actual plot area as defined by design unit	Nr.	10.55
Actual Clustered plot area as defined by design unit	ha.	42.2

Dripper and drip lateral		
Nominal discharge	l/h	1.599619941
Dripper k (to be determined from Manufacturers Catalogue)		0.4792
Dripper x (to be determined from Manufacturers Catalogue)		0.5235
Dripper Nominal Operating pressure (to be determined from Manufacturers Catalogue)	m	10
Dripper spacing along lateral is fixed based on spacing between plants	m	0.3
Length of lateral is to be fixed based on manageable unit plot length	m	50
Number of drippers on lateral (ND)	unit	166.667
Nominal discharge of the lateral	l/h	269.513
Lateral OD	mm	16
Lateral WT(to be determined from Manufacturers Catalogue)	mm	1.6
Lateral ID	mm	12.8
Pend operating pressure of the end critical dripper	m	10
Pin operating pressure at the inlet of critical lateral	m	10.75
Qd end operating discharge of the end critical dripper	l/h	1.60
Qd in operating discharge at the inlet of critical lateral	l/h	1.66
Qlat actual	l/h	269.51
Del Q	%	3.87
Del P	%	7.53
Drip manifold		
Location of the valve at the inlet of the manifold		
Lateral k (COMPUTED)		967.83
Lateral x (COMPUTED)		-0.54
Pend	m	10.75
Pin	m	10.41
QL end	l/h	269.51
QL in	l/h	274.30
QM of manifold	l/h	27696.10
Q of manifold	m3/hr	27.70
Manifold pipe OD	mm	75
Manifold pipe WT	mm	2.678
Manifold pipe ID	mm	69.644
length the manifold	m	120
Spacing of drip laterals along manifold	m	1
Number of laterals on manifold	units	120
Actual number of laterals on manifold	units	120
Operation		
Daily Application rate for 1.0 mx 0.3m between Laterals and between drippers spacing	mm/hr	5.332
Application time for one shift	hr	1.302
Actual Application time for one shift with 50percent allowance	hr	1
Number of shifts per day	No	8
Actual Number of shifts per day	No	18
total number of valves	No	84.4

Number of valves per shift	No	5.6
total hours tofinish irrigating the whole area	hr	18
TOTAL AREA COVED	**ha.**	**50.4**

188. The irrigation system layout was thus developed for each borehole and shown in the detail design drawings on maps at a scale of 1:2500. Schematic drawing for well ID PG - 4 has been presented below including sectional drawings for a borehole has been included in annex 2. Explanation of the parameters used and formulas applied in deriving the irrigation infrastructure has been further provided under annex 1 & 2.

Figure 36 System Layout of Kobo-Girana Drip Irrigation System – Well ID PG 4



189. Following the same design principles, summary of the ha of land that will be irrigated from each borehole has been provided below targeting a total of 2,532.84 ha of land targeted to be developed in Kobo Girana valley has been proposed (Table 15).

Table 15 Wells, Coordinate, Safe yield, Net Area

S.No	Well Unit	Coordinate		Hydraulic Dimension	Area(ha)
		Easting	*Northing*	*Q (l/sec)*	

1	WG9	567405	1354956	30	25.289
2	WG23	569685	1354829	47.78	40.277
3	WG28	568854	1352624	60	50.578
4	WG 29	568000	1353000	60	50.578
5	WG31	568574	1354821	24.36	20.534
6	WG32	569683	1354829	43.2	36.416
7	WG33	569408	1356020	51	42.991
8	WG40	571293	1356513	40.45	34.098
9	WG41	570153	1356181	40.45	47.206
10	WG42	569574	1353799	56	48.892
11	WG 43	570275	1355009	58	63.222
12	WG 34	568670	1356024	75	43.834
13	HG 5	571867	1334044	52	42.148
14	HG11	571055	1335915	50	42.148
15	HG13	571683	1336365	50	42.148
16	HG26	569380	1339575	50	71.652
17	HG 28	568066	1340931	85	46.363
18	HG 29	568476	1341101	55	67.437
19	HG 37 A	569485	1341610	80	42.148
20	HG43	579090	1332043	50	24.446
21	PHG-6	571823	1334961	29	597
22	PHG 8	570553	1334124	70	39.113
23	PHG 9	570085	1333953	46.4	45.098
24	PHG 10	569560	1334010	53.5	50.156
25	PHG-16	574874	1331241	59.5	21.074
26	ALTW-1	575506	1314095	25	43.834
27	ALTW2	577550	1316613	52	40.462
28	ALTW-3	574703	1315873	48	42.148
29	ALPW1	575116	1312965	50	44.677
30	MGTW-1	574345	1280320	53	52.264
31	MGTW-2	576148	1288640	62	48.049
32	MGTW3	573821	1277578	57	21.074
33	MGPW1	573583	1280146	25	60.693
34	MGPW2	574158	1290510	72	53.949
35	SWTW2	574602	1300133	64	50.578
36	TG 3	580516	1279739	60	43.834
37	TG 4	581014	1278563	52	46.363
38	PG 4	579579	1279670	55	25.289

39	PG 5	579838	1278511	30	16.859
40	PG 6	581793	1278463	20	36.247
41	TATW-1	567514	1267867	43	47.964
42	TATW-2	567307	1266660	56.9	52.264
43	HCKTW2	587540	1182638	62	50.578
44	HCKTW3	590050	1185850	60	55.635
45	HCKTW4	585874	1203916	66	50.830
46	HCKTW5	595255	1173713	60.3	16.016
47	Mekoy pw-1	564435	1355542	19	34.814
48	Mekoy pw-2	578231	1226297	41.3	25.289
49	JRTW1	600042	1164989	30	52.264
50	JRTW2	595313	1167092	62	42.148
51	STW1	603153	1136754	50	46.363
52	STW2	600793	1134590	55	27.818
53	JWTW1	602800	1117220	33	57.321
54	JWTW2	604659	1117744	68	33.718
55	SRTW1	595779	1107850	40	42.148
56	DHBH2	569800	1230107	50	34.561
57	SNBH1	610691	1204682	41	35.404
58	GKBH1	569303	1224795	42	29.504
59	THG 43	579090	1332043	35	24.446
60	TWJ3	569491	1357769	29	50.578
Total					2,532.84 ha

190. The detailed drip irrigation design configuration that considers the following parameters has been incorporated under annex 1) availability of irrigable land 2) Hydraulic design of the irrigation system 3) drainage 4) catchment of the target area 5) Water Balance Study 6) Crop water requirements 7) wet and dry season crop pattern and 8) hydraulic calculation of interceptor drain.

6.7 Borena: Centre Pivot versus Lateral Move

191. Both Centre Pivot and Lateral Move systems are among continuous move sprinkler systems, but the following matrix has been developed to categorically map the advantages and disadvantages of considering center pivot systems for this project[96] (Table 16).

Table 16 Advantages of Center pivot versus Lateral move irrigation system

Parameters	Advantages	Disadvantages

[96] Tiku, Kasa & Singh, Pratap. (2019). Evaluating the Irrigation Practice of Center Pivot Sprinkler Irrigation System at Hiwot Agricultural Mechanization, Ethiopia. Journal of Engineering Research and Reports. 1-7. 10.9734/JERR/2019/v8i316995.

Capital Cost per hectare		Center Pivots generally have higher CAPEX cost than for lateral moves, as Lateral Moves are better suited to cover and irrigate large areas.
Management	Center pivots are easier to manage as the driest ground is immediately ahead of the pivot. Lateral Moves irrigate back over the most recently irrigated land when changing direction. This poses management problems such as non-uniform irrigation intervals over the paddock causing temporary waterlogging and aggravating wheel rotating problems	
Water application uniformity	Center Pivots can have variable flow rate along their full length as compared to lateral moves, where each tower moves at the same speed.	
Energy source	Center Pivots can be powered by Solar PVs, whilst lateral moves are powered by a diesel engine mounted on the machine, which pumps out of an open channel. The machine mounted pump and motor arrangement precludes the use of electric power and off-grid systems.	
Automation	Lateral Move systems are more labor intensive because of the need to supervise the diesel operation, open channel maintenance and regular checking of the tower guidance system. Pivot operation is generally simpler.	

6.7.1 Centre Pivot System (CPS)

192. In the Center Pivot Management, application efficiency is described as a measure of the percentage of water applied that is available for the crop to use for transpiration. The types of losses that reduce application efficiency that can be affected by the sprinkler package were listed as overspray and drift, droplet evaporation, canopy evaporation, and runoff.

193. Some of the advantages of Center Pivot Irrigation Machine includes.

- high degree of automation
- Its Center Tower is Fixed on concrete pedestal and equipped with water inlet
- Every driving tower is configured with one enclosed moisture proof motor
- Allowable slope can be up 15 percent
- Overhang placed at end of the last span, 18 meter in maximum length
- The system can flexibly adapt to terrain
- Control Cabinet placed in center tower and can be flexibly configured
- Easy to operate and higher degree of automation
- End gun mounted on the overhang ensures maximum water supply even on exposed areas. The end guns can be equipped with a booster pump to ensure a reliable water pressure. When used for circle irrigation, end guns deliver the water even to the most outside edges, thereby increasing the yield. An economic solution for minimal additional expense.

6.7.2 Design parameters of the centre pivot system in Borena

194. It is against this background that a CPS has been identified as an appropriate irrigation technology for Borena. The design parameters used for the Gelchet site (Table 17) and similarly the same procedure has been applied to the CPS boreholes identified in Borena.

Table 17 Center Pivot Irrigation Design Parameter – Geltchet

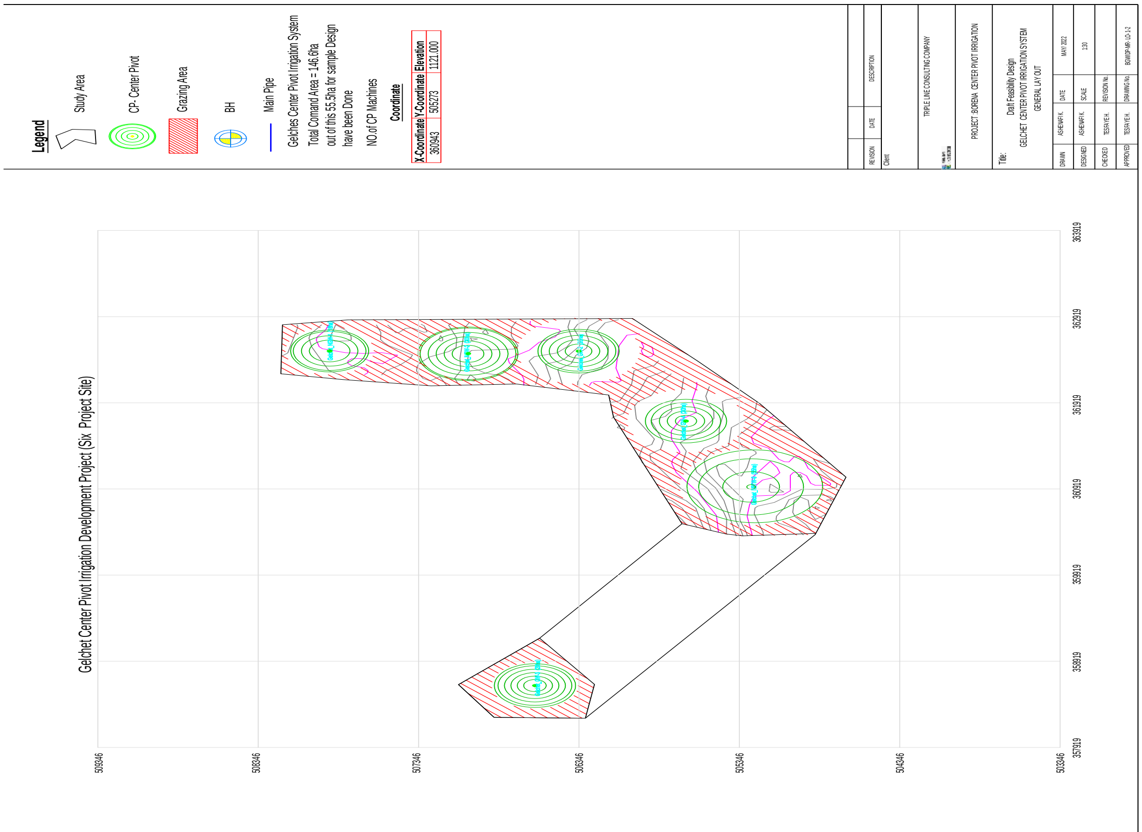
Client: Ministry of Finance, Ethiopia								
Project: Gelchet Site: 55.85 ha								
Date: 2022/06/10								
Design: Triple Line Consulting								
Borehole Yield:	180	m^3/hr						
System length	6×59.8m+17.6m						377.0	m
Irrigated area incl. additional spray range							55.85	ha
Spans								
Span type	168EL		168EL		168EL		168EL	
Span length	59.8	m	54.0	m	48.1	m	42.3	m
NO. of spans	6		0		0		0	
Span length with coupling	59.8	m	54.0	m	48.1	m	42.3	m
Pipe diameter	168	mm	168	mm	168	mm	168	mm
System height	4.2	m	4.2	m	4.2	m	4.2	m
Clearance under the truss structure	3.1	m	3.1	m	3.1	m	3.1	m
Pivot drive with electric motors	0.56	kW	0.56	kW	0.56	kW	0.56	kW

Weight with water	3410	kg	3125	kg	2845	kg	2565	kg
Tires	14.9-24		14.9-24		14.9-24		14.9-24	
Soil pressure	15.5	N/cm²	14.2	N/cm²	12.9	N/cm²	11.7	N/cm²
Nozzle	Nelson Spray D3000 BLUE							
Length with overhang							17.6	m
Extension pipe							0	m
Additional spray range							3.8	m
Irrigated radius							381.0	m
Travel angle							360	°
Total Hours per day							19	h
Total flow							180.0	m3/h
Irrigation amount							6.4	mm/d
Max.travelling speed							158.8	m/h
Total time full Rotation							15.1	h
Moisture provided at 100%							5.4	mm
Nozzle pressure at							0.10	MPa
Connection pressure							0.26	MPa
Pressure drop due to height							0	m
Voltage							380	V
Frequency							50	Hz
Demand capacity(Transformer)							6.27	kVA
Demand capacity(Solar Power)							11.76	kVA
Connection value							3.92	kW
Note: the capacitance excludes that of pump.								

6.7.3 Topography (Layout System of the proposed Sample command area)

195. The topographical map was produced (Figure 37) for the entire command area and for each borehole, summing up a total irrigable area of 816.87 ha. Fixed coordinate points of boreholes points in all sites were used to avoid complication of reference points during system installation. The topographic map is prepared from 30m x30m Digital Elevation Model (DEM) and referenced against grounded borehole location captured during the hydrogeologic study assessment. Grid of 30m x 30m DEM is processed to prepare topographic map at 1.0 m contour intervals. Significant difference during installation had not been observed mainly due to the CPS is a package that doesn't relate to elevation variations.

Figure 37 CPS Command area of Gelchet well field



196. Topography: The target area does not have a geographic limiting factor.

a) Limited number of gullies crossing the project site makes it suitable for a center pivot system and
b) All areas have slopes less than 8 percent, strongly recommended for pressurized irrigation.

197. Power interruption: submersible pumps operate with electricity from national grid supplied at the site. It is known that Ethiopian National Grid Electric System is subject to frequent interruptions which needs other alternatives such as Solar power system. Thus considering solar Power supply into this feasibility study is required in the boreholes. Accordingly, the following boreholes have been identified and specific CPS systems has been designed that is fit for individual boreholes. The irrigation command area derived (Table 18).

Table 18 Borena 24 Center Pivot Irrigation Sites Command area

Implementable 24 CP project		
El-Dima	Number of CPs	Targeted Irrigable area, ha
Mermero	1	99.14
Malka Sadeka	1	69.82
Utalo	1	64.23
Gelchet	1	57.25
Utalo	1	55.85

Yabelo	1	44.40
Yabelo	1	39.10
Liso	1	39.10
Gelchet	1	37.98
Sarite	1	30.72
Taltalle	1	25.13
miyo	1	24.74
Gomole	1	22.34
Hobok	1	20.94
Gelchet	1	20.94
Gelchet	1	20.94
Gelchet	1	20.94
Mi'o	1	19.55
wacile	1	19.55
mi'o	1	18.15
Gelchet	1	18.15
Taltalle	1	18.15
Mermero	1	15.51
Total	**24**	**816.87**

198. The detailed CPS design configuration that considers the following parameters has been incorporated under annex 1; 1) availability of irrigable land 2) Wind speed 3) Energy Requirements 4) Local Experience 5) Water Balance Studies 6) Crop water requirements 7) Effective rainfall and 8) Irrigation depth and interval

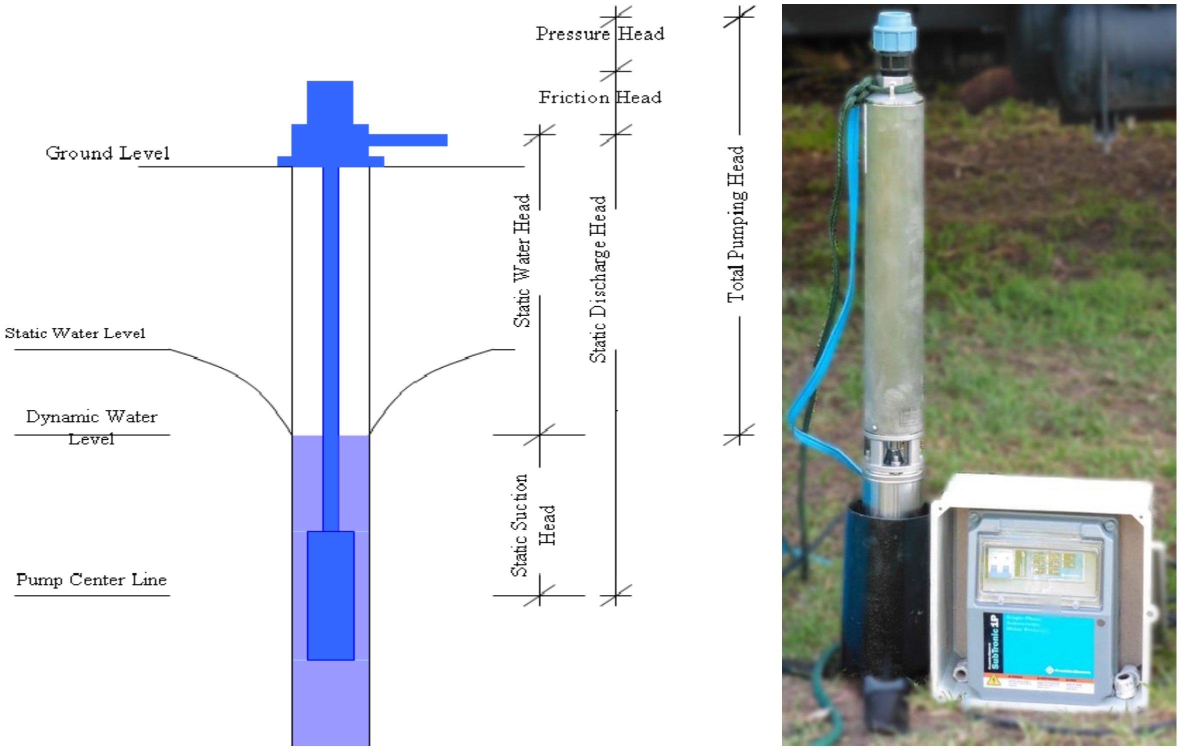
6.8 Submersible system, Solar PV and Inverter setup

199. The status of the project is 100 percent of the wells targeted to be developed through this project have been drilled, pump tested and capped. Eighteen of the total one hundred boreholes are partially operational through intermittent grid supply coupled with diesel generators. The following figures and tables show the detail project components and existing datum used for the respective designs to power all 100 wells through renewable energy.

Figure 38 Solar powered Submersible pump, Oromia Region; Ethiopia

200. In this project, the electromechanical system is prepared in detail by taking the well completion dataset, civil works including the elevations of borehole, well field collector, pressure line material, length, diameter, and other well parameters.
201. The recommended diameter of the pipe should be selected such that the flow velocity is less than 3.3 m/s in order to assure good pump performance. For the engineering analysis, the flow velocity is assumed to be 2.5 m/s. Moreover, the diameter of the well casing should be at least 5cm (2”) larger than the nominal diameter of the pump (external diameter) and riser pipe. Accordingly, diameter of mating flange of Head Control Unit has been standardized as 100mm, 150mm and 200mm for safe yields of 15, 20 l/s, 30 l/s and 50 l/s respectively.
202. The following sections presents a summary of Submersible pump (Figure 39) and Solar PV specifications for the 100-borehole targeted (Table 19 & Table 20). Detailed well hydraulics assessment on how these specifications have been derived is provided in annex – 2.a.

Figure 39 Submersible pump parameters (Drawing and actual)



* *Photograph of the submersible pump is courtesy of Borehole water journal*

203. The installation drawings and bill of quantity are also prepared and attached herewith this document in the following sections.

Table 19 Kobo Girana Submersible pump and Solar PV Specification

Kobo Girana Submersible system, Solar PV and Inverter setup															
SN#	Description	Pump			Solar PV					Inverter			Cable		
	BH	Kw	Head (m)	Q (m^3/hr)	Wp	Qty	Vmp	A (max)	A (m^2)	Kw	Pump to inverter	PV to Inverter	SxP	Pump Dia	Casing dia
1	WG9	30	76	108	540	126	575	160	350	56	4x25	4x25	18 X 7	6	10
2	WG23	45	73	1728	540	192	575	160	515	87	4x35	4x35	16 X 12	8	12
3	WG28	30	38	216	540	135	575	160	368	56	4x25	4x25	15 X 9	6	12
4	WG 29	30	29	216	540	102	575	160	287	56	4x25	4x25	17 X 6	6	12
5	WG31	15	39	87.696	540	54	575	160	166	32	4x6	4x6	18 X 3	6	12
6	WG32	45	62	155.52	540	135	575	160	368	87	4x25	4x25	15 X 9	8	12
7	WG33	45	60	183.6	540	160	575	160	445	87	4x35	4x35	15 X 11	8	12
8	WG40	45	74	145.62	540	165	575	160	445	87	4x50	4x50	15 X 11	8	12
9	WG41	45	49	201.6	540	150	575	160	406	87	4x35	4x35	15 X 10	8	12
10	WG42	30	40	208.8	540	144	575	160	396	56	4x16	4x16	18 X 8	6	12
11	WG 43	45	49	270	540	210	575	160	560	87	4x50	4x50	15 X 14	8	12
12	WG 34	45	68	187.2	540	204	575	160	548	87	4x25	4x25	17 X 12	8	12
13	HG 5	45	60	180	540	153	575	160	442	87	4x25	4x25	18 X 9	8	10
14	HG11	45	62	180	540	168	575	160	451	87	4x35	4x35	14 X 12	8	10
15	HG13	45	59	180	540	160	575	160	434	87	4x35	4x35	16 X 10	8	10
16	HG26	55	55	306	540	240	575	160	638	102	4x50	4x50	16 X 15	8	12
17	HG 28	45	50	198	540	150	575	160	406	87	4x50	4x50	15 X 10	8	12
18	HG 29	75	62	288	540	364	575	160	952	135	4x70	4x70	14 X 26	8	12
19	HG 37 A	45	55	180	540	140	575	160	379	87	4x25	4x25	14 X 10	8	12
20	HG43	30	54	104.4	540	90	575	160	258	55.5	4x16	4x16	18 X 5	6	12
21	PHG-6	45	43	252	540	208	575	160	556	87	4x25	4x25	16 X 13	8	12
22	PHG 8	45	76	167.04	540	208	575	160	556	87	4x35	4x35	16 X 13	8	12
23	PHG 9	45	59	192.6	540	176	575	160	474	87	4x50	4x50	16 X 11	8	12
24	PHG 10	45	48	214.2	540	153	575	160	417	87	4x50	4x50	17 X 9	8	12
25	PHG-16	30	61	90	540	84	575	160	236	55.5	4x16	4x16	14 X 6	6	12

26	ALTW-1	55	88	187.2	540	240	575	160	638	102	4x35	4x35	16 X 15	8	12
27	ALTW2	55	85	172.8	540	234	575	160	626	102	4x50	4x50	18 X 13	8	12
28	ALTW-3	45	61	180	540	165	575	160	445	87	4x25	4x25	15 X 11	8	12
29	ALPW1	75	97	190.8	540	288	575	160	764	135	4x70	4x70	18 X 16	8	12
30	MGTW-1	45	51	223.2	540	187	575	160	504	87	4x25	4x25	17 X 11	8	12
31	MGTW-2	45	52	205.2	540	165	575	160	445	87	4x25	4x25	15 X 11	8	12
32	MGTW3	45	110	90	540	153	575	160	417	87	4x50	4x50	17 X 9	8	12
33	MGPW1	45	50	259.2	540	210	575	160	560	87	4x25	4x25	15 X 14	8	12
34	MGPW2	45	59	230.4	540	210	575	160	560	87	4x25	4x25	15 X 14	8	12
35	SWTW2	55	72	216	540	240	575	160	638	102	4x35	4x35	16 X 15	8	10
36	TG 3	45	70	187.2	540	210	575	160	560	87	4x35	4x35	15 X 14	8	10
37	TG 4	45	52	198	540	160	575	160	434	87	4x50	4x50	16 X 10	8	10
38	PG 4	30	61	108	540	105	575	160	291	55.5	4x35	4x35	15 X 7	6	10
39	PG 5	30	76	72	540	84	575	160	236	55.5	4x16	4x16	14 X 6	6	10
40	PG 6	30	54	154.8	540	144	575	160	396	55.5	4x25	4x25	18 X 8	6	10
41	TATW-1	30	46	204.84	540	144	575	160	396	55.5	4x16	4x16	18 X 8	6	10
42	TATW-2	45	52	223.2	540	182	575	160	487	87	4x25	4x25	14 X 13	8	10
43	HCKTW2	30	27	216	540	96	575	160	270	55.5	4x16	4x16	16 X 6	6	10
44	HCKTW3	45	53	237.6	540	210	575	160	560	87	4x25	4x25	15 X 14	8	10
45	HCKTW4	45	61	217.08	540	210	575	160	560	87	4x35	4x35	15 X 14	8	12
46	HCKTW5	45	152	68.4	540	153	575	160	417	87	4x70	4x70	17 X 9	8	12
47	Mekoy pw-1	30	44	148.68	540	102	575	160	287	55.5	4x16	4x16	17 X 6	6	12
48	Mekoy pw-2	30	55	108	540	96	575	160	270	55.5	4x16	4x16	16 X 6	6	12
49	JRTW1	45	52	223.2	540	182	575	160	487	87	4x25	4x25	14 X 13	8	12
50	JRTW2	45	61	180	540	160	575	160	434	87	4x25	4x25	16 X 10	8	10
51	STW1	45	61	198	540	176	575	160	474	87	4x25	4x25	16 X 11	8	10
52	STW2	55	130	118.8	540	240	575	160	638	102	4x70	4x70	16 X 15	8	10
53	JWTW1	45	43	244.8	540	180	575	160	488	87	4x25	4x25	18 X 10	8	10
54	JWTW2	45	81	144	540	210	575	160	560	87	4x35	4x35	15 X 14	8	10
55	SRTW1	55	90	180	540	240	575	160	638	102	4x50	4x50	16 X 15	8	10
56	DHBH2	30	48	147.6	540	102	575	160	287	55.5	4x16	4x16	17 X 6	6	10
57	SNBH1	30	36	151.2	540	80	575	160	229	55.5	4x16	4x16	16 X 5	6	12

58	GKBH1	30	57	126	540	128	575	160	352	55.5	4x16	4x16	16 X 8	6	12
59	THG 43	30	59	104.4	540	96	575	160	270	55.5	4x25	4x25	16 X 6	6	12
60	TWJ3	30	41	216	540	144	575	160	396	55.5	4x25	4x25	18 X 8	6	12

Table 20 Borena Submersible pump and Solar PV Specification

Borena Submersible system, Solar PV and Inverter setup															
SN#	Description	Pump			Solar PV					Inverter			Cable		
	BH	Kw	Head (m)	Q (m^3/hr)	Wp	Qty	Vmp	A (max)	A (m^2)	Kw	Pump to inverter	PV to Inverter	S x P	Pump Dia	Casing dia
1	NBTW-6	75	140	223	540	364	575	160	952	115	4x95	4x95	14x26	8"	12
2	NBTW-5	75	140	223	540	364	575	160	701	115	4x70	4x70	14x19	8"	12
3	NBTW-12	75	160	182		364	575	160	952	115	4x95	4x95	14x26	8"	12
4	NBTW-8	75	300	113	540	364	575	160	952	115	4x95	4x95	14x26	8"	12
5	NBTW-9	75	300	113	540	364	575	160	952	115	4x95	4x95	14x26	8"	12
6	BH2WF1V1	75	300	113	540	364	575	160	952	115	4x70	4x70	14x26	8"	12
7	UTALO WF1V6	75	300	113	540	364	575	160	952	115	4x95	4x95	14x26	8"	12
8	Utalo WF2V2	75	300	113	540	364	575	160	952	115	4x95	4x95	14x26	8"	12
9	NBTW-11	75	300	113	540	364	575	160	952	115	4x70	4x70	14x26	8"	12
10	NGW-2	75	300	113	540	364	575	160	765	115	3x120+ 70	3x120+ 70	17x17	8"	12
11	Bokku-moyale	30	200	63	540	102	575	160	287	60	4x25	4x25	17x6	6"	8
12	kella qufa	15	55	112	540	42	575	160	129	30	4x8	4x8	14x3	6"	6
13	Dusse#2	30	200	63	540	42	575	160	215	50	4x25	4x25	15x5	6"	8
14	Boku-moyale (unicef)	30	200	63	540	42	575	160	243	50	4x16	4x16	17x5	6"	8
15	Dusse#3	11	100	39	540	48	575	160	147	20	4x8	4x8	16x3	6"	8
16	Gollole	11	100	39	540	48	575	160	147	20	4x10	4x10	16x3	6"	8
17	Cholkasa	11	100	39	540	34	575	160	113	20	4x8	4x8	17x2	6"	6

18	H/Samaro	18.5	200	38	540	72	575	160	212	30	4x16	4x16	18x4	6"	8
19	NBTW-1	55	230	106	540	187	575	160	504	100	4x95	4x95	17x11	6"	12
20	NBTW-7	55	230	106	540	192	575	160	515	100	4x95	4x95	16x12	8"	12
21	GW2	45	200	109	540	210	575	160	560	100	4x50	4x50	15x14	6"	8
22	GW4	45	200	109	540	210	575	160	560	100	4x50	4x50	15x14	6"	8
23	GW-3	45	200	109	540	192	575	160	515	100	4x50	4x50	16x12	6"	8
24	NGW-1	75	300	113	540	270	575	160	718	115	4x95	4x95	18x15	8"	12
25	NBTW-3	30	330	37	540	140	575	160	379	50	4x50	4x50	14x10	6"	12
26	NBTW-4	30	330	37	540	119	575	160	330	50	4x50	4x50	17x7	6"	12
27	NBTW-10	55	230	106	540	192	575	160	515	100	4x95	4x95	16x12	8"	12
28	Mexi	11	100	39	540	48	575	160	147	25	4x6	4x6	16x3	6"	8
29	Gaale	7.5	90	25	540	36	575	160	120	25	4x6	4x6	18x2	6"	8
30	Marmaro	30	330	37	540	144	575	160	396	50	4x50	4x50	18x8	6"	12
31	Kafara	15	220	22	540	64	575	160	188	25	4x16	4x16	16x4	6"	8
32	Dida Xuyura	4	45	26	540	18	575	160	55	10	4x6	4x6	6x3	6"	8
33	Romso	5.5	80	25	540	30	575	160	100	10	4x6	4x6	15x2	6"	8
34	NBTW-2	15	220	22	540	64	575	160	188	25	4x25	4x25	16x4	6"	12
35	WDW2	15	220	22	540	60	575	160	176	25	4x25	4x25	15x4	6"	8
36	Melbana	4	80	13	540	20	575	160	59	25	4x6	4x6	5x4	6"	6
37	Dolola Holaa	5.5	80	25	540	18	575	160	74	25	4x6	4x6	18x1	4"	6
38	Eloye	5.5	80	25	540	28	575	160	93	25	4x6	4x6	14x2	6"	8
39	Haro Bake	5.5	160	13	540	18	575	160	74	25	4x6	4x6	18x1	4"	8
40	NGW-3	15	220	22	540	42	575	160	129	25	4x25	4x25	14x3	6"	12

Part D – Project Delivery

7.1 Project impacts, monitoring and risks

204. This project develops a new partnership between federal, regional and community stakeholders by pioneering SWP in cooperation with local IUAs and small businesses in establishing and utilizing solar water pumping for drinking water and irrigation. Agricultural cooperatives offer existing social organizations established at the local level (kebele/woreda), but without the necessary renewable energy expertise in a context of irrigation management. The project pioneers financing and implementation arrangements that are self-sustainable and replicable, thereby accelerating the GoE's objective for universal access to safe water as well as increasing agricultural productivity.
205. Project delivery consists of carrying through the work plan established across both project components, including all sub-activities defined to achieve the desired outcomes:

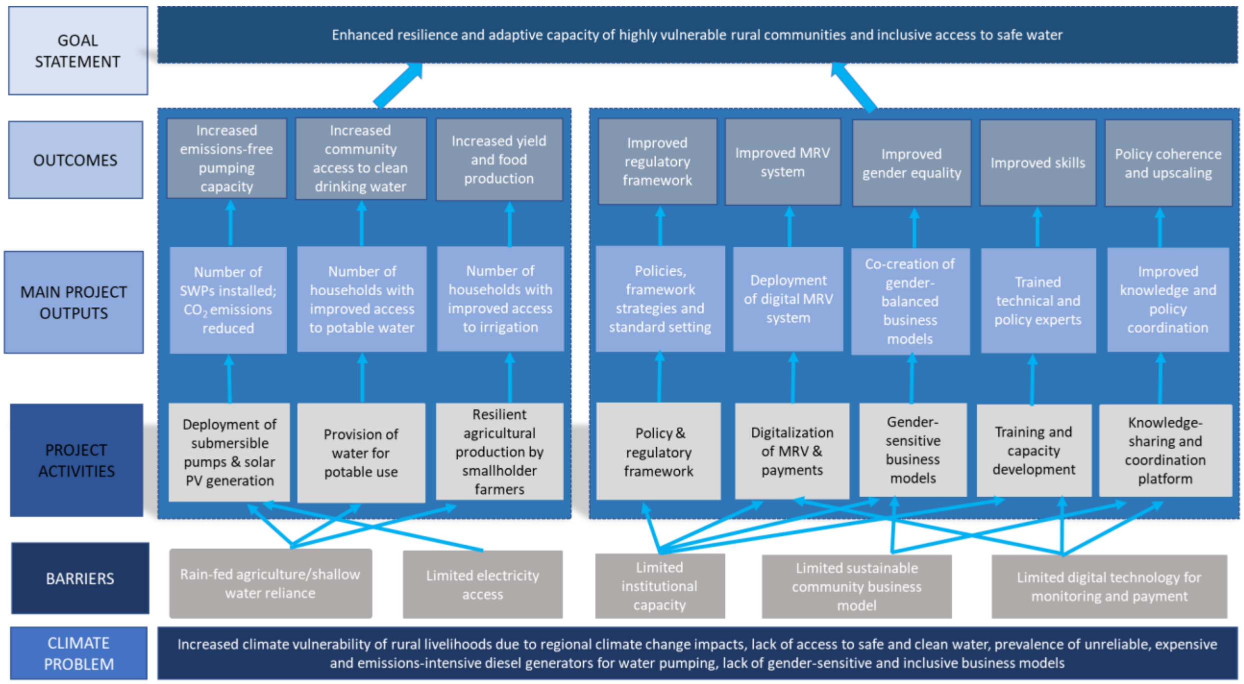
- Deployment of submersible pumps and solar PV generation (Component 1) and
- Enabling Environment (Component 2)

206. Full listing of the implementation schedule, including detailed break-down of activities and the detailed budget plan has been provided in annex 5 and 6 respectively.
207. This section seeks to support the most pertinent issues associated with project delivery based on deliberations together with executing entities (MILLs, MOWE) and the consultancy team. These issues relate to a variety of factors that will determine successful project delivery and thereby attainment of ultimate project outcomes, including from a project design and operations perspective (7.1 - 7.3), from a risk prevention and management perspective (7.4) from a 'sustainability' perspective with focus on sustaining skills and knowledge over time (7.5) as well as a financial planning perspective.

7.1 Project impacts and monitoring of key outputs, including against NDC targets

208. The project is built on a theory of change aimed at transforming the utilization of water resources from an non-transparent, ineffective and costly manner (i.e. using diesel pumps or not being equipped with irrigation and pumping technology at all) towards the sustainable and inclusive utilization of groundwater resources.
209. This theory of change is built on a clear chain of events, starting from a climate problem and ending at the principal project objective of enhancing the climate resilience and adaptive capacity of highly vulnerable rural communities. This objective is supported by various specific outputs (or "deliverables") aimed at improving access to safe and clean water productive and potable uses through modern SWP technology (Figure 41).

Figure 40 Theory of Change



210. The main project impacts will situate in GCF result areas “Energy generation and access”, “Most vulnerable people and communities” as well as “Health, well-being, food and water security”. These impacts are supported by a set of measurable project outputs that shall be monitored, especially in close alignment with the monitoring framework under Ethiopia’s updated nationally determined contribution (NDC).

211. These outputs shall be monitored based on the following set of variables (Table 21):

Table 21 Output monitoring variables

Output number	Type of indicator to monitor output
Project activity 1.1	Number of SWPs installed
Project activity 1.1	Tonnes of carbon dioxide equivalent reduced or avoided (t CO_2e)
Project activity 1.2 and 1.3	Quantity of water extraction (m^3)
Project activity 1.2 and 1.3	Number of direct beneficiaries’ potable water
Project activity 1.2 and 1.3	Number of direct beneficiaries’ irrigation infrastructure
Project activity 1.2 and 1.3	Number of indirect beneficiaries
Project activity 2.1	Number of policies, framework strategies and standards introduced
Project activity 2.2	Number and overall share of wells equipped with digital payment and metering systems
Project activity 2.3	Share of women-led agro-businesses associated with SWP technology
Project activity 2.4	Number of trained technical and/or policy experts
Project activity 2.5	Creation of knowledge-sharing and coordination platform (Yes/No)

212. Project monitoring is designed to both benefit from and inform the monitoring, review and verification system (MRV) proposed under the updated NDC. Relevant NDC adaptation targets with direct overlap to project outputs include the following:

- Agricultural sector
    - Area under irrigation (2030 target: 225,913 hectares)
    - Crop production through irrigation (2030 target: 38 million quintals)
- Water sector
    - Potable water supply per capita (2030 target for rural households: 25 l/capita/day)
    - Number of ha under medium- or large-scale irrigation schemes (2030 target: 1,3 million hectares)
    - Number of gender-balanced irrigation water user associations (2030 target: 36)
    - Number of jobs created through irrigation infrastructure expansion (2030 target: 930,000)
    - Number of persons acquired skills through tailored capacity building (no target)
    - Increase proportion of women shared development and management role in irrigation systems

7.2 Project operation and implementation

213. Project operation and implementation planning will be carried out at by executing entities, under the guidance of MILLs and, depending on the area of responsibility, MOWE and the ATA. To this end, these principal executing entities have set up a collaborative working group. Under consultations with the feasibility study team, executing entities propose preliminarily a set of operations and implementation arrangements that are set forth in the following.

214. This includes project activities, team structures, organizational structures, stakeholder engagement, licensing, procurement, the scheduled implementation of activities including sub-activities as well as auditing arrangements as per the sub-sections below.

7.2.1. Project design: activities and sub-activities

Component 1: Achieve increased community resilience through sustainable access to water

Activity 1.1 – Solar powered submersible pumps installed

- Undertake rehabilitation of 100 boreholes and laboratory test of water chemistry to make it ready for submersible pumps and solar PV
- Procurement of equipment and machineries (Solar PV's, Pumps, Drip Irrigation and Center Pivot Systems, Pipes and Fittings, Electromechanical works)
- Site preparation including excavation and community mobilization
- Commissioning, installation, and testing of equipment (Solar PV's, Pumps, Drip Irrigation and Center Pivot Systems, Pipes and Fittings, Electromechanical works)

Activity 1.2- Access to water for potable use is created

- Designing of a community led water supply payment tariffs for potable use
- Mapping and construction of a piping network and point collection
- Distribution of ground water to rural households at water distribution points pay per use services

- Operate and maintain water supply infrastructure

Activity 1.3 - Resilient agricultural production by smallholder farmers is created

- Construction of drip irrigation and center pivot
- Refine payment tariff model based on CAPEX of assets procured and installed
- Engage with Regional Irrigation Bureau to agree on terms of engagement for service providers based on the revised tariff model
- Engage with small holder farmers to agree on terms of service provision and payment model
- Conduct trainings and offer technical assistance to enhance resilience
- Synergize with other solar-powered irrigation projects, Micro-Finance Institutions in the region to collect and disseminate best practices

Component 2: Enabling environment created

Activity 2.1- Developed policy and regulatory framework

- Undertake a study to determine policy gaps and needs and develop recommendations (e.g., on minimum technology performance standards, access to finance)
- Refine CRGE Facility MRV structure in accordance with NDC implementation and integrating project results into the database

Activity 2.2 – Digitized payments systems

- Undertake study to assess the feasibility of integrating digital payment and metering systems
- Installation of digital payment and metering infrastructure
- Linkage to MRV system and operations

Activity 2.3 – Ensure that dissemination of gender-sensitive business models and financial instruments with WDRF are strengthened.

- Develop gender-sensitive business models
- Engage women groups involved with business models, follow up and support with them

Activity 2.4 – Training and capacity development provided

- Identify and engage with stakeholders
- Develop training and support programs
- Deliver training and follow up with support as required

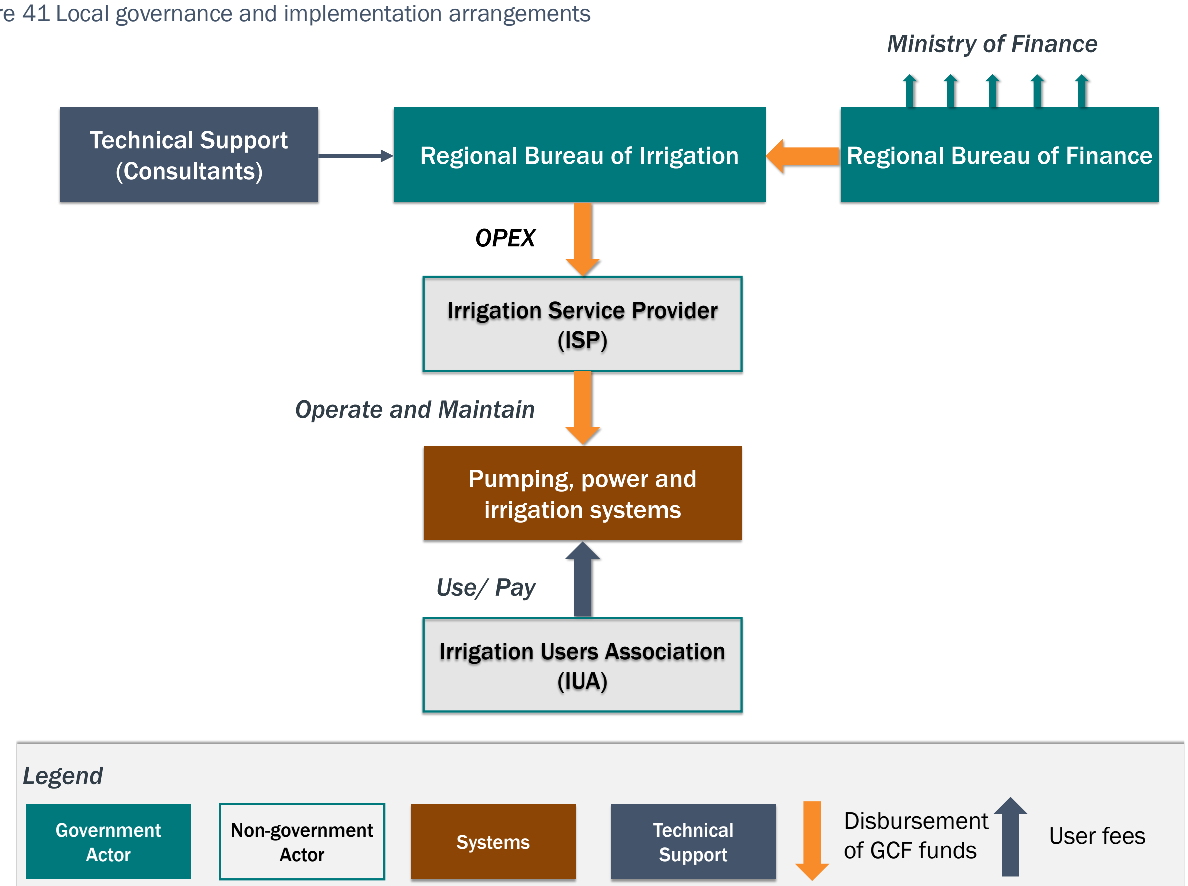
Activity 2.5 - Knowledge-sharing and coordination platform at the CRGE Facility created

- Develop a knowledge management and dissemination strategy and plan
- Establish work plan and set up an online knowledge-sharing, coordination and launching of platform
- Periodic dissemination of knowledge on data capture and best practices using online forums and different media spaces

7.2.2 Proposed local governance arrangements

215. Local governance and implementation arrangements shall be set up in a way that prioritizes local ownership and feasibility (38). This is achieved by building on existing IUA schemes, both for irrigation and potable uses. IUAs have a longstanding tradition and legal standing in Ethiopia. The central idea of the local governance and implementation structure is to separate maintenance of assets from the governance and use of assets. These clearly defined responsibilities are key to achieve long-term viability between government entities and private actors (i.e., farmers).
216. The feasibility of these proposed arrangements is underscored by similar implementation arrangements, such as the DREAM project. Here, the separation of tasks into (i) use; and (ii) maintenance is currently successfully piloted at several pilot sites of Ethiopia. Despite notable differences, (e.g., focusing on mini-grids, and larger-scale irrigation) the project can serve as a blueprint for the proposed structure.

Figure 41 Local governance and implementation arrangements



7.2.3 Stakeholder engagement

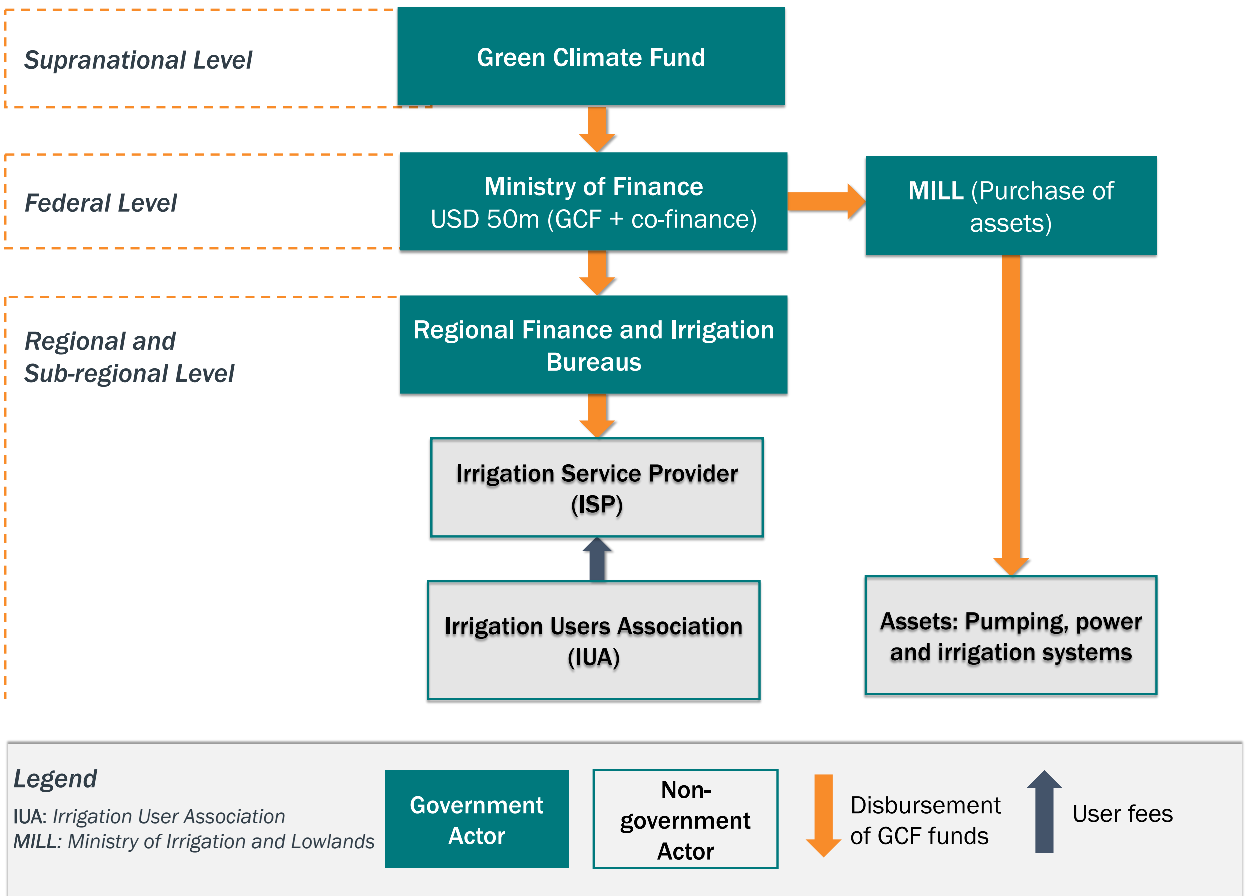
217. Broad and inclusive stakeholder engagement is an integral part of the project operations. Prior and during the feasibility study development consultative workshops have taken place, including over 50 participants representing government, civil society, community representatives (including representatives of farmer and pastoral groups in Kobo-Girana and Borena, respectively), private sector, consultants and advisors undertaking work in these localities.
218. As part of the Environmental and Social Management Plan (ESMP), this consultative process will continue as the project is kicked-off and increasing categories and numbers of stakeholders emerge.
219. No displacement or resettlement of the community during the development and implementation of the project is necessary. Finally, all impacts identified will be addressed through implementation of mitigation measures and there will be minimal residual impact after the implementation of the proposed mitigation measures.
220. The ESMP developed a comprehensive list of mitigation measures for all identified potential impacts, including preliminary costing, taking into account costing exercises that were conducted for similar ESMPs (including for GCF approved projects in Ethiopia). This project does not involve expropriation of land from individuals. Potential impacts on indigenous populations have been identified as non-existent or minimal, as it will not relocate people nor will it have negative implications on their livelihoods.

Figure 42 Consultation workshop at Adama resort, April 6-7, 2022

7.2.4 Procurement structure and contract management

221. The Public procurement at Federal level is governed by proclamation no. 649/2009 "The Ethiopian Government Proclamation and Property Administration Proclamation", September 9 and "The Federal Government Procurement Directive" of June 2010. The Proclamation has been reviewed by the World Bank and found to be satisfactory. The MoF follows the national and World Bank procurement procedures, which are currently applied and used for all public procurements. Regions and Line Minsters have procurement units which are responsible for procurement using the regional and federal procurement systems.
222. For the MoF/CRGE related service procurement, regions may not conduct direct procurement; MOF and Line Ministries are responsible for direct procurement. When procured through the National Competitive Bidding (NCB) procedures, the national Standard Bidding Documents (SBDs) issued by the federal Public Procurement Agency (PPA) are to be used. The procurement unit within MOF will conduct procurement of goods and services as defined by the operational manual of the CRGE Facility.
223. This project will be implemented through the MoF as the NIE and the MILLs as the primary executing entity (Figure 44). The CRGE Facility within the MoF will lead and coordinate the implementation of the project. The MILLs will be responsible to float the procurement of goods and equipment that follows the public procurement rules and regulations. The BOFEDs will be responsible for financial management including fund disbursement to the IUA's and service providers, account auditing and financial reporting. The Bureaus of Irrigation and lowlands in each region supported by national and international consultancy firms will provide project implementation oversight and quality control whilst the private sector operators will be the project developers. The MILLs will ensure the successful implementation of the project at the ground in line with the modus operands as outlined in the CRGE Facility operations manual guideline. The Project Implementation Manual (PIM) of the CRGE Facility has laid out project specific detailed guidance on implementation arrangement of the project including roles and responsibilities of the project stakeholders, financial and procurement management, monitoring, evaluation and reporting among others.
224. The MILLs as a lead executing entity of this project will lead the preparation of tender documents and advertising, screening of bidders, implementation supervision and quality assurance. In this regard, MILLs follow the standard practices, technical specifications, procedures consistent with the relevant national laws and procurement policies.

Figure 43 Flow of Funds



225. Depending on the threshold, volume and type, procurement could be conducted at federal, regional and woreda levels. In all circumstances, the MILLs shall ensure that the PPPA procurement policies and procedures are respected and strictly followed at all times. For bulk procurement of goods and services, the MILLs will request for the provision of services of the Federal PPPAA to conduct the procurement using agency specific rules and regulations. The MILLs, as was part of the then Ministry of Water, Irrigation and Energy, already has adequate experience of large scale procurement of goods, services and works in the irrigation and water sector at international and local levels through PPPA and directly. The tender documents shall specify inspection, quality assurance mechanisms and handing over procedures. The MILLs and the PPPAA will undertake measures such as physical inspection, cross-checking size and dimension, specifications, brand type, quantity and functionality, etc. of the items. In this regard, reference shall be made to the specifications stated in the bid documents. MILLs will assign qualified and experienced experts for the inspection and physical quality assurance before delivery and installation of items. Most of the procurement activities will be initiated around the same time, beginning from the third quarter of the project start date and should be finalized within six months. Cognizant of this, MILLs should immediately start with the procurement preparatory activities. Standardization of equipment is essential to maximize compatibility, interoperability, spare parts, safety and quality.

226. The quality of equipment and infrastructure will determine the level of success of the project. As such, the selection of appropriate technologies is one of the key issues that will require serious attention.

Furthermore, the project should ensure gender equality at all stages of the project and at least 33percent of the direct project beneficiaries are expected to be women headed households. Technologies which the project shall introduce will therefore be gender sensitive, environmental friendly as well as economically viable.

227. Machinery and equipment that shall be contracted and procured during the course of the project will be verified by a third-party consultant to be in line with the specifications outlined in the bidding document. The hiring of the consultant which could be a firm, or an individual will be conducted transparently and following the PPPA rules and regulations. The consultants could be a national or international firm or individual with proven track record of experience and capacity in validating bids submitted by solar PV, submersible pump, pipes and fittings including controllers, drip and center pivot system manufacturers, to ensure that offers submitted align with the specifications as outlined in this feasibility study.

228. This project involves procurement of goods, works and services at national and international levels. Hence, stringent quality control and supervision arrangements are vital to ensure the delivery of services and infrastructures consistent with the agreed standards, quality and timeline. In line with this, the MILLs, should put in place a robust quality control and supervision mechanism at all levels and at each stage of the project execution. MOF, as a contract partner to the GCF, will monitor and provide continuous support to the MILLs and MILLs will ensure that equipment's procured and installed comply with the standards as set out in the bidding document.

7.3 Work schedule

229. Separately included under Annex 5

7.4 Audit arrangements

230. Auditing of the project account at MoF, EEs that will be involved in this project and primarily the MILLs through which most of the procurement will be conducted, BOFED and WOFEDs will be subject exclusively to the internal and external auditing procedures provided in the National Regulatory Framework. The EE implementing this project are public bodies whose procurement activities shall be subject to procurement audit by PPPAA. The PPPAA is an entity under MoF established under proclamation No. 649, with a mandate to conduct federal public procurement in line with the Federal Public Procurement Directive[97].

231. The Internal Audit Directorate of the MoF and the Internal Audit Department at regional level will ensure good quality of internal audits at the EE levels and follow up audit recommendations noted by internal audit reports of the EEs. The Internal Audit Directorate in the MoF acts as an internal audit regulatory body while the Internal Audit Units in the EEs conduct the internal audit activities. The EEs receiving funds from MoF will conduct internal audit and the inspection service unit will conduct a regular audit of GCF fund by their respective internal audit and inspection service at each level using their internal audit guideline. The internal audit units of the EEs, BOFEDs and WOFED shall:

- Keep and provide a complete and annual check of the accounts, records, expenditure, stores, inventories, equipment, vehicles and other assets, there may also be quality assurance/spot checks on accounts as deemed appropriate.
- Review the accounts, financial documents and statements on a quarterly basis; and

[97] *Federal Public Procurement Directive, MOF 2010*

- Submit a written report to the MoF, copied to the subject of the audit, on the results of the checks carried out, along with recommended actions as necessary and a plan for their implementation.

232. The MoF is responsible to ensure the financial statements relating to project accounts are audited annually and submit the audited annual project financial statements to the GCF within six months of the end of the fiscal year. The Office of Federal Auditor General (OFAG) is responsible to audit the financial transactions of the federal government as well as subsidies to the regions. Each of the regions have a Regional Auditor General (ORAG), which is responsible for the audit of government financial transactions in the region. The OFAG usually delegates its responsibility to a parastatal or a private audit firm in the country to carry out the audit of donor-financed programs. The audit should be carried out in accordance with the International Standards of Auditing (ISA) issued by the International Federation of Accountants (IFAC). The auditor should also ensure that the executing entities get adequate coverage in the yearly audit exercises.

233. Accordingly, the GCF project auditing will be carried out by the OFAG on annual basis. The MoF will request the OFAG to undertake annual audit of the project. OFAG will then assign independent auditors, with which it has a framework agreement. The results of external auditing will be communicated to GCF. After the reports are issued, MoF has the responsibility to prepare audit action plans through its internal auditors within one month of the receipt of the annual audit report. The prepared action plan would be disseminated to EEs and the BoFEDs, who will be responsible for taking appropriate action and responding back to the MoF. The MoF would be responsible to submit the consolidated status report within a maximum of two months after the receipt of the audit report. It will then send status report to the GCF on the implementation of the comments and recommendation to contributors.

7.5 Project Sustainability

7.5.1 Proposed Project Implementation strategy

234. Increased production and productivity, assurance of food self-reliance and exportable surplus produces would be attained with the integration and implementation of the following strategies.

- Replacement of the current mono-cropping system and introduction of specialization and diversification approaches with high value crops to increase the farmers' income.
- Optimizing crop production through intensive agricultural production systems
- Operational transparency through enhancement of full level participation of the community in planning and implementation of the project
- Formation of organizational network at all levels (primarily woreda to command area WUA) for efficient water use and ease of maintenance mobilization.
- Establishment of substantial integration and coordination among the respective governmental bodies, agricultural extension delivery services, input and credit supplier institutions designed for the implementation of modern irrigation development approaches.

7.5.2 Proposed Organizational Structure of the Project

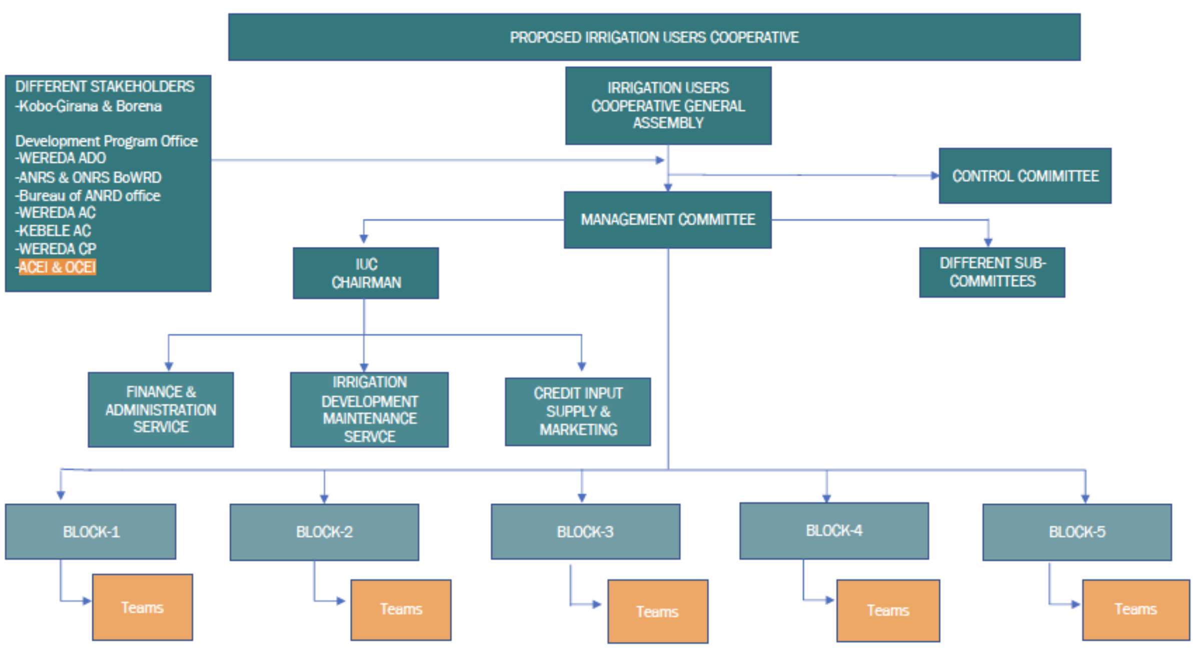
235. The proposed structure of this project follows using existing structures, institutions and experience of the KGVDP and builds on the gaps to ensure a smooth exit strategy and sustainability of the initiative. The project is designed to be implemented with a strong integration of key stake holders to achieve the

commonly shared goal and organizational framework with specific roles and responsibilities in line with their mandates.

236. At the regional and local level, KGVDP Office and Borena Irrigation Development and Pastoral (BIDP) Office, including administrative councils will be key partners that would be involved in this project (Figure 45). These offices have the ground experience, understanding of the political economy and the challenges thereof on the site. They will be key to have a buy in and mobilization of the service providers, youth SME's, community and support existing IUA's which are formally organized by the Woreda Cooperative promotion office and provide administrative support. The project will work with the Woreda agricultural office, in collaboration with Woreda cooperative promotion and organization office and Amhara credit and saving institution (ACSI) and Oromia Agriculture and Natural Resource Development Bureau to provide agricultural inputs (on credit or on cash basis) and a day-to-day routine extension service.

237. The target groups will be organized in to 'Irrigation users Association (IUA)" in which both private and communal owner ship and responsibilities are simultaneously involved. Every member will grow the selected varieties of crops in clusters, according to the technical recommendations of this. However, scheme management, water utilization and related issues will be administered by the service providers. The association would then be organized in such a way that there are" Block leaders" based on primary and secondary canals. The farmers laid in one primary and secondary canal will have one "Block leader" (leader) who is responsible for managing his/her member. "Block leaders" will be accountable for the chairman of the association. The association will have its own leadership (chairman, finance and administration service, credit service input and market) and align with the bi-laws to which they will stick in the course of the development. There are also proposed roles and responsibilities of each theme and they can modify/improve based on their design.

Figure 44 Proposed Organizational Structure



7.5.3 Operations and maintenance (O&M) plan

238. Independent service providers will be contracted through a competitive bidding process to operate and maintain the assets. A water payment tariff model will be developed to allocate payment rates that are affordable to the end user but also an amount that is able to pay for spare parts, routine maintenance activities and also reasonable margins to the service provider. The service provider will be a national firm but working with an international firm with grounded experience and capacity in operating and maintaining assets of similar scale will be working in tandem to transfer knowledge *(Knowledge transfer has been covered in sub chapter 7.5.3).*
239. While it is to the advantage of the service provider to conduct preventive maintenance activities, the MILLs will require the service provider to articulate the operational and maintenance services that will be provided in a detailed plan. This shall comprise regular visual and physical inspections, as well as verification activities with a specific task periodicity of all key components which are necessary to comply with the operating manuals and recommendations issued by the Original Equipment Manufacturers (OEMs). The service provider should also be familiar with the equipment, components and warranties in place to reduce the probability of failure or degradation. This maintenance will be carried out at predetermined intervals or according to prescribed O&M manuals. This will be required as part of the bidding document to be included in a detailed Annual Maintenance Plan with clear time schedule and the specific number of iterations to carrying out the maintenance. Maintenance contact list at the farm level will also be required to be shared with the MILLs to conduct spot checks of availability at any time. A typical frequently followed preventive maintenance routine checkup is provided below in Table 22.

Table 22 Preventative Maintenance logbook[98]

Schedule	Component	Action Items	Status	Date	Comments
DAILY	*Water Transmission*	• Record water meter readings • Water meter reading • Checking for inconsistencies in daily water usage – signals hole blockage in the drip/pivot			
	Pump Station	• Inspect pump operation • Inspect pump control unit			
	Storage Tanks	• Check and record tank water levels • Inspect tank for leaks			
	Security	• Conduct and complete a daily security inspection • Investigate and attend to customer complaints • Inspection for evidence of vandalism on the property			

[98] O&M Manual for Solar Powered potable water supply system, 2019, WaterAid

		• Inspect fence enclosure and gates			
MONTHLY	*Cleaning*	• Clean solar panels array • Flush water system			
	Security	• Check all system alarms for proper operation • Check for loose cable connections on solar array. • Check all air valves on system • Check entire system for leaks			
	Quality inspection	• Take all water samples for testing • Check and record all monthly water production • Check monthly reports • Inspect and maintain entire system.			
	Valves	• Maintain valves for leaks or when spotted			

240. Spare Parts Management is an inherent and substantial part of O&M and shall be used throughout the lifespan of the system. Record of all available spares for the system purchased through GCF funding shall be kept at the MILLs regional bureau by the maintenance team. These spare parts will be utilized upon the provision of evidence that the service provider has been conducting routine maintenance of the assets and the failure was caused due to age or other unforeseen circumstances. The MILLs will take corrective measures and or actions against the service provider if the failure occurred was due to neglect or any other reason outlined outside of the O&M plan.
241. Tariff margins will be set after having conducted a detailed tariff modeling study within respective project sites which is cognizant of communities' economic condition with the aim of i) Providing affordable rates to the IUA's ii) 10 percent of the margins will be set to purchase spare parts and iii) Operational costs and reasonable margins to the service provider. The model will be developed to be intuitive so that it can be used by the MILLs to easily revise the tariff on an annual basis and considering the increased economic income of the communities.
242. The service provider is expected to have acquired enough knowledge around the operation and maintenance of the assets at the end of the project. The systems and practice built in place during the knowledge transfer will be an invaluable knowledge for the service provider to take the service provision as forward. Numerous jobs will be created by the service provider to cater for the operations and maintenance that will be the backbone towards increased productivity for the IUA's and a diverse market systems and chains as an outcome.

7.5.4 Knowledge management plan

243. The DREAM project that is currently being implemented by the Ministry of Irrigation and Low-Lands (MILL) in partnership with the African Development Bank, Rockefeller Foundation, and the Agricultural

Transformation Agency (ATA) is the forerunner in showcasing private sector led medium to large scale irrigation projects. Substantial amount of knowledge is being generated from the project in terms of bringing medium-to-largescale irrigation powered by solar-based distributed renewable energy, enabling cluster-based farming to achieve substantial value for smallholder farmers. However, while this project takes significant amount of learning and follows similar implementation modalities, the use and management of center pivot systems is not widely applicable in Ethiopia. During project inception, the procurement will focus in bringing onboard center pivot irrigation system contractors who are able to install and also manage the system, specifically in Borena. A knowledge transfer scheme to local stakeholders including government and private sector actors has also been embedded into this project so to ensure similar systems and management systems are replicated in other parts of the country.

244. Induction and capacity building towards solar powered water pumping units at a large scale is essential to be built at all levels. In a country where there is grounded knowledge and experience in designing and installing diesel powered generators, using solar power to generate the same amount of power will be a novice experience. This knowledge will be transferred during program implementation and later when the project is commissioned through private sectors contractors who will be working with government and local stakeholders in developing the system and later embedding private sector service providers to ensure the system is managed and maintained. This will build confidence across the board that solar power can be used to generate the required amount of power including the sustainability of the system for a longer period.

245. The concept that water is not a freely available resource will be critical knowledge that will be transferred to the community. While this project will commence with embedding reasonable amounts of payments to be collected by the service providers for the water used, and the service provided, the small holder farmers would be exposed to the benefits that come with paying for their water use towards irrigation and the benefits that come with it. The knowledge management plan will ensure that the success of the project to be broadcasted widely to the public so to sensitize small holder farmers that paying for water usage and sustainable service that come with it to have enabled the small holder farmers to have increased their produce and increased their income and directly increased their adaptive capacity. This knowledge will pave the way for private sector actors to implement similar solar powered irrigation projects in other parts of the country but with margins that is in tune with the market. This project will essentially act as the market activator and will use the private sector service providers as the market accelerators to establish medium and large scale solar powered irrigation projects in other parts of the country.

Stakeholders generating, processing and disseminating this knowledge and sustainability:

246. The knowledge generated from this particular project includes but not limited to:

1) Pay for water for productive use
2) Sustainability of productive use of solar energy
3) Engagement of private sector actors to unlock capital and accelerate the productive use of energy across the country
4) Efficiency of solar technology with minimal down period and increased productivity directly leading to increased income.
5) GHG reduction
6) Informing policy and project formulation against a business as usual of considering diesel powered for energy generation. The knowledge captured will also translate to other sectors particularly Transport, Industries and Urban space, on how solar systems are efficient and a reliable source of energy.

247. It is against this background that, we have identified pertinent stakeholders as below who will be the ambassadors and the main instruments in dissipating the knowledge generated from this project.

a) Ministry of Finance, CRGE Facility – ensuring that project concept notes submitted from the Ministries pay due attention to integrate green energy solutions to their project designs. The existing MRV system will also be used as the main vehicle to measure total GHG avoided and track progress made towards NDC achievement.
b) Ministry of Irrigation and Low-Lands; Ambassador of the project that will be embedded with the DREAM project to share the knowledge generated in terms of the number of lives changed, economy gained, productivity increased, job opportunity created all within the context of reduced GHG mode of energy generation. The knowledge generated will be shared on national and international forums and also influence other ministries to make a paradigm shift in their project design approach to consider the use of green energy solution. The Ministry of Irrigation and Low-Lands has allocated a budget within this project to record the thought process behind the design of this project and follow up on the development through implementation and later commissioning. The main objective of this task is to show how the new Ministry body is bringing in new ideas and technology into the planning and design process to increase its impact whilst maintaining low GHG emissions. This shift in thinking is also reflected in the DREAM project as Productive Use of Energy sits at the heart of the Ministry. As such, the thought process will be shared with the media and newsletters both nationally and regionally to also influence other stakeholders to change their thought processes.
c) Environmental Protection Authority – The EPA is one of the strongest proponent of this project as it ticks most of the objectives the Authority was established under. The use of alternative energy source and where possible replacing existing GHG emitting assets to become green being implemented at this scale will attract recognition from the media and neighboring countries how solar power can be converted to be used for productive purposes. The EPA works across the sector Ministries and is also actively engaged in NDC negotiations, Article 5, AGN, amongst others, the platform of which will be used to also inform national and regional counterparts how alternative energy can be used to build the resilience capacity of the community whilst reducing GHG emission at the same time.
d) Media (National and International) –A project of this scale will attract the attention of media power houses both nationally and regionally on how the country is embellishing the concept of Productive use of Energy at a larger scale. Budget has been allocated for the Media to capture the project being delivered and during its inauguration in order to frequently broadcast this new concept of irrigating medium to large scale farm lands and benefiting countless number of small holder farmers to become commercial farmers through alternative source of energy. The proponents of the project understand that the scale of this project will not only influence thinking locally, but also regionally if not internationally. It is against this understanding that this project will leverage on its scale to also inform others the potential of using alternative sources of energy for productive use.
e) Banks and MFI's – Financial institutions have always been reluctant to finance projects that are financed by alternative sources of energy. While there are few private sector actors who have been able to access finance to import portable solar powered irrigation pumps, the interest rate is not cheap making the product expensive to the consumer. This on the other hand encourages both the importer and the end user to import large and small scale diesel powered irrigation pumps and to purchase the same. This project however, will unleash the knowledge and the confidence into the finance sector which is the critical driver to steer the NDC into play. The Bank of Abyssinia and Awash Bank have experience working with USAID funded projects as guarantors to the private sector to import solar powered systems. The two Banks will be contacted and updated on the status of the project so to build confidence on the efficiency and sustainability of alternative energy systems. This is a leverage to their existing knowledge and to open the window of opportunity for these entities to avail finance to import and or purchase these systems at an affordable rate. The government, finance institutions coupled with

the private sector are the main instruments to drive the national agenda of using alternative sources of energy at a national level thus steering us away from the business as usual of considering diesel powered energy generation.

f) The private sector – The private sector and specifically the Solar Energy Development Association (SEDA-E) which is an independent non-profit association dedicated to facilitating the growth and development of Solar energy business in Ethiopia will be the main vehicle this knowledge will be shared through. Whilst SEDA has been established and running since 2010, the lack of funding towards the association in addition to the lack of conducive environment to activate and accelerate the solar business has not made it a champion for the private sector to see the increased use of Solar power into the country. SEDA is an umbrella association that brings together all the private sector actors who are engaged in the import and or distribution of solar powered equipment's. This project will thus empower SEDA thorugh the budget allocted through it to increase its manpower and also be the driver in the private sector stream that this project is recognized and understood across the board. SEDA has been targeted as the main actor to bring together the private sector actors, finance institutions and bottom of the pyramid community to ensure that knowledge with regards to using solar energy at this scale is built and the required confidence in using the systems is embedded across the board.

Figure 45 Seedling growing center - Kobo Girana

Knowledge beneficiaries

248. Government entities will be the primary beneficiaries of the knowledge created from this project. Ensuring that alternative energy sources can replace diesel power energy generation plays a crucial role in informing policy, regulations, and directives. This will directly have its bearing on regulations to import and or assemble alternative energy sources locally, tax levied on the same equipment's and how national and regional programmes and projects are informed and designed. Changes at the grass top at the policy, regulatory level will have its trickledown effect on the mass adoption, affordability and increasing the resilience capacity of the community at the grass roots.

Addressing special needs of the beneficiaries:

249. Project beneficiaries targeted under this project have long been waiting for diesel powered generators to be purchased to power the submersible pumps. However, the regional governments experience with

using diesel generators to irrigate mass swaths of land for the past ten years has shown that such systems are highly expensive to run and eventually will shut/break down for it is difficult to transport the considerable volume of fuel required to run these systems and or maintain them frequently as most of them are located remotely. This has left the regional authorities undecided for a significant period of time making the boreholes targeted under this project unproductive for there was no alternative means as a solution.

250. The technological advancement in solar photo voltaic, its price drop coupled with the availability of the GCF funding has now brought about an opportunity to power these same boreholes by solar and use them for their initially intended purposes i.e. productive use. From the engineering point of view, this project will benefit both men and women who own a patch of land that is within the reach of the water that will be extracted from the borehole. Marginalized women however who are beneficiaries of this project will be specifically profiled to pay the minimum amount of payment when receiving water to their land. This project is cognizant that while most of the land is owned by the men, as a household there are women and children who will be benefitting from this project and thus this project deems important to also consider them as part of the household.

251. There will also be significant amount of job opportunities that will be created for the youth that will be employed under the service providers. Maintenance of the drip irrigation system specifically is labor intensive and will create an opportunity to maintain both the drip and center pivot systems in addition to also working in bill collection and clerical services within the service providers. Furthermore, supply of parts for the irrigation system, periodic cleaning of the solar arrays amongst others will be additional benefits that shall go into the community and beyond.

Figure 46 Wheat produce - Diesel powered generator systems for drip irrigation

Knowledge benefits beyond the life of GCF Funding:

252. This project will build on the momentum created by the DREAM project but at a larger scale. The Ministry of Irrigation and Low-Lands owns this project, the integral design of using alternative sources of solar sits well within the Ministry office strategy. The MILLs considers the knowledge extracted from the design to the implementation and later commissioning stage as the center of its strategy to scale similar projects in other areas through line ministries, private sector and predominantly the private sector.
253. The MoF will be the other proponent to ensure that knowledge generated will be used to influence Sector Ministries to inform their thinking into their planning and design phase. The CRGE Facility will be the main instrument to ensure that alternative sources of energy are considered when designing a project and or a programme.

Figure 47 Mango plantation - Water supply network powered by diesel generator; Kobo Girana Valley

7.5.5 Capacity building/Knowledge transfer

254. The local level planning takes place based on the overall development policy priorities and indicative budget communicated from the federal and regional levels. The CRGE Strategy elaborates sectoral and cross-sectoral climate smart initiatives, that will enable Ethiopia to realize its CRGE vision and NDC commitments. The realization of the vision depends on the degree to which the relevant stakeholders at federal, regional, and local level integrate the various initiatives into their planning process.
255. The updated NDC of Ethiopia that was submitted on the 23rd of July 2021 includes updated greenhouse gas (GHG) emissions projections using the most recent national and sectoral emissions inventory data. Second, the NDC integrates the country's national climate and development objectives by aligning the GHG emissions pathways with national development priorities and sectoral targets from Ethiopia's new 10-year development plan. Third, even though Ethiopia's contribution to global GHG emissions is

minimal, the country has increased its overall mitigation ambition with a commitment to reduce economy-wide emissions by at least 68.8 percent by 2030 against the business-as-usual projection. This is an additional 4.8 percent below the reductions committed in the previous NDC. While these ambitions are welcomed both at the national and global level, specific challenges have also been identified that will become bottle necks to meet with the NDC. In order to ensure that capacity is built, and knowledge is transferred towards meeting with the NDC, this project will (i) strengthen the Institutional framework and local management instruments (ii) build human capacity and strengthen the communication and learning at the local level and (iii) increase market supply chain efficiency.

256. Strengthening the institutional framework and local management instruments - The main focus of this objective is to translate national CRGE plans into local development planning, making existing Woreda plans climate smart and aligning them with the national targets. Activities under the enabling environment component will focus on supporting the IUA's for integrated climate smart planning. Furthermore, activities under the enabling environment will seek to address gender inequalities that may prevent women from benefitting from these interventions. It will also be linked to awareness raising, monitoring and learning initiatives to ensure this approach is developed and implemented with the local community, and that sufficient learning elements are put in place to ensure the results of activities can help inform future planning. This component will also develop climate resilient and gender responsive planning for integrated productive use of energy, with a focus on building the capacity of the private sector and youth establishment, increased ground water management, increased productivity and vibrant market systems. Under this component, three main activities, which aim to strengthen the human and institutional capacities and capabilities will be executed. The specific activities under each main activity are presented as follows:

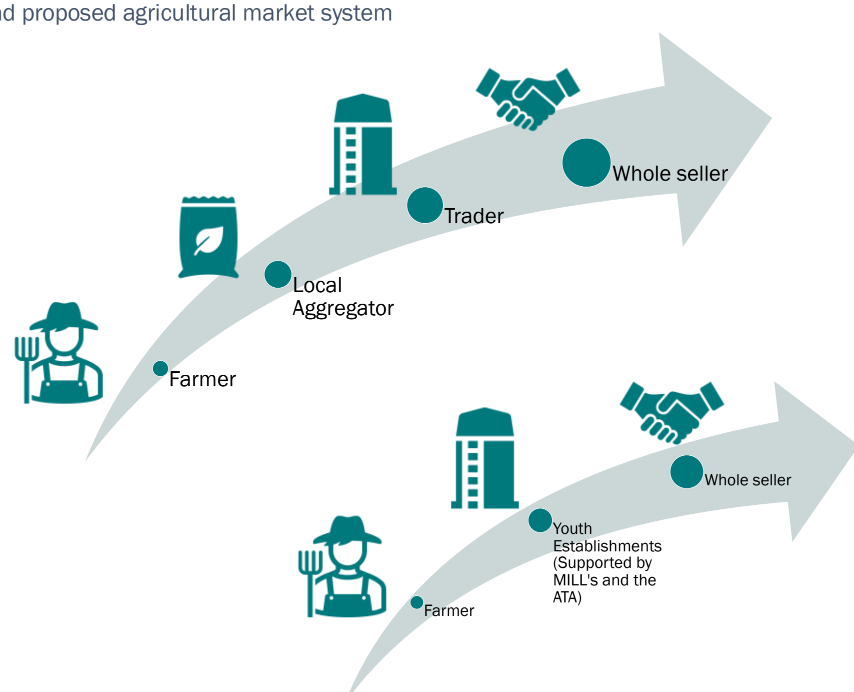
Figure 48 Seedling distribution to farmers - Kobo Girana valley

257. Improve human capacity - the project will contract capable consultants to operate and manage irrigation systems that are powered by solar energy. These consultants will be working in tandem with a service provider until the end of the project life and ensure that the selected service provider will be able to operate and manage the systems on its own at the end of its tenure. The MILLs will conduct periodic checks on how the knowledge transfer is progressing. The knowledge transfer will not only

focus on smooth operation of the whole system rather it will also ensure that women are equally benefitted and own or are hired by the service provider. Specifically, the project will facilitate:

- Knowledge transfer to the service provider on management, operations, and maintenance of the assets
- Capacity building and continuous support of the CRGE Facility, MILLs and regional bureau on effective communication mechanisms, via news and social media channels to influence others in the country and in the region to show case the power of renewables and become a sounding board for other sectors to consider green technologies into their planning
- Water meters will be used to capture the volume of water extracted and monetize it. Awareness will be created through this project that water as a finite resource and that the farmers will be required to pay for this resource for productive use. The payment tariff will start with the bare minimum when the project is commissioned but will be revised to reflect actuals when the farmers eventually get in a better economic condition. Furthermore, understand the ground water dynamics for better ground water management for this project as well as to replicate the project in an informed manner at the regional and national level.
- Capacity building on knowledge management that will be essential in scaling and replicating the project and avoid the use of diesel-powered generators to power their submersible pumps
- Conducting an annual assessment of regulatory bottle necks across the project delivery from procurement, to commissioning of the assets to operation and maintenance. Bottlenecks identified will be relayed back to the MoF and MILLs to address the regulatory shortcomings that could be an impediment for the green technology to thrive.
- Training and awareness raising for Environmental and Social Management.

Figure 49 Existing and proposed agricultural market system



258. Strengthening market supply chains - long supply chain of agricultural commodities have always been a challenge in Ethiopia and are the primary causes of high price disparity between farm-level price and the retailer. The government has established the Ethiopian Commodity Exchange (ECX) and removed the middlemen in the supply chain. The ECX has been successful in ensuring that most of the margins

are kept at the farmers hand and the produce reaches the retailer and then the consumer at a reasonable price. However, the ECX only trades selected variety of crops such as Coffee, Sesame and certain kinds of Beans and is not trading the spectrum of agricultural products that are being produced in the country. High price disparity between farm-level and retailer is also not necessarily brought about by elongated supply-chains but also by the efficiency of the chain itself. Common weaknesses include limited accessibility and/or affordability of quality inputs, lack of access to finance, storage and adequate extension support, high degree of dependence on informal markets and farmgate sales to traders with a much stronger bargaining position, limited value addition, and low-price premiums for high-quality produce in absence of stronger market linkages.

Figure 50 KGVDP supported farmers - Onion produce, ready for the local market

259. The current market dynamics in the target areas is broken i.e. in Kobo Girana the conflict has disrupted existing market systems and in Borena, it is not existent. Youth associations in these localities will be established under this project to serve as the middle men between the producer and the market, thus removing the long line of middle men. Lessons captured from the ECX and the ATA will inform the establishments of these youth associations and in effect remove the supply chain inefficiencies via an up-to-date market data they will be receiving from the ATA. Efficiency of the chain will be improved by creating enabling business environment and achieved via transparency in price and quality grade. Information and Communication Technology (ICT) via mobile phones will be an integral part of this information relay, where good and reliable flow of such information will be the foundation upon which the trade will be conducted.

260. Sector specific consultants will be contracted to establish these youth associates in line with the regulatory provisions of the country to link these establishments with the ATA, provide them with the required training on utilizing the ATA data and also identifying a market that will fetch the highest price for the produce. These youth establishments will in essence become the farmers agent and will be instrumental in removing the supply chain inefficiencies (Figure 50). Critical bottle necks to increase efficiency, transparency of contracts and reliability, including road access to markets will be continuously identified by the consultant in due course of program implementation and communicated to the MILLs and MoF in a periodic manner. The MILLs and MoF will be responsible to address the bottle necks and challenges and continuously improve the market supply chain. Lessons learned and best practices captured throughout the project will be important to replicate the same when the other boreholes become productive and/or in other regions of Ethiopia.

7.6 Project Financing Plan

7.6.1 Financial model

261. A separate financial model including detailed economic analysis has been included as part of the main GCF Funding Proposal (Annex 3).

7.6.2 Project budget and detailed budget disbursement plan

262. Separately included under Annex 10.

Part F - Recommendations

263. Ethiopia requires financial, capacity-building and technical support to implement its NDC and fully achieve its long-term climate and development objectives. Realizing Ethiopia's ultimate climate ambitions will simultaneously support the achievement of its ambitious development agenda. It also sends a clear signal of its objective and request for support from the international community.

264. While the NDC is a critical step forward, the government of Ethiopia will also require support to implement its climate-compatible development pathways that will look further into the future as it prepares its mid-century Long-Term Low Emission Development Strategy. This project proposal is thus part of the parcel that would help the country ensure transformative climate actions, which will help it realize the national green structural transformation. General and specific recommendations in carrying out this project proposal to the ground has been summarized below:

8.1 General:

265. The project proponents followed the principle of *"plan to implement"* and thus have designed this proposal to build the resilience capacity of the communities through green energy solutions. This will be conducted as an addon to their way of life and building on their local knowledge but also adding awareness on the power of renewable energy that will be used to increase their productivity. In both regions, solar energy will be used to extract ground water and avoid/replace the use of fossil based energy solutions which are expensive to run and are not sustainable in the long run. This should be the premise to be followed in the execution of this project, where enough budget has been allocated to capture the knowledge generated so to replicate the same project on boreholes in the same vicinity that are not targeted by this project. Furthermore, the knowledge and lessons generated form the execution of this project will also be an invaluable asset to other line ministries to use renewable energy in their project design and thus advance the national ambition of meeting with the NDC.

266. Several studies[99, 100, 101, 102] on PUE Markets and appliances completed underline that there is a huge potential in Ethiopia towards accelerating the use of productive use of energy systems. The same studies show that several appliances can return favorable commercial returns on investment in various context including solar water pumps, grain millers, refrigerators and coolers, milking machines, poultry production implements, among others. Renewable energy solutions have that leverage to provide energy for productive use and tip the scale towards increasing productivity of the community and thereof building their resilience capacity. Activating the market systems will bring in additional opportunities to add value to their produce whilst also increasing the job opportunities for the youth. Delivery of this project thus is not only about increasing productivity, sustainability and building resilience but also a paradigm shift in thinking, planning and designing that will also become an impetus for other projects to consider using renewable energy. For a country to meet with its ambitious NDC commitment, a shift on how we design our projects and implement them using renewable energy is necessary.

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[99] *Borgstein, E., Wade, K., and Mekonnen, D. Capturing the Productive Use Dividend: Valuing the Synergies Between Rural Electrification and Smallholder Agriculture in Ethiopia, Rocky Mountain Institute, 2020*

[100] Scarlett Santana, Zihe Meng, Kester Wade, Patience Bukirwa, Francis Elisha, Productive Uses of Energy in Ethiopia: Agricultural Value Chain and Electrification Feasibility Study, RMI, 2021

[101] *Offgrid Productive use of Energy - 2020 Catalogue, USAID, 2020*

[102] *Sustainable Energy for Small Holder Farmers in Ethiopia, Kenya and Uganda, 2021*

8.2 Delivery of this project:

a) This project is designed on a 90 percent grant financing from the GCF and 10 percent country co-financing. The grant funding is allocated towards financing to the full cost of the CAPEX cost and technical assistance to ensure sustainability of the project, whilst the country financing is allocated towards OPEX cost. Thus, to ensure sustainability, payment tariff models should be developed based on the current income of the targeted communities with reasonable margins also left towards the service provider. However, periodic assessment should be conducted in the target areas to understand their status of socio-economic income and measure the degree to which this project has built their adaptive capacity and gaps to be identified in the market systems including barriers. The results of these assessments are important as it feeds back into the model to recalibrate the tariff, address the bottle necks at the federal level and also identify gaps in the market systems for the private sector and or financial institutions to intervene.

b) Knowledge management and lessons learned are a critical component of this project. It is for the same reason that this project will be primarily executed by one entity i.e. the MILLs under the auspices of the MoF as the owner of the project. Streamlining the project implementation structure is necessary so that lessons learned are not dissipated and diluted across the different actors, rather are collated under one umbrella i.e. the MILLs. There has been enough budget allocated to capture the lessons and effectively manage the knowledge that will be generated from this project as it will directly feed into pipeline of projects that are currently being designed by the various sector Ministries.

c) The small holder farmers in Kobo-Girana and the pastoralists in Borena are an integral part of this project where their indigenous knowledge has been weaved in the design of this project. This approach should be followed through in the implementation of this project as it will form the basis of the project's sustainability.

d) Digital water meters will be installed to understand the amount of ground water extracted at each borehole. This information will feed back to gauging the ground water abstraction against the water balance study conducted for this project, which is a critical information for effective water management. It will also give an estimation of the amount of Diesel saved thus GHG avoided, which will directly feed into the existing MRV framework of the CRGE Facility and track the record against NDC achievement.

e) The service providers should be established by the time the equipment's and assets are procured and ready to be installed. The service providers will need to work closely with the project developers in erecting and commissioning the assets. Knowledge transfer starts at this stage and building ownership of the assets will be embedded as part of the project sustainability. In addition to providing technical support in installing the systems, they will also be working in close partnership with the regional irrigation bureau and the consultant in mobilizing the community and setting up the IUA's that will envelop the small holder farmers receiving the services.

f) The 100 water wells targeted for this project will need to be rehabilitated and the water quality re-tested for contaminants. An air compressor integrated with truck water well rig and a minimum working pressure of 30bar and free air delivery 1,200 CFM is recommended for the rehabilitation works across all project sites to remove any debris, silt and incrustation that might have developed within the boreholes. A mandatory water quality/environmental testing in line with the WHO standards against the major Cations, Anions, PH and TDS will need to be conducted.

g) A monocrystalline 540W solar PV array with a module efficiency of not less than 20 percent was considered in designing the energy system for this project. The solar array should be installed not less than 130 meters above ground to provide ample space to grow seedlings and horticulture products that require minimal sunshine. The space provided will also allow for ease of maintenance and repair.

Part G – Annex

Annex 1 Design - Irrigation system: Drip and center pivot

PRINCIPLES OF PRESSURIZED IRRIGATION

The use of pressurized irrigation method has brought improvements in the irrigation efficiency and land utilization due to its suitability to the application of irrigation water to farms with undulating topography, shallow soils, and higher slopes. Thus, application of improved irrigation methods and techniques on small farms is expanding rapidly because of the increasing demand for higher irrigation efficiency, improved utilization of water and intensification and diversification of production.

Experience gained locally and from many African countries has shown that piped irrigation techniques are successfully replacing the traditional open canal surface methods at farm level. This is due to its ability of irrigating undulating and higher slope fields, shallow and light soils, increased crop water use and simplified operation and maintenance.

A pressure piped irrigation system is a network installation consisting of pipes, fittings and other devices properly designed and installed to supply water under pressure from the source of the water to the irrigable area. Moreover, the implementation of CP irrigation Machine requires interconnected trusses of mechanical systems in addition to experience of lumbering.

1.1 Kobo Girana: Drip Irrigation System

1.1.1 Terminologies, principle and design considerations and strategies

Terminologies

Subunit: This is the smallest unit of the plot (0.25ha) or the command area that is operated with one independent valve, also this unit where basic irrigation application is carried out.

Basic Distribution Unit (BDU): This is the basic unit of the well plot in which four to eight subunits are included under the same operation point. Basically, there are three types of BDU in well systems for design convenience. Also, the operation design is carried out at this basic irrigation unit level. (See Drawing No.s from RP-HW-01/00- RP-HW-04/00)

Well Unit: It is irrigation field that is to be irrigated by single well upon which all irrigation system is set.

Operation Unit: It refers to a point in a BDU where operating valves (ball valves) are located. The number of valves is equal to the number of subunits in the BDU. The valves are operated in turn. That is, when one of the valves is open to supply water to a subunit, the others remain closed.

Shift: It refers to a fixed interval of time during which a subunit in a BDU is irrigated. Also, this refers to total irrigation shift in a well unit during total irrigation duration in a day level.(See operation tables on design drawings).

Main Control Head: It is the main control point of the system at which discharge and operating pressure of the system is delivered. And, system operation is also started and closed at this point.

Secondary Control/Field Control Head: It is the control point at which the discharge and operating pressure for the BDU is checked. It contains an operation point which has got valves enabling irrigation of the subunits in shifts.

Manifold: This is an HDPE pipe which is taken off from the submain riser pipe and delivers irrigation water to laterals.

Riser: This is a vertical HDPE pipe which rises from the submain pipe which is buried and delivers water to manifolds which are laid on the ground surface.

Submain Pipe: This is a buried HDPE/PVC pipe which is connected to the main line and delivers water to the riser pipes

Main Pipe: It is a buried HDPE/PVC pipe which takes off from the main control and delivers irrigation water to the submain pipes.

2.1 Basic Design Input Data

In preparing the detail design of the drip irrigation plot in Kobo Girana valley, the following parameters have been included;

Topography

1. A topographical map at a scale of 1:5,000 with contour interval of 1.0m and showing all physical features of the development area was used for the overall planning, layout and design of the system.

2.1.1 Water source

The water source for developing the area is identified as boreholes/drilled wells. Necessary design parameters of the wells appropriate for the system development had been used from the current hydro-geological study conducted for the project. Based on the hydrogeological and water balance studies, the locations and the average safe yield of the wells used for the design is indicated in table 19 & 20.

2.1.2 Irrigable Area and Irrigation Unit

The irrigable area of each plot was delineated on the map through the assessment of all existing physical features on the plot which include location of water sources, boundary of existing farms, area for development using other water sources, location of villages, rivers, and other topographical features.

In order to design the system for small holder farmers, there is a need to ensure that each plot holder has a degree of individual responsibility for use and maintenance of the irrigation equipment. To promote this sense of ownership and responsibility, a plot is divided into smaller plots of equal size called Basic Distribution Unit (BDU). The BDU is further divided into smaller land units of equal size (0.25ha) called subunit. The subunit is the smallest field unit determined to be managed by each house hold. Each BDU is 2.0 ha with 8 subunits of 0.25 ha each, with exception where available land size/shape does not permit BDU of 2.0 ha or 8 subunits of 0.25 ha. However depending on field topographic conditions, the nature of the field layouts is made fragmented. That is, the length of manifolds and sub-mains can be varied and the size of Basic Design Unit of operation can be varied too. Nonetheless, no BDU to be of less than 1 ha with 4 plots of 0.25 ha.

Based on the available water at each site and hence the lengths of the manifolds and sub-mains that vary from plot to plot, the following standard BDUs has been adopted.

Basic Design Unit (B.D.U.): 200m long and 100m wide (2 ha net area). It has eight subunits of each 0.25ha (50mx50m) served by an operation point with eight valves provided on it. The subunit discharge in such BDUs is ±10m³/hr.

Additionally, each BDU is having a control unit which is provided with secondary filters, pressure regulator valves, & fertigation unit. It is also proposed that the organization of the beneficiaries & reallocation of the irrigable area should follow the layout set in each designed plots. As a result, farmers in each well unit are expected to be organized for the overall management of the irrigation asset.

2.1.3 Climate and Crop

Cropping pattern and crop-water requirement has been developed and outlined below, table 23. Based on this, three wet season and two dry season crops were selected to fix the maximum daily deficit which is a major input for the system design (Table 24).

Table 23 Wet & Dray season crop pattern

Wet season							
S/N	*Crops*	*p-value*	*Sa (mm/M)*	*p.Sa*	*D (mts)*	*Ea*	*d (mm)*
1	Papaya	0.6	144	86.4	0.85	0.95	77
2	Mung bean	0.5	144	72	0.6	0.95	45
3	Onion	0.42	144	60.48	0.425	0.95	27
Dry season							
S/N	*Crops*	*p-value*	*Sa (mm/M)*	*p.Sa*	*D (mts)*	*Ea*	*d (mm)*
1	Onion	0.42	144	60.48	0.425	0.95	27
2	Mung bean	0.5	144	72	0.6	0.95	45

Table 24 Net irrigation Water Requirement

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Precipitation deficit						
Wet/rainy season crops												
1. Papaya	142.7	147.5	189.4	162.4	188.1	175.8	28.4	0	99.6	133.2	133.4	136
2. Onion	0	0	0	0	0	108.4	26.2	3.8	120.2	9.2	0	0
3. Mung bean	0	0	0	0	0	0	0	4.6	101.5	4	0	0
Dry or Irrigation season crops												
1. Onion	90.1	122.7	184.5	154.6	0	0	0	0	0	0	0	0
2. Mung bean	53.4	123.9	162	8.4	0	0	0	0	0	0	0	0
Net scheme irr.req.												
in mm/day	3.6	4.8	5.9	4.6	3	4	0.7	0.1	3.4	2.3	2.2	2.2
in mm/month	110.9	135.3	183.6	136.6	94	120.4	22.1	1.8	101.1	70	66.7	68
in l/s/h	0.41	0.56	0.69	0.53	0.35	0.46	0.08	0.01	0.39	0.26	0.26	0.25

Irrigated area (% of total area)	100	100	100	100	50	80	80	45	95	95	50	50
Irr.req. for actual area (l/s/h) for 24hr	0.41	0.56	0.69	0.53	0.18	0.37	0.06	0.0	0.37	0.25	0.13	0.13
Irrigation efficiency (%)	0.90	0.90	0.90	0.90	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Gross duty for 24hr	0.46	0.62	0.77	0.59	0.19	0.41	0.07	0.01	0.41	0.27	0.14	0.14
Gross Irr. Water Requirement for 24hrs	1,220.2	1,505.3	2,053.4	1,526.4	520.8	1,059.8	190.5	13.4	1,067.0	735.1	374.4	372.0

2.2 Drip Irrigation System

Drip line of 16 mm dia. having integral emitters with 2 lph discharge per emitter to be used. Drip line spacing of 1.0 m, row to row is agreed and crop geometry to be adopted accordingly. Each BDU, according to soil type is made to have one outlet with 10 to 12.5 m^3/hr discharge/outlet/operation and 20m3/hr for double operation. Each BDU will have 8 subunits of 0.25 ha or 50mt x 50mt. However, in exceptional cases, where the geometry of the land is not suitable and the safe yield are small, 4 to 6 subunits of 0.25 ha are arranged under respective BDUs by allowing some irregularities in shape of the BDUs.

2.2.1 Operation Design

The duration of irrigation has been computed as follows:

$$\boldsymbol{Duration\ (hr)} = \frac{[Water\ requirement\ (mm) * Interval\ (day)]}{Application\ rate\ \left(\frac{mm}{hr}\right)}$$

Where;

$$\boldsymbol{Application\ rate\ \left(\frac{mm}{hr}\right)} = \frac{\left[Dripper\ discharge\ \left(\frac{l}{hr}\right)\right]}{Lateral\ spacing\ (m) * Dripper\ spacing\ (m)}$$

2.2.2 Net Irrigation Area

The net amount of irrigation area to be developed $\mathbf{A}_i$ is computed as follows:

$$\boldsymbol{Ai} = Q\ /\ (10 *\ Dg)$$

Where,

Q = Daily total discharge from specific well (m^3/day);
*= Safe yield (m^3/hr) * T (hr),*

Here, T is daily pumping hours, T= 8hr,
D_g = Gross maximum daily deficit (mm);

To determine the governing size of irrigable land the system efficiency of sprinkler 75%, is used. Hence, gross maximum daily deficit is determined by:

$$D_g = Dn / \eta$$

Where,

Dn = net depth of irrigation which is equal to net ETc

Dg = gross depth of irrigation which is equal to gross Etc

η *= efficiency, %*

According to the proposed ETc, the net irrigation area to be developed by each well A_i could be computed in tabular form. But due to the layout, operational design and arrangement of BDUs, the net irrigated areas under each well is prepared was outlined accordingly.

2.3 Hydraulic Design of the Irrigation System

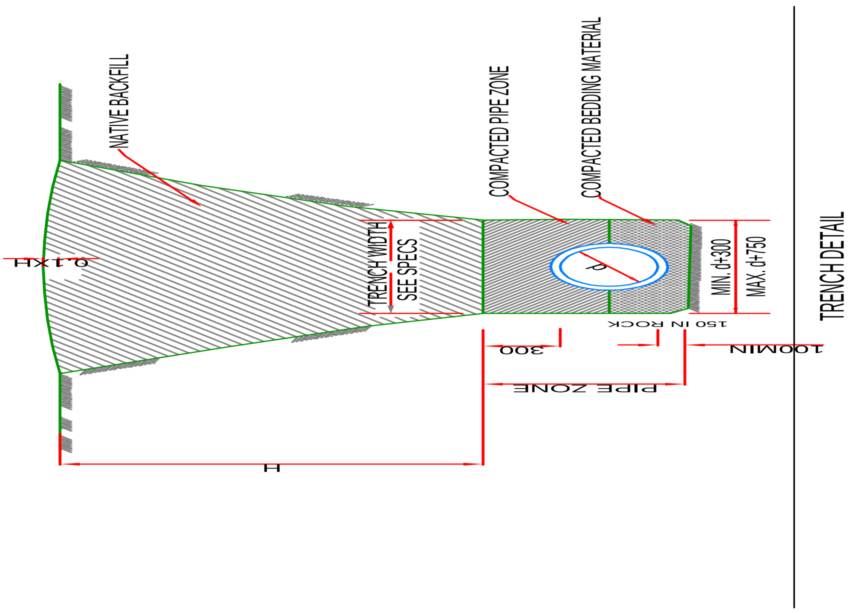
2.3.1 Distribution System

The distribution system design includes the hydraulic design of laterals and manifold. In order to determine the basic parameters of the distribution system a 20percent rule of maximum variation in head had been used to control the variation of discharge within 10percent. The pressure at the inlet of the laterals and manifold was determined considering the pressure required in the emitters, head loss in each pipe and slopes in each pipes from the topographic map.

Minimum water head of 25 meters is required for efficient operation of sprinkler irrigation systems. As far as possible maximum velocity of water in any pipeline was kept less than 1.5 m/sec, with exception in segments where sharp elevation difference of the ground necessitated use of small diameter pipes to check large variations in pressure. It is generally good to maintain pressure at outlets within 25-30 m head.

HDPE pipes of 4 kg/ are recommended from BDU to each plot. Portable quick coupling HDPE pipes of 4 kg/cm^2 and LLDPE tubes of 2.5 kg/cm^2 for drip lines (inline and blind tubes) are recommended. To offset variations in pressure at BDU outlets and ensure inlet pressure for drip irrigation does not exceed 12 m head at plot level, use of pressure regulating valve at secondary head control at each BDU is recommended.

Figure 51 Longitudinal section of Trench detail

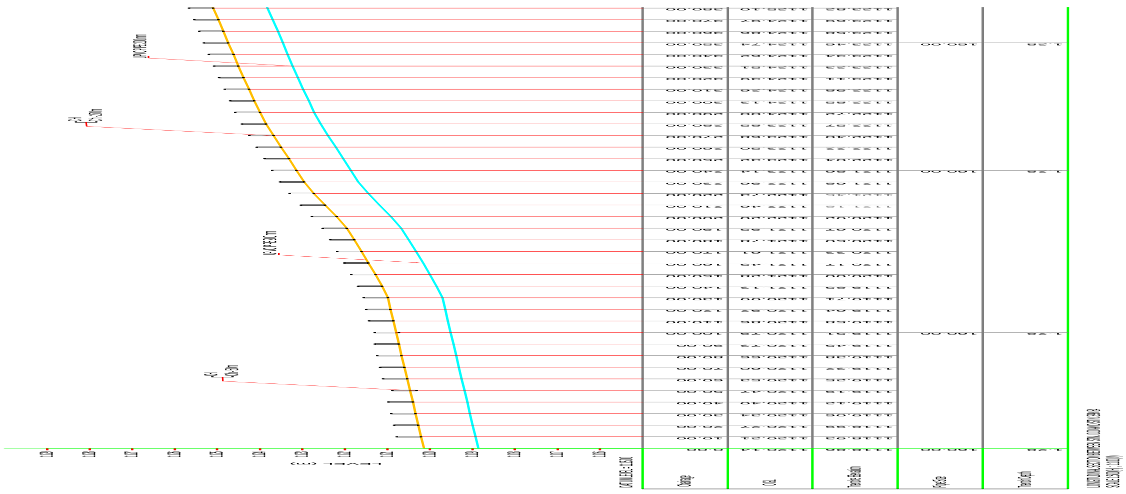


2.3.2 Main and Sub-mainline

The flow rates in the main and submain pipes reduce along the length of their run. As a result, the hydraulic design of these pipes is determined through dividing the pipes into several segments. The submain pipes are first designed and then followed by the design of mainlines using the backward step by step hydraulic calculation.

As much as possible, pipe size uniformity is tried to be kept the same so as to minimize pressure variation within the system to maximum 20 percent. For many of the plots, the submain and main pipe lines together in interface with AutoCAD 2007 software. HDPE and uPVC pipes of 6 kg/cm ^{2} class is recommended for mains and submains from Head Control Unit till BDU. Maximum head loss in the Head Control Unit is to be kept at 7.0 m head by selecting components such as Hydro cyclone, Strainer Filter and Check valve of correct size and capacity (Figure 53).

Figure 52 Longitudinal section of main pipeline



2.3.3 Head Loss Calculation

Hydraulic design of the system has been done while keeping minimum of 25 m head at the field control outlet to suffice sprinkler irrigation system demand at the BDU level so that considering friction losses in manifolds and laterals and elevation effect, minimum pressure of 20 m head is available at the sprinkler head.

In analyzing pipe network, the head loss due to friction is determined using Hazen-Williams and Darcy-Weisbach equation with the help of Water CAD software. Design of mains and sub-mains has been done keeping the average velocity within permissible limits of 1.5 m/sec. Also, where there is excess pressure and to dissipate the energy, the velocity is kept to maximum of 2.25m/sec by reducing the pipe sizes particularly for short segments.

The required pressure head at the outlet of main control head is calculated including head loss in fittings and accessories using Water CAD software. Head loss in the main head control unit and secondary head controls at BDU is added to the total head requirement and the same is taken as 10 m and 5 m head respectively.

2.4 Drainage

2.4.1 Introduction

The Kobo-Girana Pressurized Irrigation project also involves drainage work as an important component. The drainage component of the study is driven by the need for ensuring the productivity of the land and reclaiming swampy areas.

The drainage design is for pressurized irrigation farm areas at the proposed sub basins of the kobo valley. Generally the design is concentrated on both flood drainage design, which is done for surface run-offs outside the irrigation field area. Generally, irrigation field and its surroundings drainage systems will be designed to prevent the field and irrigation infrastructures during floods. In this section the approach to hydrological investigations of the project area, for the purpose of the project area drainage channels and other structures is presented. The investigation includes hydraulic computations of drainage channels and the associated structures.

2.4.2 Drainage requirements

In light of the topography and other catchments characteristics of the project area and the proposed irrigation scheme, the Kobo valley pressurized irrigation project requires surface drainage system to remove excess runoff from irrigation fields during wet season and interceptor (flood) drainage systems to protect the irrigation area from runoff that comes from upland catchments.

2.4.3 Catchment of the project area

The hydrology of the project area has been examined in terms of rainfall, climate, runoff and flood flows. The catchments area (mainly for flood computations from off farm catchments) has been examined with regard to catchment's topography, vegetation cover, soil type, land-use and climate to determine the runoff characteristics of the area as a basis for estimation of floods.

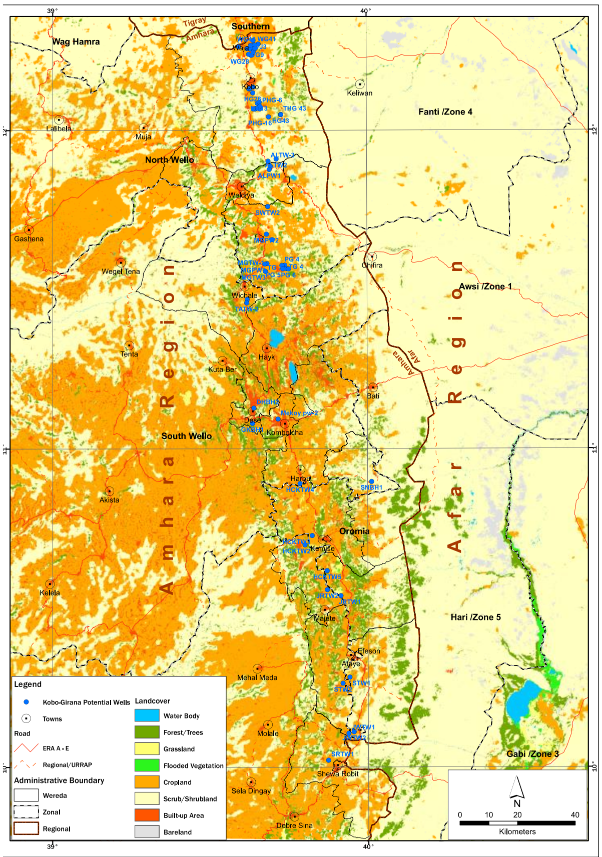
Catchment's Characteristics

All catchment characteristics including catchments cover area, topography, slope, soil type, land use and land cover are used in detail in the hydrology computations for each of flood drainages.

Topography: The average altitude of the project area (Kobo-Girana Valley) varies from 1380 m a.s.l to 3250 m a.s.l. However entirely for each irrigation plot, this value is not highly variable. While the flat irrigation plots have an average slope of 0.01 to 0.015, the most mountainous and upstream sub-catchments terrain has an average slope of 0.21. Generally the catchment topography varies from flat and very flat to mountainous and escarpments.

Land Use and Cover: The land use and land cover of the project area is predominantly cultivated farms and grazing area (Figure 54).

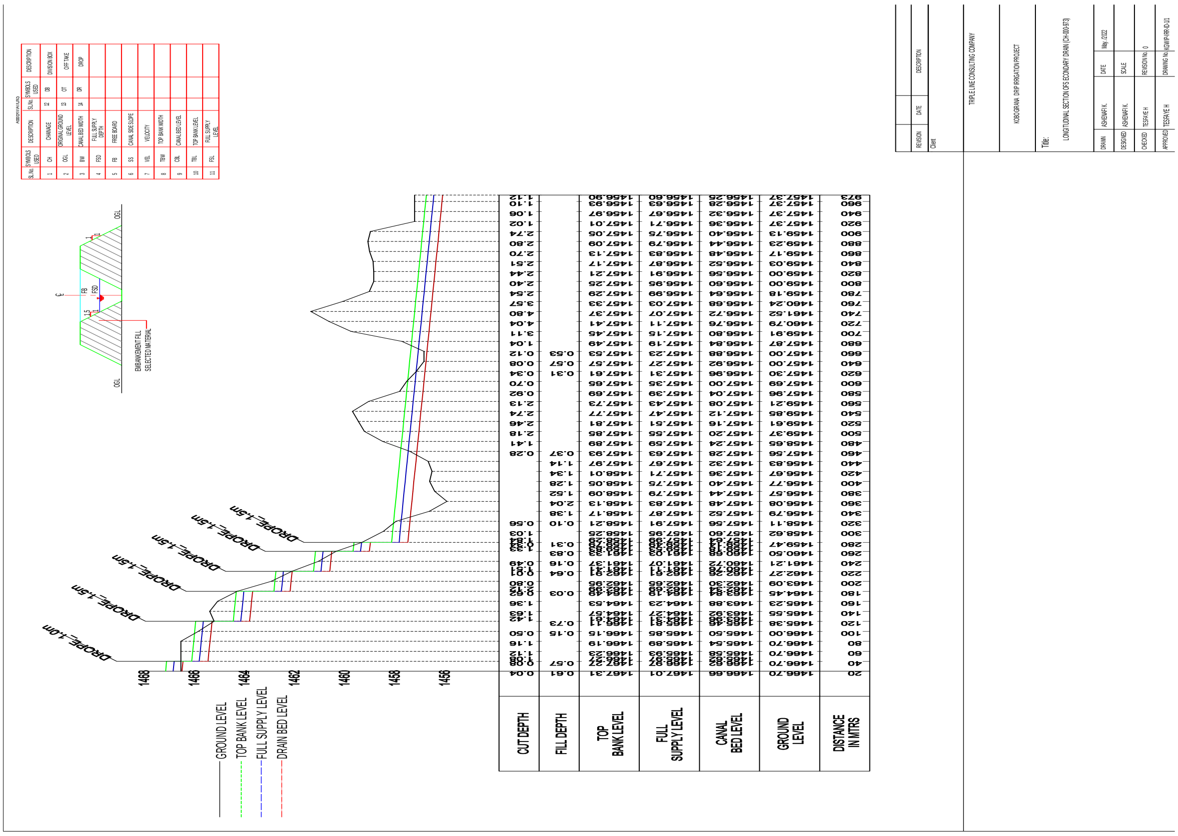
Figure 53 Land use cover map - Kobo Girana valley



Rainfall: The rainfall record in the project area is found quite sufficient for the present drainage study. According to hydrological study report of the Kobo Girana valley pressurized irrigation project, monthly records of rainfall in the project area are available for Alamata, Kobo, Korem and Woldya stations.

Since Kobo station is the nearest station for most of the project areas and since it has longer records, the data from this station have been considered as a hydrologic data for drainage design (Figure 55). The data from this station is also used to determine the rainfall statistics.

Figure 54 Cross sectional drawing of drainage design



Borena: center pivot Irrigation System

The CPS consists of one single sprayer or sprinkler pipeline of relatively large diameter, composed of high tensile galvanized light steel or aluminum pipes supported above ground by towers moving on wheels, long spans, steel trusses and/or cables. One end of the line is connected to a pivot mechanism at the center of the command area; the entire line rotates about the pivot. The application rate of the water emitters varies from lower values near the pivot to higher ones towards the outer end by the use of small and large nozzles along the line accordingly.

The center pivot (CP) is a low/medium pressure fully mechanized automated irrigation system of permanent assemble. It is also used for supplementary irrigation for rain fed grain. The cost of each system unit is relatively high and is therefore best suited to large irrigated farms. The area covered can be from 10.19 ha to 71 ha, according to the size of the CP, and the larger the area the lower is the cost of the system per unit area.

Centre Pivot systems are self-propelled irrigation systems which apply water to pasture or crop, generally from above the canopy. Centre Pivot systems are anchored at one end and rotate on a fixed central point. Lateral systems are not anchored and both ends of the machine move at a constant speed up and down a paddock. Centre Pivot systems require an energy source to move water from the source to the plant as well as energy to move the machine on farm.

Definitions

The understanding of irrigation system includes all-round understanding of terms used in the system. The following are some of the terms used in the system and need to be known:

Head Control: This consists of a supply line (rigid uPVC, or threaded galvanized steel) installed horizontally at a minimum height of 60 cm -1.0m above ground. It is equipped with an air release valve, a check valve, a shut-off valve. The filtration system is not required here as water quality is reasonable one and only care shall be taken during maintenance operations to sufficiently flush the opened system part.

Main pipeline: It is the largest diameter pipeline of the network, capable of conveying the flow of the system under favorable hydraulic conditions of flow velocity and friction losses. The pipes used are buried permanent assembly, UPVC pipes, push fit socket and spigot fittings and quick coupling galvanized light steel pipes in sizes ranging from 110mm to 250mm depending on the area of the farm for all pipes from boreholes to CP machines.

Various types of pipes are common for center pivot systems. Steel pipe is typical for pivot laterals, pivot risers, and other above ground components. Other types of pipes are also available depending on the corrosively of the irrigation water. Steel, polyvinyl chloride plastic (PVC), polyethylene plastic (PE) or aluminum pipe are usually used for the mainline. Drop tubes for conveying water from the pivot lateral to individual sprinklers are frequently steel, PVC or PE pipe.

Pipe performance depends on the characteristics of the pipe. Standard dimensions are used in manufacturing pipes to allow for interconnections and to provide adequate strength to avoid bursting during pressure surges when operating the irrigation system. The type of pipe affects the required thickness of the wall of the pipe for an upper limit of operating pressure. Pipes are often characterized by their outside diameter and the thickness of the wall of the pipe. Pipes that connect by inserting fittings into the pipe require a controlled inside diameter. In those cases, the outside diameter varies depending on the required wall thickness. The standard dimension ratio (SDR) is also used to characterize pipes. The SDR is the ratio of the outside diameter of the pipe relative to the thickness of the wall. Smaller SDR values represent thicker pipes that can withstand higher operating pressures.

PVC pipe is frequently used for mainlines. The pipe diameter and the wall thickness determine the maximum operating pressure for the pipe. Therefore, pressure classes are used to further categorize PVC pipes.

2.1 Selection of Areas to be Irrigated and Blocks Division

Normally delineation of the command area and irrigation blocks will be carried out according to the project size, shape and topography of the command area, type of crops to be grown, yield of the boreholes and skill of operating unit. Command area and irrigation blocks delineation differs in each particular project based on the yield of boreholes. Moreover the area of the particular borehole is determined by irrigation Machine (CP) designed for the system irrigation.

2.2 Design parameters of the center pivot system

2.2.1 Reference Crop Evapo-Transpiration (ETo)

Reference crop evapo-transpiration (**Eto**) is the rate of evaporation from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground with no shortage of water. The only factors affecting ETo are climatic parameters. As a result, ETo is a climatic parameter and can be computed from weather data (i.e. temperature, humidity, wind speed, sunshine hour). ETo expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors.

The Reference crop evapo-transpiration (ETo) for the project is calculated by modified Pen man-Monteith method using CROPWAT 8.0 software and the minimum and maximum ETo was obtained

- *2.22 and 4.41mm/day on December and May on Elkune and Bule Dambi;*
- *2.33 and 4.52mm/day on December and March on Mermero and Kobo;*
- *2.63 and 5.01mm/day on December and May on Malka Sadeka;*
- *2.65 and 4.78mm/day on December and March on Eldima;*
- *2.56 and 4.91mm/day on December and May on Hobok irrigation sites.*

The climatic factors used for calculation are temperature (minimum and maximum), humidity, wind and sun shine hour. The monthly ETo calculated for each irrigation site is depicted on the Tables (25 – 30) below.

Table 25 Mean Monthly Temperature, Humidity, Wind speed, Sun shine hours & Evapo-transpiration of Elkune & Bule Danbi Project

Project Command Woreda: Teltele
Project Command Kebele: Elkune
Country: Ethiopia *Station: Konso*
Altitude: 1242-1309masl *Latitude: 37.3 N* *Longitude: 5.03 E*

Month	Temp (oc)		Humidity (%)	Wind		Sunshine (hours)	Rad (MJ/m²/day)	ETo	
	Min	Max		M/sec	Km/day			mm/day	mm/month
January	18.6	31.7	44.0	1.4	123	9.3	12.3	2.63	81.53
February	19.5	33.3	43.0	1.6	139	8.9	14.6	3.68	106.72
March	19.5	32.6	56.0	1.7	150	8.2	17.1	4.36	135.16
April	18.4	29.6	67.0	1.6	134	7.1	18.5	4.28	128.4
May	18.1	28.3	73.0	1.4	117	7.4	20.5	4.41	136.71
June	17.6	27.7	73.0	1.3	113	5.8	18.7	4.12	123.6
July	17.1	27.4	67.0	1.4	117	4.8	17	3.91	121.21
August	17.5	28.4	66.0	1.5	129	5.5	16.8	3.9	120.9
September	17.8	29.6	63.0	1.5	131	6.3	15.6	3.69	110.7
October	17.7	29.2	72.0	1.4	121	6.6	13	2.79	86.49
November	17.6	29.8	64.0	1.4	125	7.6	11.3	2.38	71.4
December	17.7	30.9	54.0	1.4	120	9	11.2	2.22	68.82
Average	18.1	29.9	62	1.5	127	7.2	15.6	3.53	1291.64

Table 26 Dependable and Effective Rain-fall Elkune & Bule Danbi Project

Project Command Woreda: Teltele

Project Command Kebele: Elkune
Country: Ethiopia Station: Konso
Altitude: 1309masl Latitude: 37.3 N Longitude: 5.03 E

Months	Rain-fall (mm)			
	80% Dependable R.F		Effective R.F	
	Monthly	Daily	Monthly	Daily
January	0	0	0	0
February	3.6	0.12	0	0
March	42.9	1.38	15.7	0.51
April	100.9	3.36	56.7	1.89
May	65.3	2.11	29.2	0.94
June	9.9	0.33	0	0
July	5.1	0.16	0	0
August	8.9	0.29	0	0
September	23.1	0.77	3.9	0.13
October	60.1	1.94	26.1	0.84
November	26.8	0.89	6.1	0.20
December	0.8	0.03	0	0
Total	347.4	11.58	137.6	4.59

Table 27 Mean Monthly Temperature, Humidity, Wind speed, Sun shine hours and Evapo-transpiration of Mermero & Kobo Project

Project Command Woreda: Teltele
Project Command Kebele: Mermero Kobo & Mermero Kelo
Country: Ethiopia Station: Konso
Altitude: 1097masl Latitude: 37.24 N Longitude: 4.75 E

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind		Sun	Rad	ETo	
				M/sec	km/day	hours	MJ/m²/day	mm/day	mm/month
January	19.8	33.9	44	1.4	123	9.3	12.3	2.8	86.8
February	20.9	34.9	43	1.6	139	8.9	14.6	3.85	111.65
March	20.8	34.1	56	1.7	150	8.2	17.2	4.52	140.12
April	19.6	31	67	1.6	134	7.1	18.5	4.4	132
May	19.3	29.6	73	1.4	117	7.4	20.5	4.51	139.81
June	18.8	29	73	1.3	113	5.8	18.7	4.21	126.3
July	18.3	28.7	67	1.4	117	4.8	17	4.01	124.31
August	18.7	29.7	66	1.5	129	5.5	16.8	4	124
September	19.1	31	63	1.5	131	6.3	15.6	3.81	114.3
October	18.9	30.5	72	1.4	121	6.6	13.1	2.88	89.28
November	18.8	31.2	64	1.4	125	7.6	11.3	2.48	74.4
December	18.9	32.4	54	1.4	120	9	11.2	2.33	72.23
Average	19.3	31.3	62	1.5	127	7.2	15.6	3.65	1335.2

Table 28 Dependable and Effective Rain-fall of Mermero and Kobo Project

Project Command Woreda: Teltele
Project Command Kebele: Mermero Kobo & Mermero Kelo
Country: Ethiopia Station: Konso
Altitude: 1097masl Latitude: 37.24 N Longitude: 4.75 E

Months	Rain-fall (mm)			
	80% Dependable R.F		Effective R.F	
	Monthly	Daily	Monthly	Daily
January	0	0	0	0
February	3.2	0.11	0	0
March	38.3	1.24	13	0.42
April	90	3	48	1.60
May	58.3	1.88	25	0.81
June	8.8	0.29	0	0
July	4.6	0.15	0	0
August	8	0.26	0	0
September	20.6	0.69	2.4	0.08
October	53.7	1.73	22.2	0.72
November	23.9	0.80	4.3	0.14
December	0.7	0.02	0	0
Total	310.1	10.34	114.9	3.83

Table 29 Mean Monthly Temperature, Humidity, Wind speed, Sun shine hours and Evapo-transpiration of Eldima Project

Project Command Woreda: Dillo
Project Command Kebele: Hobok Sigirso
Country: Ethiopia Station: Konso
Altitude: 907masl Latitude: 34.76 N Longitude: 4.39 E

Month	Temp (oc)		Humidity (%)	Wind		Sunshine (hrs)	Rad	ETo	
	Min	Max		M/sec	Km/day		MJ/m²/day	mm/day	mm/month
January	20.5	35	44	1.4	123	9.3	13.2	3.13	97.03
February	21.6	36.1	43	1.6	139	8.9	15.4	4.16	120.64
March	21.5	35.3	56	1.7	150	8.2	17.8	4.78	148.18
April	20.3	32	67	1.6	134	7.1	18.9	4.56	136.8
May	20	30.6	73	1.4	117	7.4	20.7	4.62	143.22
June	19.4	30	73	1.3	113	5.8	18.8	4.29	128.7
July	18.9	29.7	67	1.4	117	4.8	17.1	4.08	126.48
August	19.3	30.7	66	1.5	129	5.5	17	4.12	127.72
September	19.7	32	63	1.5	131	6.3	16.1	3.99	119.7
October	19.6	31.6	72	1.4	121	6.6	13.7	3.1	96.1
November	19.5	32.3	64	1.4	125	7.6	12.1	2.76	82.8
December	19.6	33.5	54	1.4	120	9	12.1	2.65	82.15
Average	20	32.4	62	1.5	127	7.2	16.1	3.85	1409.52

2.2.2 Monthly Rainfall

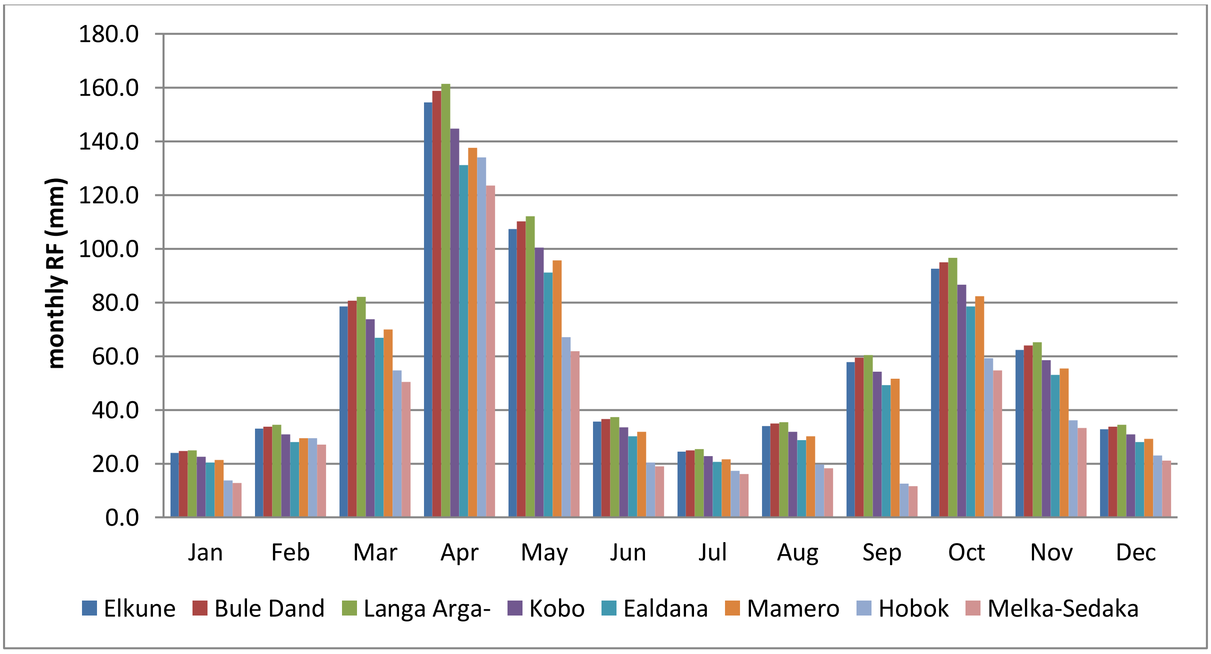
The rainfall data shows that the area has bimodal types of rainfall with the first rainy season window from March to May with peak of the season on April and the second rainy season from August to

November, with the peak in the month of October. The months of January, June, July, February and December have low rainfall months as shown in Table 30 and Figure 56).

Table 30 Monthly areal Rainfall values of the study area

Monthly rainfall of command Area (mm)													
Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Konso	25.8	34.3	83.9	167.4	116.7	41.3	26.0	36.5	62.9	98.5	67.6	35.8	796.7
Mega	21.0	40.5	78.7	177.6	89.9	28.7	24.2	24.6	15.3	79.1	54.2	35.0	668.8
Elkune	23.9	32.9	78.6	154.5	107.2	35.6	24.3	33.9	57.8	92.5	62.3	32.9	736.5
Bule Dand	24.6	33.8	80.7	158.7	110.2	36.6	25.0	34.9	59.4	95.0	64.0	33.8	756.9
Langa Arga-	25.0	34.4	82.1	161.5	112.1	37.3	25.4	35.5	60.4	96.7	65.1	34.4	770.0
Kobo	22.4	30.9	73.6	144.8	100.5	33.4	22.8	31.8	54.2	86.7	58.4	30.8	690.3
Ealdana	20.3	28.0	66.7	131.2	91.1	30.3	20.7	28.8	49.1	78.5	52.9	27.9	625.4
Mamero	21.3	29.3	70.0	137.6	95.5	31.8	21.7	30.2	51.5	82.4	55.5	29.3	656.2
Hobok	13.8	29.4	54.8	134.0	67.1	20.5	17.4	19.8	12.6	59.3	36.1	23.0	487.7
Melka-Sedaka	12.8	27.1	50.5	123.5	61.8	18.9	16.1	18.2	11.6	54.6	33.3	21.2	449.5

Figure 55 Monthly rainfall data for the target sites



2.2.3 Effective Rainfall

Effective rainfall means useful or utilizable rainfall. All the rainfall received are not used by the crops because of its erratic nature such as untimeliness, lesser or higher quantity amongst other factors. Effective rainfall is the proportion of rain, which is stored in the root zone and therefore is available to the plants. Rainfall, which percolates beyond the root zone or lost to the plants through surface runoff is not effective, in that it is not available for plant growth.

It is calculated using the CROPWAT 8.0 software by effective rainfall method for CWR calculations using dependable rain (FAO/AGLW formula) which is;

- *Peff = 0.6*P-10* *for P month <=70 mm*
- *Peff = 0.8* P-24* *for P month >70mm*

Where; Peff = effective rain fall

- *P = total rainfall in a month (mm per month)*

The calculated effective rainfall of the Konso meteorological station which was transferred to each irrigation site and is the nearest station to the project common both in distance and similar with elevation, relation of rainfall, effective rainfall and half ETo with LGP of each irrigation site. The monthly minimum effective rainfall is similar in all project sites which is nill or zero, while, the maximum effective rainfall were obtained is about 56.7mm, 48mm, 35.2mm, 46.7mm and 40.2mm Elkune and Bule Danbi, Mermero and Kobo, Malka Sadeka, Eldima and Hobok sites respectively.

Several factors influence the proportion of effective rainfall and these may act singly or collectively and interact with each other. These factors are described as follows.

Rainfall characteristics - Large quantity as well as high intensity will reduce effectiveness because of excess run off and less infiltration rate. A well-distributed rainfall with some frequent light showers is more conducive to crop growth than downpour.

Land slope - Here, because of the slope very less infiltration opportunity time is available which results in rapid run off loss and less effective.

Soil property- Properties like infiltration rate, retention capacity, releasing capability and movement of water influence the degree of effectiveness. High infiltration, high water holding capacity etc., increase effectiveness by avoiding run of losses. High moisture content, low infiltration rate, low water holding capacity reduces effectiveness.

Ground water characteristics - Shallow water table causes more run off and effectiveness is low. Deep water table causes more infiltration and percolation and effectiveness of rainfall is more.

Management practices - Bunding, terracing, contour tillage, ridging, mulching, etc., reduce the runoff and increases the effectiveness of rainfall.

Crop characteristics - Crop with high water consumption creates greater deficits of moisture in the soil. The effective rainfall is directly proportional to the rate of water uptake by the plant.

Carry over soil moisture - It is the moisture stored in the crop root zone depth between cropping seasons or before the crop is planted. This moisture is available to meet the consumptive water needs of the succeeding crop. The contribution of rain occurring just prior to sowing may be equivalent to one-full irrigation.

Seepage and percolation - Surface and sub-surface seepage and deep percolation below root zone will also influence effectiveness of rainfall.

2.2.4 Irrigation Depth (d)

Depth of irrigation (d), including application losses, applied to the soil in one irrigation application and which is needed to bring the soil water content of root zone to field capacity in mm. The depth of irrigation application (d) including application losses is;

- $d = (p\ X\ Sa)\ X\ D(mm)$

Where:

- p = fraction of available soil water
- Sa = total available soil water mm/m soil depth
- D = Rooting depth, m

Since P, D and ETc will vary over growing season, the depth in mm and interval of irrigation in days will vary. Moreover, irrigation depth were computed based on 85% field application efficiency.

2.2.5 Irrigation Interval

The irrigation schedule or days of interval between two consecutive applications may be determined with simple formula. For this particular study, cropwat software was used to calculate the depth and schedule based on daily soil moisture balance.

$$\mathbf{i} = \frac{\mathbf{D}\ (\mathbf{p\ X - Sa})}{\mathbf{ET\ Crop}}$$

Where

- *i = Irrigation interval*
- *p = fraction of available water (%)*
- *sa = Total available soil moisture (mm/m): Soil laboratory results for the project area*
- *D = Rooting depth (m), tabulated reference*
- *ETcrop (ETc) = Crop water requirement*

Table 31 Average irrigation interval in days and irrigation depth in (mm) of first season crops of Elkune and Bule Danbi site

Crops	**Irrigation interval (days)**	**Irrigation depth (mm)**	**Remark**
Forage grass	18	70	

Table 32 Average irrigation interval in days and irrigation depth in (mm) of first season crops of Mermero & Kobo sites

Crops	Irrigation interval (days)	Irrigation depth (mm)	Remark
Forage grass	19	84	

2.2.6 Irrigation Efficiency (E)

The irrigation efficiency refers to the amount of water from source that will be used for by plants. Part of the water is lost during transport through the canals and the fields. The remaining part is stored in the root zone and used by plants. However, since the sprinkler irrigation is proposed on both sites, the overall efficiency will be 85%.

2.2.7 Water application efficiency (Ea)

It is the percentage of applied irrigation water stored in the soil and available for consumptive use by the crop. Field losses consist of surface run off and deep percolation. The purpose of irrigation is to replenish the available moisture in the root zone depleted by evapotranspiration. The application of the least amount of water required to bring the root zone moisture content up to field capacity is considered as efficient irrigation. If on the other hand, the amount of water applied grossly exceeds than that is actually needed for replenishment; the irrigator application efficiency will be very low. Therefore, for this specific project, 85% field application efficiency is considered.

$$\textbf{application efficiency } (\textbf{Ea}) = \frac{\textbf{water required to bring soil to FC level}}{\textbf{water received at field inlet}} X\ 100$$

$$\textbf{conveyance efficiency } (\textbf{Ea}) = \frac{\textbf{water received at inlet to a block of fields}}{\textbf{water released at project head works}} X\ 100$$

$$\textbf{project efficiency } (\textbf{Ep}) = \frac{\textbf{water made directly available to the crops}}{\textbf{water released at head works}} \textbf{X 100}$$

The overall project efficiency represents the efficiency of the entire operation between diversion of source of flow and the crop zone. Water delivery system improvements and farm irrigation improvements would significantly improve the ability of the farmer to apply more uniform and efficient irrigation.

2.2.8 Net and Gross Irrigation Requirements

- **Net irrigation requirement (IRn)**

It is a depth of water needed to bring the soil moisture level in the effective root zone to field capacity from the soil moisture. The net irrigation requirement does not include losses that are occurring in the process of applying the water. IRn plus losses constitute the Gross Irrigation Requirement (IRg). IRg is calculated by using the relationship between crop water requirement (ETcr) and effective rainfall, i.e.

$$\boldsymbol{net\ irrigation\ requirement = ETcr - effective\ rainfall}$$

Accordingly the total net scheme irrigation requirement of Elkune and Bule Danbi, Mermero and Kobo, Malka Sadeka, Eldima, and Hobok is about 722.4, 773.3, 931.6, 817.2, and 901.9mm per annum respectively.

- **Gross irrigation requirement**

The total quantity of water used for irrigation is termed as gross irrigation requirement. It includes net irrigation requirement and losses in water application and other losses in the conveyance system due to seepage, evaporation, etc. Accordingly, the total gross irrigation requirement of Elkune and Bule Danbi, Mermero and Kobo, Malka Sadeka, Eldima, and Hobok project site with about 85% overall application efficiency is 849.88, 909.76, 1096, 961.41, and 1061mm per annum respectively.

$$\textbf{gross irrigation requirement} = (\textbf{net irrigation requirement})/(\textbf{overall project efficiency}) \textbf{ X 100}$$

2.3 Scheme Supply of the Project

As shown on the crop water computation, the highest irrigation requirement for actual area is found in a month of May. The net irrigation requirement for actual area will be computed after delineating the target area for irrigation development in l/s/ha for 24hour irrigation without considering the project efficiency. The net irrigation requirement will be divided by project efficiency (%) to obtain the gross water requirement which in l/s/ha for 24 hour irrigation. The proposed irrigation hour for the project is 6.5 hour. Therefore, the scheme supply of Borena area teltele project is 0.41 l/s/ha for 24 (Figure 57). A summary of the project supply computation teltele irrigation site is depicted on (Table 49).

Figure 56 Sectional Geltchet Borehole NBTW - 9

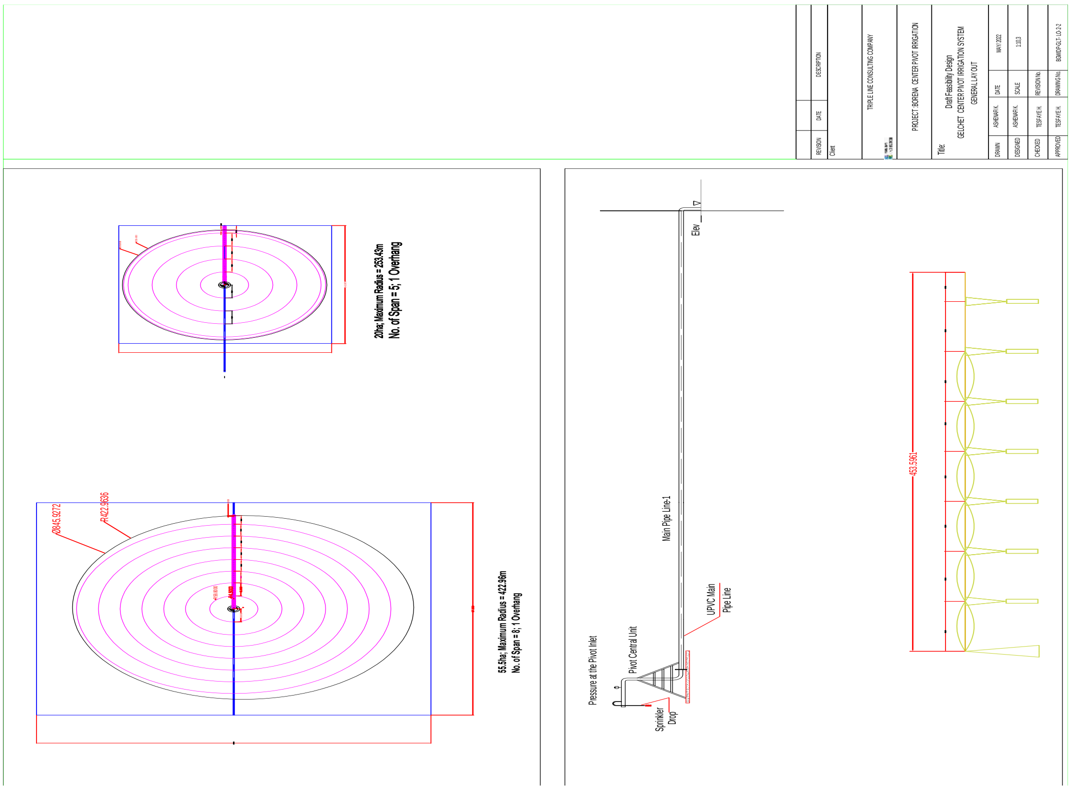


Table 33 Borena Project area (Teltele site) Groundwater Irrigation Development Project Command Site Scheme supply

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
First & Second season grasses												
1. Rhodes grass	74.5	84.6	96.8	58.4	85.9	101.3	101.1	101.4	89.7	52.8	57.6	61.6
2. Guinea grass	83.1	95.2	110.6	71.7	99.7	113.9	113.2	112.9	100.1	61.3	64.6	68.7
3. Buffel grass	74.4	84.6	96.8	58.4	85.9	101.3	101	101.1	89.4	52.6	57.4	61.5
Net scheme irr.req.												
in mm/day	2.5	3.2	3.3	2.1	2.9	3.5	3.4	3.4	3.1	1.8	2	2.1
in mm/month	77.9	88.9	102.3	63.7	91.4	106.3	105.9	105.9	93.8	56.2	60.4	64.4
in l/s/h	0.29	0.37	0.38	0.25	0.34	0.41	0.4	0.4	0.36	0.21	0.23	0.24
Irrigated area (% of total area)	100	100	100	100	100	100	100	100	100	100	100	100
Irr.req. for actual area (l/s/h)	0.29	0.37	0.38	0.25	0.34	0.41	0.4	0.4	0.36	0.21	0.23	0.24
Irrigation efficiency (%)	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Gross duty for 24hr	0.32	0.41	0.42	0.28	0.38	0.46	0.44	0.44	0.40	0.23	0.26	0.27
Gross Irr. Water Requirement for 24hrs	863.04	994.56	1130.88	720	1011.84	1180.8	1190.4	1190.4	1036.8	624.96	662.4	714.24

2.4 Wetted Diameter

The wetted diameter of the sprinkler package is very important to the selection of sprinklers and management of a center pivot. The wetted diameter is the distance that sprinklers throw water perpendicular to the lateral. The wetted diameter depends on the design of the sprinkler device, nozzle size and pressure at the nozzle. The wetted diameter also depends on the height of the sprinkler above the surface of application when the droplets maintain a horizontal velocity. Smaller wetted diameters reduce the uniformity of application and increase the potential for runoff.

Runoff can occur when water is applied at a rate higher than the infiltration rate of the soil and after the surface storage has been filled. The type of sprinkler used on a system affects the potential runoff by changing the duration of water application and therefore the peak application rate. The total time that water is applied to a point in the field as the pivot moves over it is directly related to the wetted diameter. A sprinkler package that has a larger throw diameter will spread water over a larger area, thus increasing the total time that water is being applied at a point in the field. If water is applied to an area longer, the rate of application decreases compared to a sprinkler with a smaller wetted diameter, wetted diameter of common sprinkler designs has been provided in the table below (Table 34). Impact sprinklers have the largest wetted diameter while devices on drops usually have smaller wetted diameters. Stationary spray-pad devices often have the smallest wetted diameter.

Runoff occurs when the water application rate from the center pivot is too high. The peak application rate decreases as the wetted diameter increases—i.e., it is inversely related to the wetted diameter. These results illustrate that the sprinkler package has a strong impact on the peak application rate and therefore the runoff potential for a given soil. One method to minimize runoff is to select sprinkler packages that have large wetted diameters that provides smaller peak rates and longer application times. The minimum wetted diameter needed to avoid runoff can be determined based on the soil intake family and the amount of water that can be stored on the soil surface (i.e., surface storage).

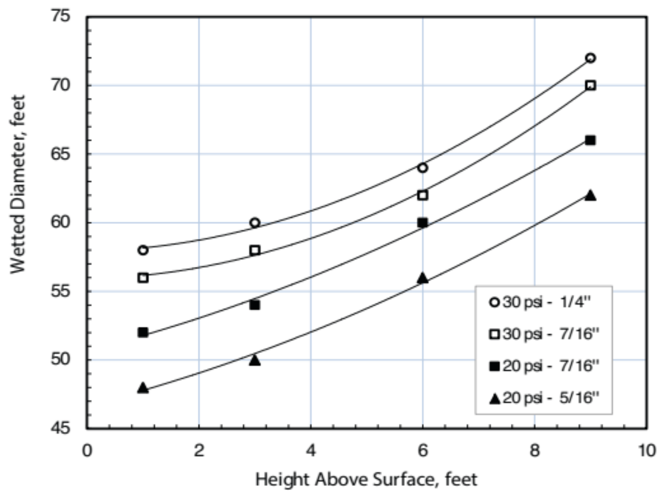
Table 34 Generic description of soils included in intake families by the USDA-NRCS

Intake Family	Generic Description Including Several Subgroups.
0.1	• Deep soils on bottomland with clay, silty clay, or silty clay loam surface layers and slowly or very slowly permeable subsoils, underlain by clayey to sandy alluvium. • Deep soils on uplands and stream terraces with clay, silty clay, clay loam, or silty clay loam surface layers and slowly permeable subsoils. • Moderately deep soils with clay, silty clay, clay loam or silty clay loam surface layers and slowly permeable subsoils.
0.3	• Deep soils with silt loam, loam, or fine sandy loam surface layers and slowly permeable subsoils. • Deep soils with clay loam, silty clay loam, or sandy clay loam surface layers and subsoils with moderate to moderately slow permeability.
0.5	• Deep soils with silt loam or loam surface layers and subsoils with moderate to moderately slow permeability.
1.0	• Deep soils with a fine sandy loam or sandy loam surface layer and moderate or moderately slow permeability in the subsoil. • Deep soils with a silt loam, loam, or very fine sandy loam surface layer and moderately permeable, medium-textured subsoils. • Moderately deep soils with a silt loam, loam, or very fine sandy surface layer and moderate or moderately rapid permeability in the subsoil; underlain by bedrock or mixed sand and gravel.
1.5	• Deep soils with fine sandy loam to loam surface layers and moderately rapid to rapidly permeable subsoils. • Moderately deep soils underlain by bedrock or moderately deep soils over sand and gravel with a fine sandy loam or sandy loam surface layer and moderately rapid or moderate permeability in the subsoil.
2.0	• Deep soils with a sand, fine sand, loamy sand, loamy fine sand, or loamy very fine sand surface layer and moderately rapid permeability in the subsoil. Included are a few soils with a loamy subsoil and underlying material. • Deep soils with a loamy sand, loamy fine sand, or fine sandy loam surface layer and rapidly permeable subsoil.
3.0	• Deep soils with a fine sand or loamy coarse sand surface layer and subsoil. Permeability is rapid.

2.4.1 Sprinkler Height and Spacing

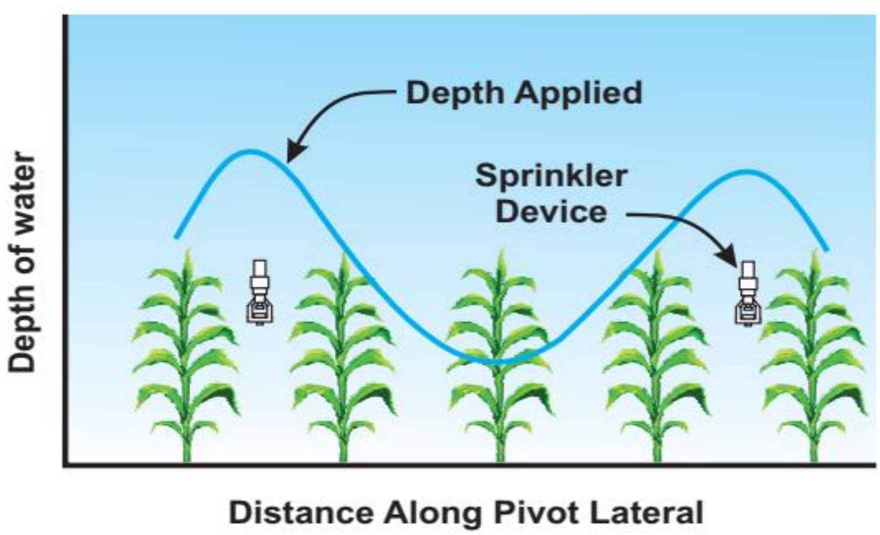
The height that sprinklers are mounted has an impact on the throw diameter. Figure 58 below, shows the change in wetted diameter for a rotating pad sprinkler device for four combinations of nozzle size and pressure. These data show that the wetted diameter increases with the pressure and the nozzle size.

Figure 57 Effect of height of sprinkler above surface on throw diameter for four combinations of discharge pressure and nozzle size.



If sprinklers are mounted at a height that places them into the crop canopy during the growing season the wetted diameter will be smaller than if the devices were installed above the canopy. Figure 59 below shows the effect that placing sprinklers in the crop canopy can have on application uniformity. Crops interfere with the throw of the sprinklers and cause more water to fall near the sprinkler and less reaches the crop rows between the sprinklers.

Figure 58 Reduction of application uniformity when sprinklers are mounted low enough to be in the canopy during the season.



2.4.2 Recommendations regarding sprinkler spacing:

Keep sprinklers out of crops canopy to the extent possible. Placing devices into the crops canopy reduces uniformity and can increase runoff on steep slopes in cases of crops on the ridge.

Results show that the spacing must be reduced (to as little as twice the row spacing) when sprinkler devices are placed deep into the crops canopy.

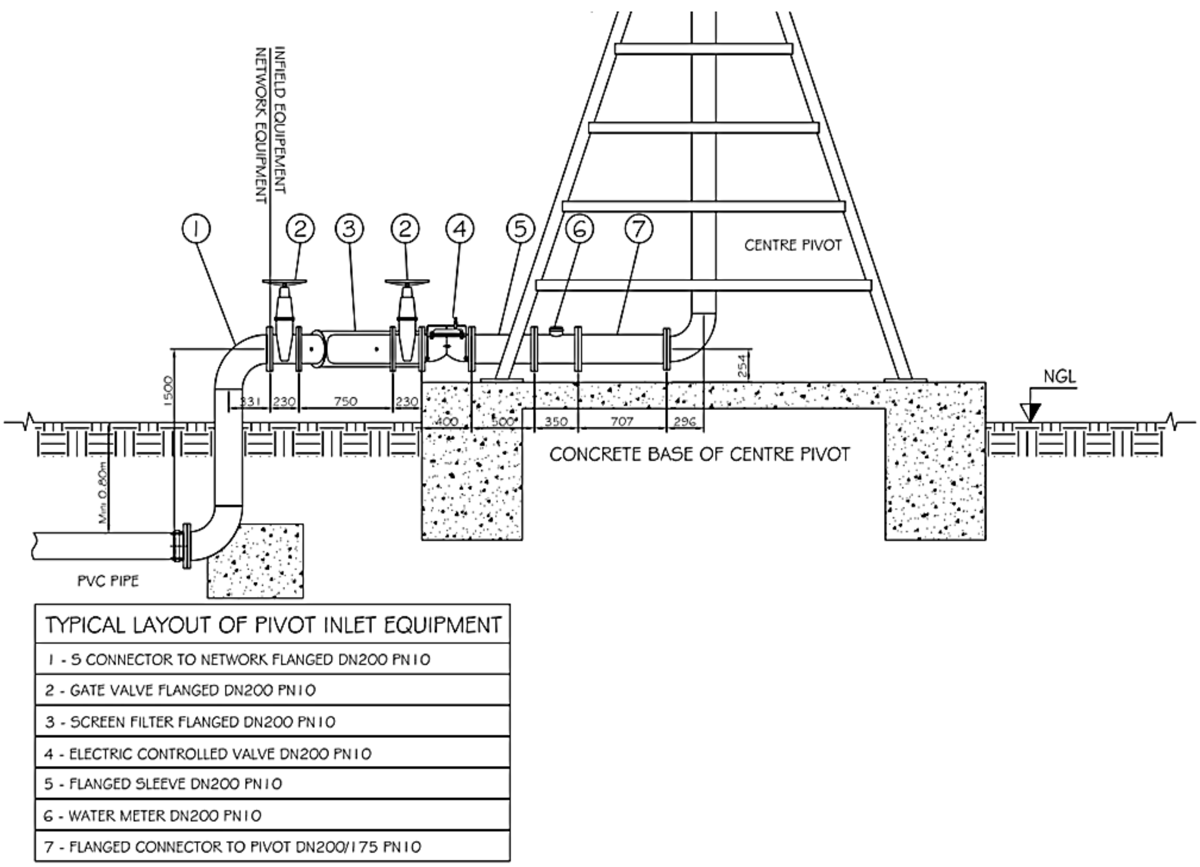
Narrow spacing for expensive sprinklers may not be advisable. The larger diameter from expensive devices may be unneeded when placing sprinklers close together.

If the wetted diameter is too small, runoff may occur. The runoff often accumulates when the pivot lateral aligns with crops rows. Runoff is more severe on steep slopes as well.

2.5 Wheel Tracks

As the center pivot moves through the field, the wheels can create ruts in the wet soil. These ruts can make the field rough and cause damage to equipment during field operations. The irrigation system (Figure 60) may also become stuck in the saturated soil with higher application depths. A method to reduce these problems is to use boom backs. These are designed to extend the sprinklers behind the wheels and most use part-circle sprinklers. With this design, the wheel tracks are kept dry until the pivot passes.

Figure 59 Infield Pivots Connection to Network



2.6 Operating Pressure

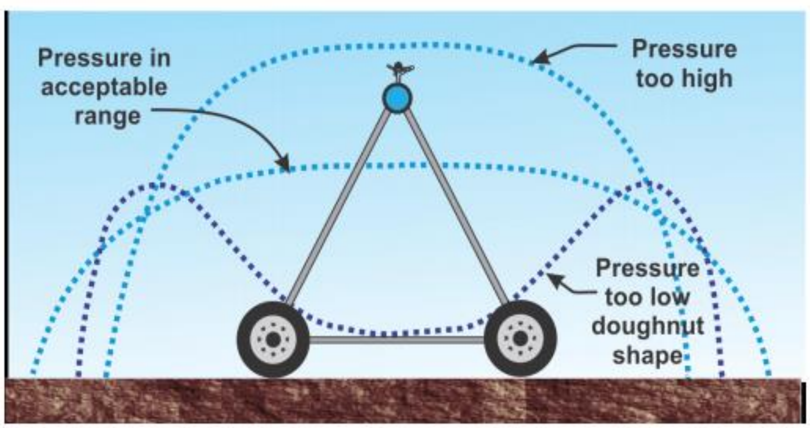
Once a sprinkler package is designed and installed, operating the system at the designed pressure is vital to the application uniformity of a sprinkler package.

Figure 61 shows the droplet distribution of an impact sprinkler when operating at the correct pressure. Smaller drops have a higher drag to momentum ratio. This drag will slow the smaller drops faster causing them to fall closer to the sprinkler. Larger drops have more momentum and travel further from the sprinkler.

When the system is operated at a pressures greater than recommended for the sprinkler, the increased pressure causes larger drops to break into many small drops. These small drops decelerate and fall near the sprinkler. The wetted diameter is reduced and the application rate is increased near the sprinkler, increasing the potential for local runoff. On the other hand, when a system is operated below the

designed pressure, the large drops do not break up enough and most of the water is applied in an annular ring located near the radius of throw. Also, reducing the pressure decreases the velocity of water as it exits the nozzle, causing a reduction of the wetted diameter. This pattern is often referred to as a doughnut-shaped pattern.

Figure 60 Application distribution for three operating pressure scenarios.



2.7 Sprinkler Irrigation Layout and Design Criteria

The engineering design is the second stage in irrigation planning. The first stage is the consideration of the crop water requirements, the type of soil, the climate, the water quality and the irrigation interval, depth of application, irrigation scheduling etc. The water supply conditions, the availability of electricity and the field topography also need to be considered. The economic considerations, the labor and the know-how also need to be taken into account. The irrigation system is selected after a thorough evaluation of the above data based on the computation of the system's flow, the irrigation dose, the duration of application and the irrigation interval. Once the design is completed, a detailed list of all the equipment needed for the installation of the system are prepared with full descriptions, standards and specifications for every item – annex 6.

2.7.1 Designing of Center Pivot irrigation systems

Designing of Center Pivot irrigation systems needs knowledge in soil-water-plant relationship, hydraulics, and irrigation practice and field experience. Stages of collecting data for designing the projects and analyzing them are very important.

There are two philosophical approaches in designing a pressurized irrigation system. The first approach is designing the system emitter from the outlet to the water source (control head). The other approach is designing the system from the water source (control head) to the outlet. Generally, it is recommended to design by either of the two concepts and crosscheck it by the other. In this particular design the former option is considered. There might be a number of ways to design the systems, and hence optimization of the system is indispensable. However, the system optimization is not as such a simple task by considering only initial cost for the economic analysis.

Therefore, running and maintenance cost and cost of energy should also be analyzed. That is the ultimate target of the irrigation system design and needs to be optimizing so as to increase the yield of the irrigation in line with attempting to minimize the cost of the irrigation system, labor and energy and hence make the whole system more profitable.

2.7.2 System Capacity Estimation

It is often desirable to compute the unit system capacity required for different water use rates. If a 7-day-per-week operation is assumed and Q in metric units:

$$\mathbf{Qa} = \frac{\mathbf{2.78\ Ad'}}{\boldsymbol{T}}$$

OR

$$\mathbf{Qb} = \frac{\boldsymbol{R^2 d'}}{\mathbf{1.146}\ \boldsymbol{T}}$$

Where:

- *Q = required system capacity, lit/sec*
- *A = design area, ha*
- *d ́ = daily gross depth of application required during peak moisture use rate period, mm*
- *R = maximum radius irrigated when a corner system, end sprinkler, or both is in operation, m*
- *T = average actual operating time, hr/day*

Equation (Qa) is the better equation to use when an end gun or corner system is not operated full-time. In these situations, the system discharge must be sized for when the corner is fully extended, the end gun is on, or both. The use of equation (a) will underestimate the design system Q due to the design area being smaller than πr^2.

If a part circle machine is operated dry on the reverse leg, then the fraction of operating time, T, should be adjusted as:

$$T = \frac{0.9}{1 + \frac{speed\ (wet)}{speed\ (dry)}}$$

Where:

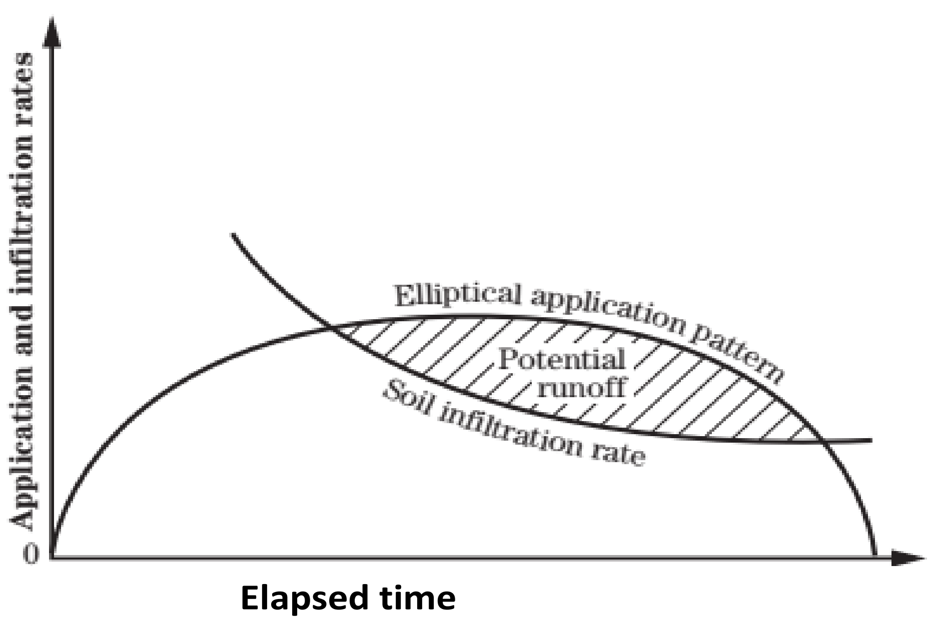
- *Speed wet = the speed of the end of the lateral during application of water, m/min*
- *Speed dry = the speed of the end of the lateral during the dry return, m/min.*

2.7.3 Application Intensity

The geometrical characteristics of the center pivot system are such that the application rate must increase with the distance from the stationary pivot point to obtain a uniform depth of application. As a result, the application rates, especially near the moving end of the lateral, often exceed the infiltration capacity of moderate- to heavy-textured soils. The resulting runoff may severely reduce the uniformity of irrigation and cause considerable loss of water, energy, and crop production.

An elliptical water application rate pattern at right angles to the moving lateral is usually assumed. A stationary water application pattern can be transformed into a moving one by dividing the pattern base width by the speed of the pivot. For the same stationary pattern and pivot speed, different moving patterns are obtained at different points along the lateral. The peak water application rate of the pattern is obtained by equating the area of the ellipse to the depth of water applied to the soil. Theoretically, the depth of water applied does not include the drift and evaporation losses; however, this is very difficult to control in practice (Figure 62).

Figure 61 Intersection between a typical elliptical pattern of water application rate under a center pivot and a potential infiltration curve



2.7.4 Application rate

Assuming that the application pattern under the sprinklers is elliptical, the average and maximum application rates at any location under the center pivot lateral are:

$$\mathbf{I = 2\ X\ (Ku)\left(\frac{Q}{R^2}\right)\left(\frac{r}{w}\right)}$$

And

$$\mathbf{Ix = \left(\frac{8}{\pi}\right)(Ku)\left(\frac{Q}{R^2}\right)\left(\frac{r}{w}\right)}$$

Where:

- *I = average application rate at any point r, in/h or mm/h*
- *r = radius from pivot to the point under study, ft or m*
- *Ix = maximum application rate at any point r, in/h or mm/h*
- *Q = system capacity, gpm or l/sec*
- *R = maximum radius irrigated by the center pivot, ft or m*
- *w = wetted width of the water pattern, ft or m*
- *Ku = 3,600 for metric units*

The application rate is a function of geometric and irrigation demand factors and independent of the travel speed.

i. Sprinkler-nozzle configuration

The sprinkler-nozzle configuration used for most center pivot laterals is one of these:

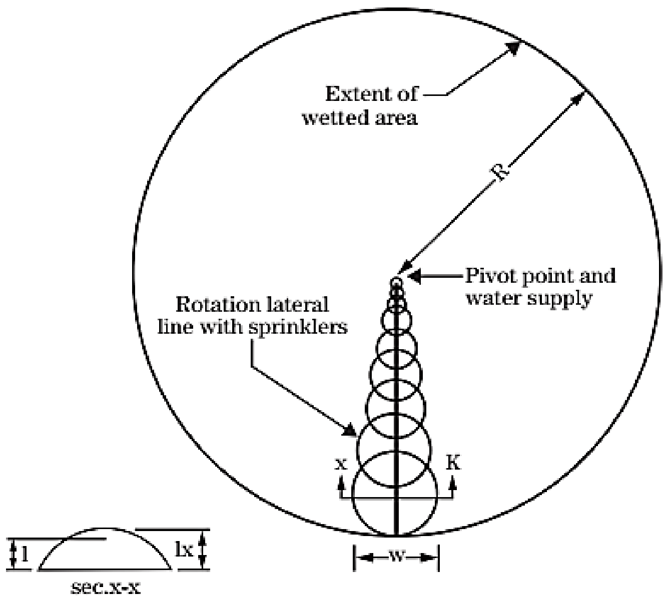
- Uniform spacing of 30 feet (10m) to 40 feet (12m) between nozzles, with the discharge increasing in proportion to the distance from the pivot
- Uniform sprinkler discharge, with the distance between nozzles decreasing from maximum allowable spacing's near the pivot to 5 feet (1.5m) toward the end of the lateral in inverse proportion to the distance from the pivot

ii. Combination of sprinkler configuration

Uniform spacing between outlets is most commonly used for simplicity of manufacture and ease of field assembly; however, when uniform sprinkler spacing's are used, relatively large nozzles and high pressures are required. The high pressures result in high energy costs, and on delicate soils without cover, the droplets from the large nozzles may cause crusting land surface sealing.

To avoid the problems associated with the use of large nozzles, combination spacing's are often used. A typical combination spacing strategy is to use a 40 foot sprinkler spacing along the first third of the lateral, a 20 foot spacing along the middle third and a 10 foot spacing along the last third of the lateral. Thus, the outlets can be uniformly spaced at 10 foot intervals along the lateral. To vary the sprinkler spacing merely close off some of the outlets with pipe plugs. Sprinklers are installed in every fourth outlet along the first third of the lateral, every other outlet along the middle third, and every outlet along the last third of the lateral (Figure 63).

Figure 62 Watering characteristics of center pivots



The general strategy for selecting the nozzle sizes along a center pivot lateral is:

- Determine the discharge required from each sprinkler to apply a uniform application of water throughout the irrigated area.
- Determine the pressure available at each sprinkler outlet starting with a design pressure at the end.
- Select the appropriate nozzle size in accordance with the required discharge and available pressure (Figure 64).
- For above-canopy sprinklers and nozzles, it is recommended that from a point midway between the first and second tower to the distal end of a center pivot, spray nozzle spacing along lateral lines must not exceed 25 percent of the effective wetted diameter and impact sprinkler spacing must not exceed 50 percent of the effective wetted diameter (Figure 65).

Figure 63 Recommended maximum nozzle spacing's (feet) for spray devices at 6 foot height (Kincaid 1996)

Type of spray device	Pressure (lb/in^2)			
	10	15	20	30
Fixed-plate sprays	6	8	8	10
Rotator—four-groove	8	10	12	14
Rotator—six-groove	8	10	12	14
Wobbler—low angle	12	14	14	16
Wobbler—high angle	14	16	16	18

Figure 64 Ranges of normal operating pressures and associated pattern widths for different sprinkler type and spacing configurations most commonly used on center pivot laterals.

Sprinkler type and spacing configuration	Pressure range [1/]		Pattern width range [2/]	
	(lb/in^2)	(kPa)	(ft)	(m)
Low-pressure spray: [3/]				
1. Single-row drop [4/]	6–40	40–280	10–35	3–11
2. Single-row top	10–40	70–280	20–40	6–12
3. On-boom drops	6–40	40–280	20–55	6–17
Low-pressure spinners: [3/]				
4. Single-row drop	10–30	70–210	25–50	7–16
5. On-boom drops	10–30	70–240	30–65	10–20
Low-pressure rotating or wobbling sprays: [3/]				
6. Single-row drop [4/]	15–40	100–300	50–70	15–21
Low-pressure impact: [5/]				
7. Variable spacing	20–35	140–240	60–75	18–23
8. Semiuniform spacing	30–40	205–275	70–80	21–24
Medium-pressure impact:				
9. Variable spacing	40-50	275–345	90–110	27–34
10. Semiuniform spacing	40-55	275–380	100–120	30–37
High-pressure impact:				
11. Uniform spacing	55–65	380–450	130–160	40–50
LEPA (Low Energy Precision Application):				
12. Uniform spacing	6–10	40–70	point	point

1 Values are sprinkler or boom inlet pressures that include typical pressure regulator losses at the high end of the range.
2 Pattern width (diameter) with full-circle devices at the moving end of lateral with L ? 1,300 ft (400 m).
3 For all sprayers the range depends on height of sprayers above crop, configuration of spray plate, and pressure.
4 Sprayers on drops should be at least 3.3 ft (1 m) above the crop.
5 These sprinklers have nozzles that diffuse the jets for better breakup and distribution.

Given the same discharge per nozzle, a nozzle that has the smaller diameter of W will have the largest application rate and intensity (Figure 66 & 67). The smaller diameters of coverage will be more prone to runoff. This should be a major consideration in the selection of the type and pressure of the spray or impact device.

Figure 65 Relationship between width of wetted coverage (W) and application intensity for the same discharge rate

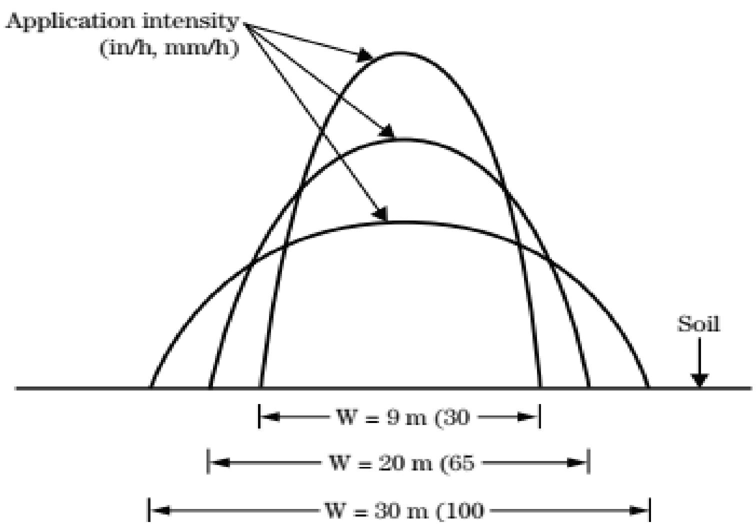
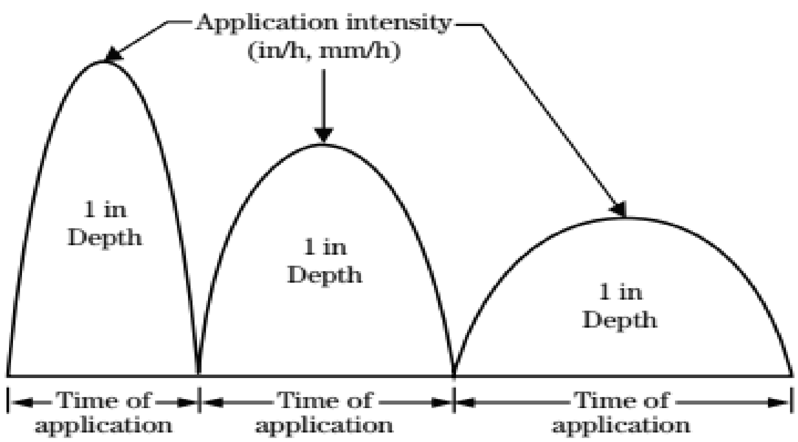


Figure 66 Relationship between required application intensity and time of application for the same depth of application



2.7.5 Sprinkler discharge

The sprinkler or nozzle discharge required at any outlet along a center pivot lateral can be computed by:

$$\mathbf{qr} = \boldsymbol{r\ X\ Sr}\left(\frac{\mathbf{2}\boldsymbol{Q}}{\boldsymbol{R}^{\mathbf{2}}}\right)$$

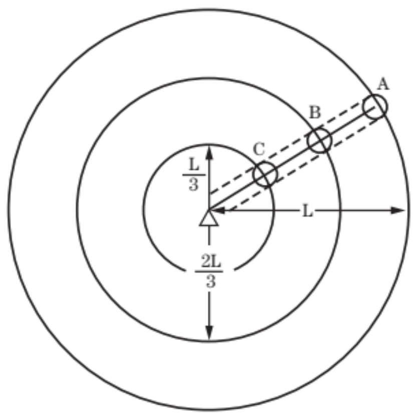
Where:

- *qr = sprinkler discharge required at r, gal/m or l/sec*
- *r = radius from pivot to outlet under study, ft or m*
- *Sr = sprinkler spacing at r, which is equal to half the distance to the next upstream sprinkler plus half the distance to the next downstream sprinkler, ft or m*
- *Q = system capacity, gpm or l/sec*
- *R = maximum radius effectively irrigated by the center pivot, ft or m*

2.7.6 Selecting the nozzle type to avoid runoff

The distance traveled by each sprinkler along a center pivot lateral is equal to 2πr, where r is the radial distance of the sprinkler (or spray nozzle) from the pivot point (Figure 68). The application rate must increase with increasing r to obtain a uniform application depth. Even given identical widths of w along a center pivot lateral, because the lateral is traveling faster toward the end, the opportunity time for application is reduced. The reduction is proportional to the speed of the lateral, which is proportional to the distance, r, from the pivot. Because the same depth of water is applied all along the center pivot, and because application depth equals the application rate multiplied by opportunity time (i.e., mm/min multiplied by minutes = mm), then as the speed increases toward the outer spans of the lateral, the application rate must necessarily increase. This is demonstrated in figure 68 below for a center pivot lateral using variably spaced sprinklers that produce a uniform wetted width. The areas under the three curves are all the same, and represent the depth of water applied each pass.

Figure 67 Water application rates at different points along a center pivot with uniform width of wetted strip



2.7.7 Time of wetting

Often it is useful to calculate the minutes of wetting time at various locations along the lateral. Wetting time, coupled with application rate intensity can be useful in predicting whether runoff may occur on specific soils. The wetting time at any radius r from the pivot point can be calculated as:

$$\mathbf{t}\ (\mathbf{wet}) = \left(\frac{\boldsymbol{w}}{\mathbf{speed}}\right)$$

Where:

- *t(wet) = time that any point on the soil surface at radius r gets wet, min*
- *w = wetted width (diameter) of nozzle pattern at r, ft or m*
- Speed = speed of the lateral at radius r, ft/min or m/min

2.7.8 Speed of the lateral

Speed can be calculated knowing the rotation time of the center pivot and the distance r:

$$\mathbf{speed} = \left(\frac{2\pi r}{60t}\right)$$

Where:

- *t = time required for one rotation of the center pivot system, h*
- *r = radius from the center pivot to point r, ft or m*

2.7.9 Lateral Hydraulics

The discharge per unit length of lateral increases linearly along center-pivot laterals. Therefore, the hydraulic characteristics of center-pivot laterals are different than for periodic-move or linearly moving sprinkler laterals.

Lateral Flow Rate -The flow rate at any point along a center-pivot lateral can be computed by:

$$\mathbf{Qr} = \boldsymbol{Q}\left(\mathbf{1} - \frac{\boldsymbol{r}^2}{\boldsymbol{R}^2}\right)$$

Where:

- *Qr = lateral flow rate at r (gpm) or (l/sec)*
- *r = radius from pivot to point under study (ft) or (m)*
- *Q = system capacity (gpm) or (l/sec)*
- *R = maximum radius effectively irrigated by the center pivot (ft) or (m)*

2.7.10 The end-gun flow rate

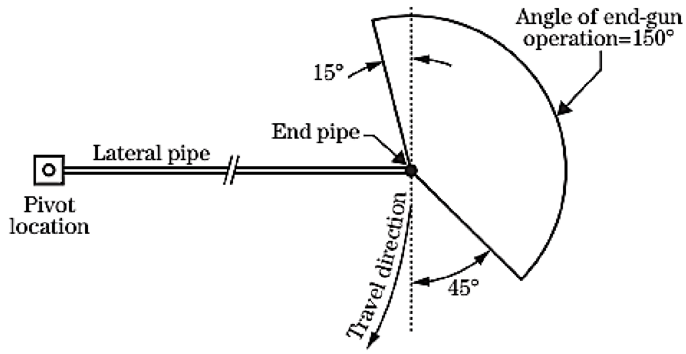
The end-gun flow rate can be computed by setting r equal to the length of the lateral pipe (L) and R equal to L plus 90 percent of the radius wetted by the end gun to obtain (Figure 69):

$$\mathbf{Qg} = \boldsymbol{Q}\left(\mathbf{1} - \frac{\boldsymbol{L}^2}{\boldsymbol{R}^2}\right)$$

Where

- *Qg = the end gun discharge (gpm)*
- *L = the length of the lateral pipe (ft)*

Figure 68 Top view of end gun sprinkler wetting pattern showing recommended angle of operation



2.8 Friction Loss

The viscosity of water and the drag of water along the walls of the pipe cause a loss of pressure as water flows through pipes. These factors act together to create a variation of water velocity in the pipe. Water near the wall of the pipe flows very slowly and the maximum velocity occurs in the center of the pipe. The pressure loss due to friction depends on the flow rate of water in the pipe, the inside diameter of the pipe and the roughness of the pipe. Higher flow rates result in higher water velocities in the pipe and increased friction loss. The viscosity of water depends on the temperature of the water, thus the friction loss also depends on the water temperature. However, temperature effects are smaller than the influence of flow rate, pipe diameter or pipe roughness; thus, friction loss charts are developed based on a standard temperature.

With overhead irrigation systems, it is important to choose the correct pipe size for main and sub-main lines. Larger pipes will cost more initially but will lower pumping costs through reduced friction losses. Several approaches have been developed to compute the friction loss in pipelines. The irrigation industry often uses the Hazen-Williams equation to compute friction loss.

2.8.1 Velocity and Design Coefficients

Water hammer damage can result from a combination of high pressure and high velocity. For field pipes since pressure regulator valve limits the pressure below 40m and the industry standard allows the use of velocity as high as 2m/s, the same is adopted for pipes in the field. For mainline, to prevent water hammer effect before the valve, the velocity should not be above 1.5m/s.

Normally the pressure rating of the pipe should be between one and half and double of the actual water pressure. Based on the field setup of the project,(Center Pivot Irr.Machine Pressure requirement) the minimum pressure at the inlet of the pressure regulator valves should be 26m.

Because of economy, UPVC pipes are used in the design of Main pipe network. But due to the cumulative discharges of the main pipes and relatively higher pressure, steel pipes are recommended for header pipes of pump stations. As shown in Table 35, the maximum velocity of 1.5m/s and 2.0m/s for suction and delivery pipes including the pump head pipes, which is up to the mainline pipe connection point, are kept during pump system design, respectively.

Table 35 Velocity, Pipe type and Design Coefficients

Parameters	Maximum velocity (m/s)	Hazen William coefficient	Pipe type
Main pipe network	1.5	150	UPVC
Pump: Submersible pumps			
Suction pipe (Riser Pipe Steel)	1.5	130	Steel pipes
Delivery and head pipes	1.5	130	Steel pipes

Minor loss coefficients: Minor losses in the design of the pipe and pressure networks are considered during design of the systems. Values of resistance coefficients K for using in loss calculation formula for fittings and valves have been adopted from SCS 1968 GO Schwab, et al (2002), Fluid Mechanics and Hydraulics (2004). The K values are listed in Table 36 below.

Table 36 Values of Resistance Coefficients K for Minor Loss Calculations

	Elbow (<60o)	Elbow (90o)	Tee-inflow	Tee- off take	Reducer	Gate valve	Check valve	Regulator valve	Foot valve
K	0.6	0.75	1.5	2.0	1.5	0.5	3	3	0.8

The Hazen-Williams equation is given by:

$$\mathbf{H} = kL\left[\frac{\left(\frac{Q}{c}\right)^{1.852}}{D^{4.87}}\right]$$

Where;

- *K = 1.22*1010 for Metric and 4.73 for English Units*
- *H = frictional head loss, ft, m*
- *L = length of pipe, ft, m*
- *D = inside diameter of pipe, ft, m*
- *Q = flow rate, ft^3/s, m^3/sec*
- *C = Hazen-Williams C factor or roughness coefficient, dimensionless*

The roughness coefficient (C) represents the roughness of the pipe. Smooth pipes, such as PVC, have high values for C, typically 150. Steel pipe is rougher and has smaller values roughness coefficients. The C value for 12-gauge galvanized steel pipe used for center pivot lateral varies from about 135 to 140. Typical values for the roughness coefficient for pipe materials used with center pivots are included in Table 37. The multiplier value can be used to compare the friction loss of the specific pipe to the loss for PVC pipe, which has a roughness coefficient (C) value of 150. For example, if the pipe dimensions were the same then the friction loss for aluminum pipe with couplers would be approximately 50% more than for PVC.

Table 37 Table Roughness coefficient (C) values for Hazen-Williams method

Pipe Material	C Value	Multiplier

Aluminum pipe with couplers – 30 ft. pipes	120	1.51
Cement Asbestos pipe	140	1.14
Galvanized 12-gauge Steel Pivot Pipe	135	1.22
Galvanized Steel Pipe	100	2.12
Polyethylene Plastic Pipe	150	1
PVC Plastic Pipe	150	1
Steel – 15 years OLD	100	2.12
Steel -- NEW	130	1.3
Cast Iron Pipe	100	2.12

The friction loss is sensitive to the flow in the pipe. Doubling the flow increases the friction loss by a factor of 3.6. The friction loss is very sensitive to the diameter of the pipe. The friction loss for the same flow for a pipe with an inside diameter of 4 inches is about 30 times the loss for an 8-inch pipe.

We also need to consider the velocity of water flow in the pipe. The average velocity of water can be computed as:

$$\boldsymbol{V = \frac{0.408\, Q}{D^2}}$$

Where

- *V is the velocity in feet or meters per second,*
- *Q is the flow in gpm or lps and*
- *D is the inside diameter in feet or meters.*

The velocity of flow in the pipeline is important because pressure surges can occur in the pipeline when valves close quickly, the system is started or due to other changes that cause the water velocity to change rapidly. The surge pressure depends on the flow velocity. For example when a valve is quickly closed, a pressure surge occurs because water upstream of the valve continues to flow when the valve is first closed.

The rapid change of water velocity in the pipe creates the pressure surge. The pipe walls initially absorb the pressure surge. If the pressure surge is too large, the pipe may burst. This is especially significant for plastic pipes. To avoid high pressure surges the velocity of flow should be less than 5 feet per second for enclosed pipelines such as mainlines.

The velocity should be less than 7 ft/sec (2.1m/sec) when the pipe is used for a sprinkler lateral where the pressure surge could be partially released through increased flow from nozzles.

2.8.2 Pressure loss in pipes and fittings

Pressure is also lost when the direction of water flow changes such as through an elbow or tee or when fittings are included in the pipeline such as valves. To account for these losses we use a resistance (K) factor times the velocity head for flow in the pipeline:

$$\boldsymbol{Hm = k\ X\ Hv}$$

Where

- *Hm is the friction loss in the fitting in units of feet,*
- *K is the resistance coefficient and*
- *Hv is the velocity head in feet for the flow in the pipe line.*

2.8.3 Pressure loss in the lateral pipes

Sprinkler discharge depends on the operating pressure. Proper selection of sprinklers requires information on the sprinkler pressure. The pressure in the lateral varies from the pressure at end sprinkler Pg to the pressure at the pivot Pp. Based upon the energy equation and assuming the elevation p difference is negligible, we have

$$HL = Pp - Pg$$

Where;

- *Pg = the pressure at the end sprinkler,*
- *Pp = pressure at the pivot*
- *HL = the friction loss in the lateral,*

2.9 Energy Use in Center Pivot Irrigation System

Solar power is generally preferable for convenience, ease of operation and lower operating costs, Climate-resilient community access to safe water powered by renewable energy. The main consideration in system power supply selection is the cost of providing Solar energy to the pump site. Maintaining a well-designed center pivot system, and periodic evaluations can help minimize operational costs.

Irrigation scheduling can minimize the total volume of water applied to the field. Demonstration projects over time have indicated that 1.5-2.0 inches of water can be saved by monitoring soil water and estimating crop water use rates. The goal is to maximize use of stored soil water and precipitation to minimize pumping.

Improving the efficiency of water application is a second way to conserve energy. Water application efficiency is a comparison between the depth of water pumped and the depth stored in the soil where it is available to the crop. Irrigation systems can lose water to evaporation in the air or directly off plant foliage. Water is also lost at the soil surface as evaporation or runoff. Excess irrigation and/or rainfall may also percolate through the crop root zone leading to deep percolation. For center pivots, water application efficiency is based largely on the sprinkler package. High pressure impact sprinklers direct water upward into the air and thus there is more opportunity for wind drift and in-air evaporation. In addition, high pressure impact sprinklers apply water to foliage for 20-40 minutes longer than low pressure spray heads mounted on drop tubes. The difference in application time results in less evaporation directly from the foliage for low pressure spray systems. Caution should be used so that surface runoff does not result with a sprinkler package. Good irrigation scheduling should minimize deep percolation.

Energy use can also be reduced by lowering the operating pressure of the irrigation system. One must keep in mind that lowering the operating pressure will reduce pumping cost per acre-inch, but reducing the pressure almost always results in an increased water application rate for a center pivot. The key is to ensure that the operating pressure is sufficient to eliminate the potential for surface runoff. Field soil characteristics, surface roughness, slope and tillage combine to control how fast water can be applied to the soil surface before runoff occurs. If water moves from the point of application, the savings in energy resulting from a reduction in operating pressure is counterbalanced by the need to pump more water to ensure that all portions of the field receive at least the desired amount of water.

2.10 Efficiency and duty

Referring local experiences and literatures, the topography setup of the project area and the slope of the areas are very suitable for center pivot sprinkler operation. Furthermore, average wind speed of 1.7 m/s that is prevailing in the target site will not be a limiting factor for sprinkler irrigation. Due to these factors the overall sprinkler efficiency considered for system operation (application efficiency) is considered to be 85% for 8 hr operation.

2.11 Center Pivot Management

2.11.1 Management of the CPS

Some of the challenges that comes with center pivot systems include:

- Lack of knowledge regarding the depth of water applied per irrigation.
- Sprinkler installation and maintenance problems that reduce uniformity or efficiency.
- Inappropriate pressure to provide desired flow rate and uniformity.
- Sprinkler placement that decreases uniformity and does not provide expected evaporation savings.
- Runoff due to inappropriate sprinkler selection or system operation.
- Inappropriate monitoring of systems to ensure proper operation.
- System capacity is not appropriate for crop needs.

2.11.2 Depth of Application

Accurate control of the depth of application is one of the advantages of center pivots. Pivot manufacturers provide guides that describe the percent timer setting or other parameter to apply a specified depth of water. They also provide the time required to make a revolution of the pivot in the field for those settings. Occasionally these guides are lost or not passed along with the sale of irrigated land.

2.11.3 Challenges behind sprinkler Installation

Improper installation and maintenance of sprinkler packages can be an issue with center pivots. Installing sprinklers, regulators and/or nozzles at the wrong location along the lateral leads to reduced uniformity. Irrigators often over-irrigate the wet areas of the field when the uniformity of application is low. Measuring the depth of water caught in containers placed at short intervals under the pivot lateral provides a method to measure the uniformity of application. Plotting the depth of water caught in the containers along the lateral shows the location of dry and wet areas.

2.11.4 Challenges with pressure

Center pivots cannot operate properly if the pressure available at the inlet to the pivot is not appropriate. Two problems occur when the pressure at the pivot inlet is too low. First, the water available for the outer end of the pivot is inadequate and the depth of application tapers off in the outer spans which contains the majority of the area.

Reduced pivot inflow is the second problem that occurs when the inlet pressure is too low. When pressure is 30 psi at the pivot inlet the flow through the pivot drops to 665 gpm instead of the intended flow of 750 gpm. Therefore, when irrigators thought they were applying an inch of water each irrigation they actually applied only 0.89 inches. This shortage would build throughout the season. Obviously, irrigators should monitor soil moisture to ensure that they keep up with crop water use during the season.

Finally, to get the maximum productivity out of any irrigation system, it must be well managed. The key management aspects are:

Irrigation management: Bogging and/ or wheel ruts can be a significant problem. New installations should be fitted with a "dry-wheel pack" (half-throw sprinklers on solid drops or boom backs) to keep water off the wheel track. To avoid the formation of wheel ruts, wheel tracks should be built up and compacted during installation of the system to prevent water from ponding on the tracks. Regular maintenance of the tracks is recommended to avoid ruts developing.

2.12 Sprinkler Selection and Spacing

2.12.1 Optimum Water Application Rate

The water application rate of CP irrigation machine is regulated at the speed control setting to control the tires movement. The machine applies 3.5mm/day in 24 hrs at its 100% working efficiency. But at its 85% efficiency it applies 6.4 mm in 8 hours operation. Much performances of the machine shall be evaluated and the operation schedules shall be adjusted at site during installation. This is because water application efficiency can be adjusted at tyres speed regulator set as desired.

2.12.2 Filter Requirements

The water source of the project is from boreholes of depths up to 250m deep. These will enable to have a clean and free of silt water for irrigation. Thus, the use of filters along the irrigation pipe line will not be necessary. However, the potential danger is dirt or debris that will be brought with pipes and fittings during transport and installation. New pipes may have considerable amount of sands and some debris, which should be flushed from the mainline network and infield pipes, before installing the valves and commencing sprinkling. Some small silt could be settling and form algae within the part of pipe networks through time. Therefore, it is critically required to flush all silts and dirt in the new pipes before the valves are installed and also periodically the system should be flushed by removing the end cap which is provided at the end of each lateral. Hence, flushing system at the end of sub main, manifold and lateral pipes is provided in the design.

2.12.3 Pressure Network Analysis

The pressure network analysis is computed in the same way as that of any pressurized irrigation system for CP irrigation with the only difference is that in CP there is less networks of pipes than in dragline sprinkler system. The maximum pressure requirement at connection with supply system of Center Pivot is 2.6 bar.

Topography: The topography supports the requirement of pressure in pressurized system. Topographically the system performs efficiently up to 15% between inlet and outlet points of the supplying system.

Discharge: The inlet discharge in to the CP irrigation machine is the respective well yields from boreholes and the precipitation amount in mm is determined by tyre movement.

2.13 Design of Main and Sub-Main Pipelines

Where the mains or sub-mains are laid downslope, their head loss due to friction in the pipeline would be compensated by the elevation difference existing between the end points of the pipeline. Therefore, taking the velocity and the network pressure the design strategy would be to select a pipe diameter and length whose head loss due to friction compensates the elevation difference. In this case the velocity is kept in the permissible range of 1.5 to 2.0 m/s. The cumulative pressure due to head losses and elevation differences from point of water source to the connection point to CP machine range from 40 m to 50m in all of the 7 CP irrigation sites.

Pipeline friction is calculated on the basis of Hazen-William and Darcy Wisbach Equations depending pipe sizes, from which the head loss Hf can be expressed in terms of velocity head. The Hazen-William equation is explained under annex 1 section 2.8.1. The Darcy Wisbach Equation can be as shown in below;

Darcy-Weisbach Equation:

- *For Pipes with D < 125mm, the following formula was applied*

$$\mathbf{J} = \frac{\boldsymbol{hf}}{\frac{\boldsymbol{L}}{\mathbf{100}}} = \boldsymbol{K}(\boldsymbol{s})\boldsymbol{Q}^{\mathbf{1.75}}\boldsymbol{D}^{-\mathbf{4.75}}$$

- *For Pipes with D > 125mm, the following formula was applied*

$$\boldsymbol{J} = \frac{\boldsymbol{hf}}{\frac{\boldsymbol{L}}{\mathbf{100}}} = \boldsymbol{K}(\boldsymbol{l})\boldsymbol{Q}^{\mathbf{1.83}}\boldsymbol{D}^{-\mathbf{4.83}}$$

Where,

- J = *The head loss gradient, m per 100m length of pipe*
- L = *Length of pipe, m*
- Q = *Flow rate in the pipe, m3/hr*
- D = *Internal diameter of pipe, mm*
- K = *Conversion constant = 1.131x1011*
- C = *Friction coefficient*
- K(s) = *Conversion constant = 8.38 x 106*
- *K(l) = Conversion constant = 9.19 x 106*

Isolation valves: In the supply system, isolation valves are normally installed at junctions for repair, inspection and maintenance. The rule of thumb for how many valves to install at a junction is one less valve than there are at legs in the junction. It is encouraged however, to evaluate seriously the need to isolate a critical segment and is required to assign a valve at an appropriate location. Accordingly, isolating valves are recommended to be provided at every branching junction points. The use of butterfly valves is encouraged due to their versatility, less cost and ease of maintenance. For the project, due to economic (initial and maintenances) and operation purpose butterfly valves are proposed. Butterfly valve Wafer type with dismantling joints (long-body style) for pipes less than 250mm and Flanged butterfly valve with by-pass and dismantling joints (short-body style) for pipes greater than 250mm diameters are recommended. All the project sites are equipped with regulating butterfly valves as well as pressure sustaining valves as indicated in the pump house pipe detail drawings.

2.14 Installation of Pressure Pipes

Pressure pipes of different type are suitable for the installation. Thus, the main criteria for selection will be their availability and cost. GRP pipes are worthwhile for higher diameters and UPVC or HDPE are commonly used for lower diameter requirements. Based on their cost implications and existing performances of the pressure pipes installed at the sugar estates, it has been found that GRP pipes are suitable for both the conveyance and distribution systems, hence designed for diameters higher than 600 mm. In this particular Ground Water Irrigation project cases the maximum size UPVC pipe is 200 mm and the smaller size is 110 mm.

Pipe coupling types: Depending on the topography and the layout socketed UPVC, bell and spigot uPVC fittings are to be used.

Trenches and Bedding: All mainlines are buried in trenches on 10cm soft gravel beddings. A minimum burial depth of 1.20m is recommended for feeding pipes in order to avoid damages during plowing and cultivation.

Table 38 Recommended Depth

Description	Diameter	Trench depth
Laterals	All pipe size	Maximum of 0.8m
Distribution system	All pipe size	OD + 0.8m
Conveyance system	All pipe size	OD + 1.0m

Thrust block: Thrust forces are unbalanced forces in pressure pipelines that occurs at changes in direction (bends, wyes, and tees and Saddles), at changes in cross-sectional area (reducers), or at pipe terminals. Therefore, trust blocks, which increase the ability of fittings to resist movement by increasing the bearing area, are provided at wherever required. Drawing will be provided for typical standard trust block design with the appropriate dimension.

2.15 Design of Drainage System

2.15.1 General

Good water management of an irrigation scheme requires not only proper water application but also a proper drainage system. Drainage system protects irrigation system such as mains, manifolds, structures and the field from damage during flood times either due to excessive rainfall and/or tail water due to excess irrigation water application.

2.15.2 Drainage Requirements in the proposed Project area

For the design of a drainage system, the drainage requirement or the drainable surplus has to be identified. Drained water is the amount of water that must be removed from an area within certain period to avoid an unacceptable rise in the levels of the groundwater or surface water.

Removing the drainable surplus has the following advantages:

- It prevents water logging by artificially keeping the water table sufficiently deep.
- It removes enough water from the root zone so that salt brought in by irrigation cannot reach a concentration that would be harmful to crops.
- It prevents the irrigation systems (canals, structures and land) from damage

2.15.3 Drainage Design Consideration

- **Field Interceptor Drains**

The field interceptor drains are designed for each of the project sites by taking the sub-catchment area that is contributing run off for a particular area and multiplying it with the average duty value computed for the whole catchment of that natural drain. Accordingly, duly computed values and the share of the catchment area that contribute to the run off for particular interceptor drainage within the project sites were computed and applied.

- **Main Drain / Drain collector**

Main drain generally are classified as natural waterways which follow the path of existing drainage gullies and collect water from smaller drains. One or more primary drains may flow into a collector / Out-falling Drain.

In case of Borena CPS, one or more natural drains are available to direct the flood collected from periphery of the circular boundary of command area. As the area is circular, the interceptor drains are made to follow the periphery of the area and to join the existing natural drain.

Annex 2: Submersible pump and solar PV sizing

1.0 DESIGN HEAD

Pumping water from a Borehole to an elevated reservoir, the required pumping head, “

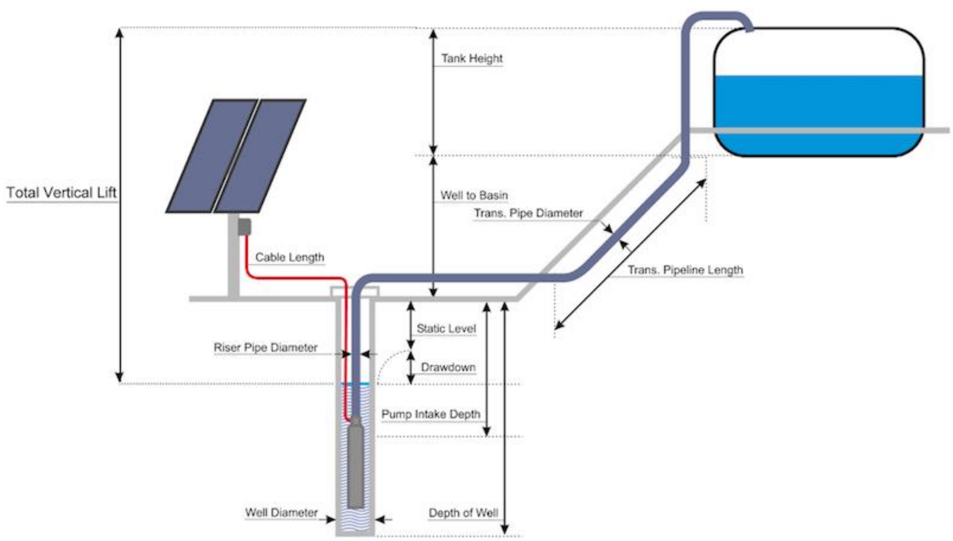
$$H = Hst + Hdy$$

Where;

- *H = total vertical lift, consists of a Static Head,*
- *H_{st} = static head*
- *H_{dy}. = dynamic head*

The Static Head, “H_{st}“ is the vertical difference in water levels between static level and discharge point, i.e. the reservoir maximum water level and borehole static water level. Dynamic Head, “H_{DY}” is the sum of all energy lost pumping water from the pump suction to water delivery point while maintaining the required flow of water. Dynamic Head, “H_{DY}” of a pump includes energy lost in riser pipes, collector pipes, transmission pipes, valves and fittings (Figure 70).

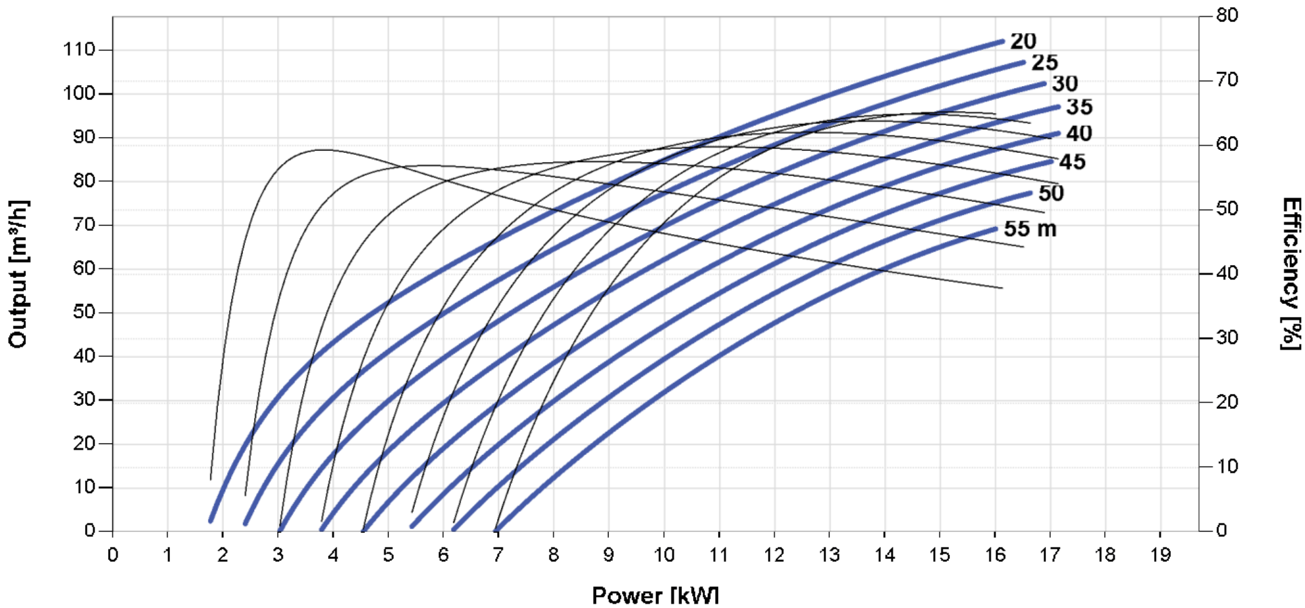
Figure 69 Submersible pump vertical lift factors



1.1 Pump Size

In the design of borehole submersible pumps, the pump size mainly governed by borehole diameter, available safe yield and drawdown. This will inform the selection of the type of pump that will be able to accommodate these factors and lift the ground water to the point of discharge. A wide array of pumps are available in the market but with varying degree of efficiency and delivery capacity. This study used pump specification charts developed by Lorentz, a German firm with grounded experience in manufacturing a wide variety of pumps that are suitable for different scenarios. These pumps are also known to have a higher threshold to accommodate for high delta in the dynamic water level whilst putting a minimal amount of load on the Solar PV array, which will ensure longeviety of the whole system (Figure 71).

Figure 70 Pump characteristic chart



1.2 Riser Pipes

Riser pipe has been appropriately sized to safely transport the optimum design yield of each borehole to the point of discharge. The Hydraulic analyses was conducted for individual boreholes against the different size of pipes available on market. The hydraulic analysis result (refer to Annex 2.a Borehole Hydraulics) for the parameters that were derived and used to design the discharge configuration. Throughout the analysis, the base specification used for the Galvanized Steel (GS) pipes is DN 100 to 150 mm with velocities varying from 0.8 to 3 m/s, pump pressure between PN10 to PN25 and head loss of economical range.

1.3 Hydraulics of Pumps

Hydraulic design of a pump includes the determination and sizing of the following parameters:

1) Hydraulic parameters of pump tests, i.e. safe yield, aquifer depth and hydraulic characteristics of the system
2) Design Flow Rate (maximum and minimum)
3) Design head (maximum and minimum)
4) Selection of performance curve and system characteristics (operating point)
5) Selection of Best Efficiency Point and energy consumption (Power)
6) Selection of appropriate pump size that could fit into well size

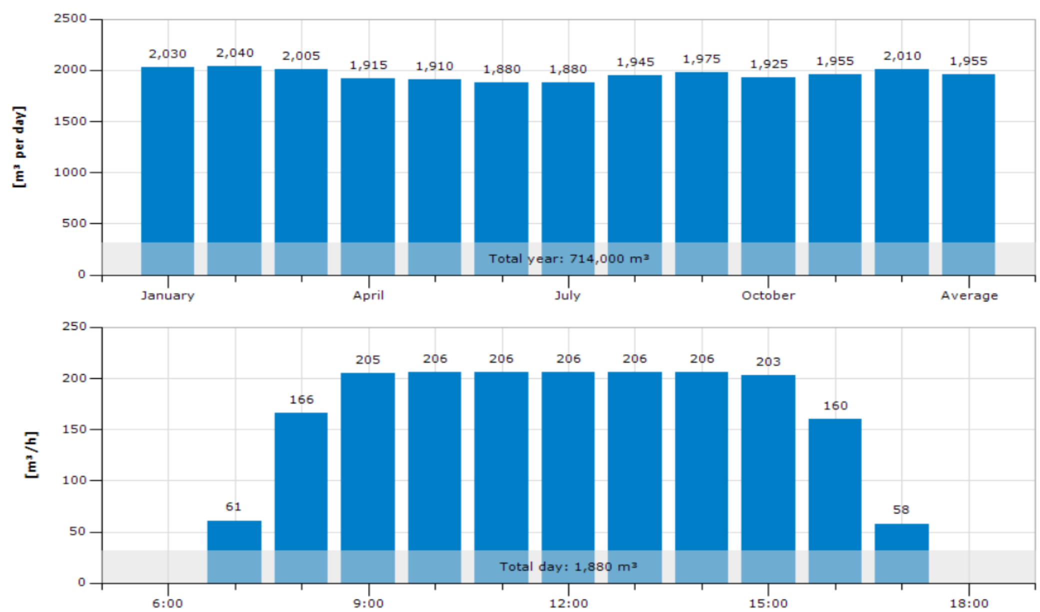
Hydraulic parameters of pump tests, i.e. safe yield, aquifer depth and other borehole characteristics are presented Annex 2.a Borehole Hydraulics.

2.0 DETAIL ELECTROMECHANICAL DESIGN ANALYSIS OF (NBTW-6)

2.1 Detail Hydraulic Analysis for Total Dynamic Head (TDH) Determination

According to the borehole characteristic data, the pump position identified for NBTW – 6 is 138m below ground level with a recommended safe yield of Q = 71 l/s. Considering a 12" well casing, a 10" pump that will be fitted with a 200mm GS riser pipe with flow velocity of 2.26m/s is selected (Figure 72).

Figure 71 Design output (Q)



TDH=Dynamic Water Level + Vertical Rise +Friction Loss (TDH = dwl + y + h_f)

a) Dynamic water level =Static water level +maximum drawdown = 59.25m b.g.l.
b) Vertical Rise (y) = Reservoir Top Elevation (Z of reservoir) –Well Elevation (z of well) =10m
c) Friction Loss (h_f) is calclulated as the sum of friction and head loss in the riser pipe to delivery point.

2.1.1 Frication loss (h_{f1})

Hazzen-William's formula to calculate **friction loss h_f** [103];

$h_f = h_{f1} + h_{f2} + h_{f3}$

$$\mathbf{hf = 10.7 * \left(\frac{q}{c}\right)^{1.85} * \frac{l}{d^{4.87}}}$$

Head Loss **h_{f2}**

h_{f1}= friction loss from recommended pump position to borehole-head in "m"

- q = flow rate in m^3/s = 0.71

[103] *Galvanized Steel (GS) pipe is considered*

- c = roughness coefficient of pipe = 120[104]
- l = length of pipe in m =138m
- d = diameter of riser pipe = 200mm

Therefore, h_{f1}= 10.7*(0.03/120) $^{1.85}$*183/ (0.2)$^{4.87}$ = 4m

Thus TDH = 59.25 + 10 + 4 = 73.25 m

2.1.2 Head loss (hf2) of L-1 (GS Pipe)

The major head loss accounted of the submersible pump at borehole-NBTW-6 are:

- h_{f2} [along transit pipe line(Figure 70)], i.e pressure line layout from borehole to service reservoir. Pressure loss will be calculated using standard figures of the diameter of the pressure line (DN 200) and flow the rate (0.071 m^3/s) in these respective lines.

Using Hazzen William's formula to calculate head losses we get:

$$\mathbf{hf2 = 10.7 * \left(\frac{q}{c}\right)^{1.85} * \frac{l}{d^{4.87}}}$$

- q_2 = 0.071m^3/s, c=120, l_2= 100m, DN 200mm
- h_{f2}= head loss from well head to reservoir head in "m"
- Therefore, h_{f1}= 10.7 * (0.071/120) $^{1.85}$ * 100/ (0.2)$^{4.87}$ = 2.84 m
- Thus H_f (major loss) = H_{f1} + H_{f2} = 4m + 2.84m =6.84m

2.1.3 Fitting Loss (hf3)

Loss accounted in the gate valves, check valves, elbows qualify as fitting loss and and calculated using the formula **h_{f3} = kv^2/2g.**

The summation of loss encountered in the Tee, Check valve, dismantling joint, gate valve, bends, water meter calculated is 3.83m. The type of installation proposed at the headwork will be done for all boreholes.

- *h_{fl}= kv^2/2g*
- *k = 0.75*
- *v =2.26*
- *g = 9.81*

Thus Friction Loss (h_f) = h_{f1} + h_{f2} + h_{f3}

Therefore, from the above calculation we get total head:

- Tdh = Dynamic Water Level + Vertical Rise + Friction Loss
- **Tdh = 59.25m+10m+6.84m+3.83m = 80m**

Pump power (P_p) **=Q*TDH/(102*η_p), in kW**

---

[104] *The conversion factor k was chosen so that the values for C were the same as in the Chézy formula for the typical hydraulic slope of S=01, The value of k is 01−0.04.*

Where,

- *Q: discharge [l/s] = 71*
- *TDH: Total dynamic head (m) =80 mts*
- *η_P: Overall efficiency (Taken value is 74%) = 0.74,*

Thus **P_p = 75KW** is the rated power of motor considering the overall efficiency (i.e hydraulic efficiency and motor efficiency combined.)

The hydraulic analysis for all 100 boreholes followed the same principles and is attached herewith this report in annex 2.a.

2.2 Determination of hydraulic energy requirement

Hydraulic energy requirement (**E_h**) is the energy required to lift the daily water demand through the total dynamic head. It is estimated using the following well characteristics and total demand which is equivalent to safe yield of the boreholes.

Considering the borehole NBTW-6, the safe yield calculated from the pump test is 71 liters/second. Assuming eight (8) hours of pumping and a minimum irradiance of 5.47kwh/m^2/day, the daily water demand or out put from the borehole is 2044.8m^3/day.

$E_h = (\rho \times g \times Q \times TDH)/3.6\times10^6$

- E_h: hydraulic energy requirement (kWh/day)
- ρ = water density = 1000 kg/m^3
- G = acceleration due to gravity = 9.81 m/s^2
- Q = daily required volume of water in m3/day
- TDH =Total dynamic head in meters

E_h = (1000 kg/m^3 x 9.81 m/s^2 x Q x TDH)/3.6x10^6

Eh=02725 Q x TDH = 445.77 kWh/day

2.3 Size of pump motor and pump selection

The size of the water pump motor required (in Watts) is calculated from the flow rate (in liters/sec) and the total dynamic head (in meters), and the efficiency of the motor (Figure 73). The required power for the motor is calculated from the hydraulic power requirement and the motor efficiency as follows:

P (W) = ρ (kg/ m^3) * g (m/s2) * q (m3/s) * TDH (m)

P = 1,000 * 9.81 * 0.071* 80= 55,720.8 Watt

Motor power = P/η

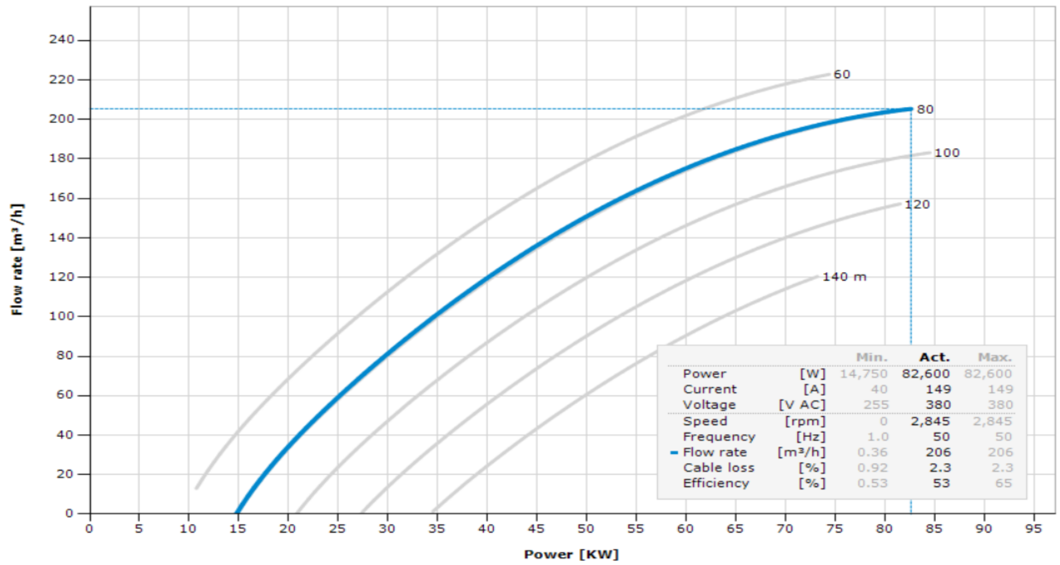
Where: -

- P = Hydraulic Power (Watts)

- η = Efficiency of pump, in most cases η=70%

Motor power = 55.72kw/0.70 = 79.6 Kw

Figure 72 Pump Characteristic Data



2.4 PV sizing

Solar PV sizing for all boreholes was calculated manually and the results were counter checked for accuracy using proprietory software designed for this specific purpose. Deriving the power requirements of a solar system gives accurate results, the software was used as an additional control measure to ensure there were no outliers in the result matrix.

Solar insolation & determination of design month

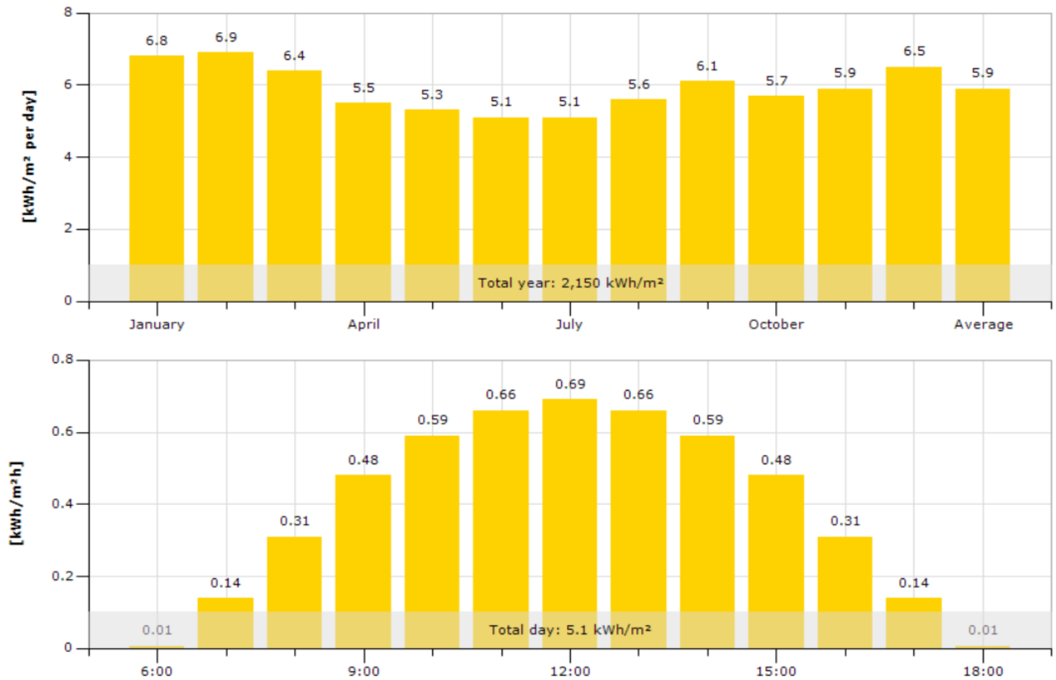
Solar irradiance data collected in KWh/m2 / day that was used in the development of this feasibility studies was gathered from Global Solar Atlas (NASA). Accordingly, the El-Dima borehole (NBTW – 6) is located at 4.4˚ latitude and 37.1˚ longitude (Table 39).

Table 39 Inclined Solar irradiance data with 10-degree tilt Angle obtained from NASA Web site for El-Dima (NBTW – 6) Borena, Ethiopia

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(kWh/m²/day)	6.8	6.9	6.4	5.5	5.3	5.1	5.1	5.6	6.1	5.7	5.9	6.5

The tilt angle is the angle of inclination of the solar array. In regions near the equator, inclination levels between 10 to 15 degrees will be sufficient to drain rain water or to wash away dusts from the solar array. Design month used is when the irradiance is at its minimum (5.47 kWh/m²/day) while the corresponding hydraulic energy is maximum. This will ensure the solar pumping system is sized to ensure sufficient water supply even during cloudy days but with limited rainfall.

Figure 73 Solar Irradiation Data



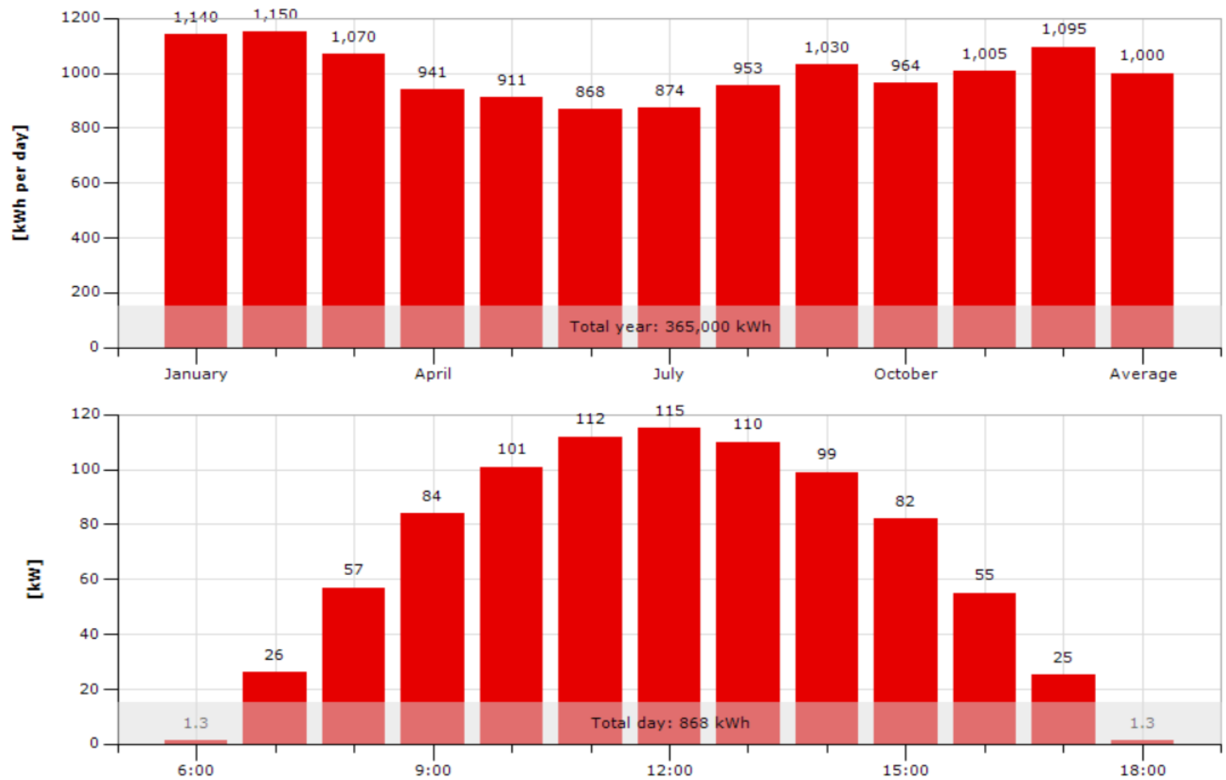
The size of the solar array required (in kWp) is calculated by dividing the hydraulic energy required (in kWh/d) by the mean daily solar irradiation (kWh/m2. D) (Figure 74 & 75). This is then adjusted for efficiency including array mismatch and sub system efficiency.

$$\textbf{solar array power required (kWp)} = \frac{\textit{hydraulic energy required } (Eh)\left(\frac{kWh}{day}\right)}{\textit{Average daily solar radiation}\left(\frac{\frac{kWh}{m2}}{day}\right) * F * E}$$

Where: -

- *F = array mismatch factor = 0.85 on average (a safety factor for real panel performance in hot sun and after 10 - 20 years) and*
- *E = daily subsystem efficiency = 0.25 - 0.40*

Figure 74 Solar Energy Data



The solar array power required (kWp) = (445.77 kwh/d)/ (5.1kwh/m^2/d*0.85*0.4) = 257kWp

2.4.1 Size of pump controller

Modern PV water pumping systems generally use:

- Control inputs for dry running protection, remote control etc
- Protected against reverse polarity, overload and over temperature
- Integrated MPPT (Maximum Power Point Tracking)

The size of the inverter is calculated from the size of the motor with consideration for inverter efficiency as follows:
Pumping controller size = 25% to 30% higher than total pump motor power = (1.25 to 1.30)

Motor power

- $P_{controller}$ = 79 KW*1.27
- $P_{controller}$ = 101 KW

2.4.2 Controller/Invertor Selection

Power	max.101kW
Maximum System Voltage	Umax = 1500 V DC
Max. Current	Imax = 160 A

2.4.3 PV selection

Selected module size	540 Wp
No.of modules in series	14
No. of modules in parallel	26
Total KWp	196.56kWp

Figure 75 Solar Control room Truss and Top Tie Beam Layout

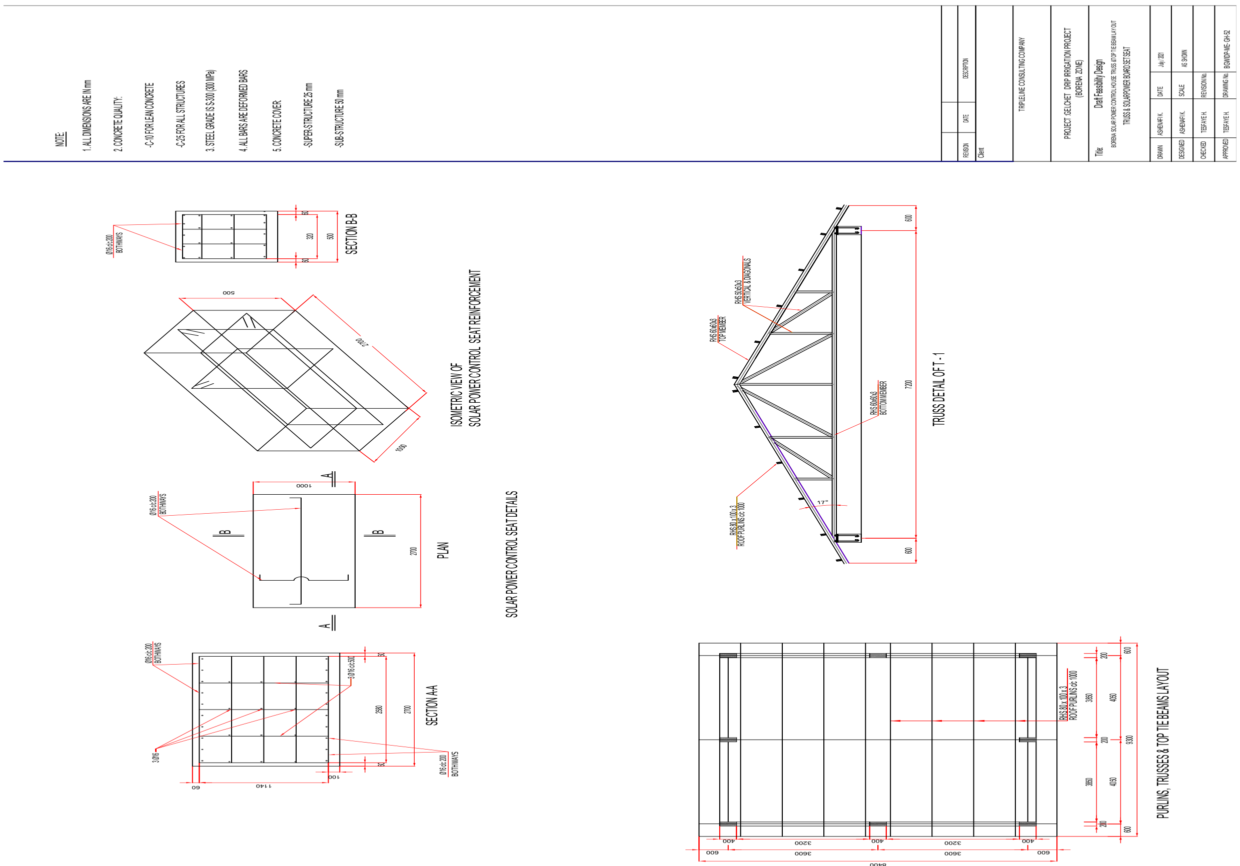


Figure 76 Solar Power control room and Guard house

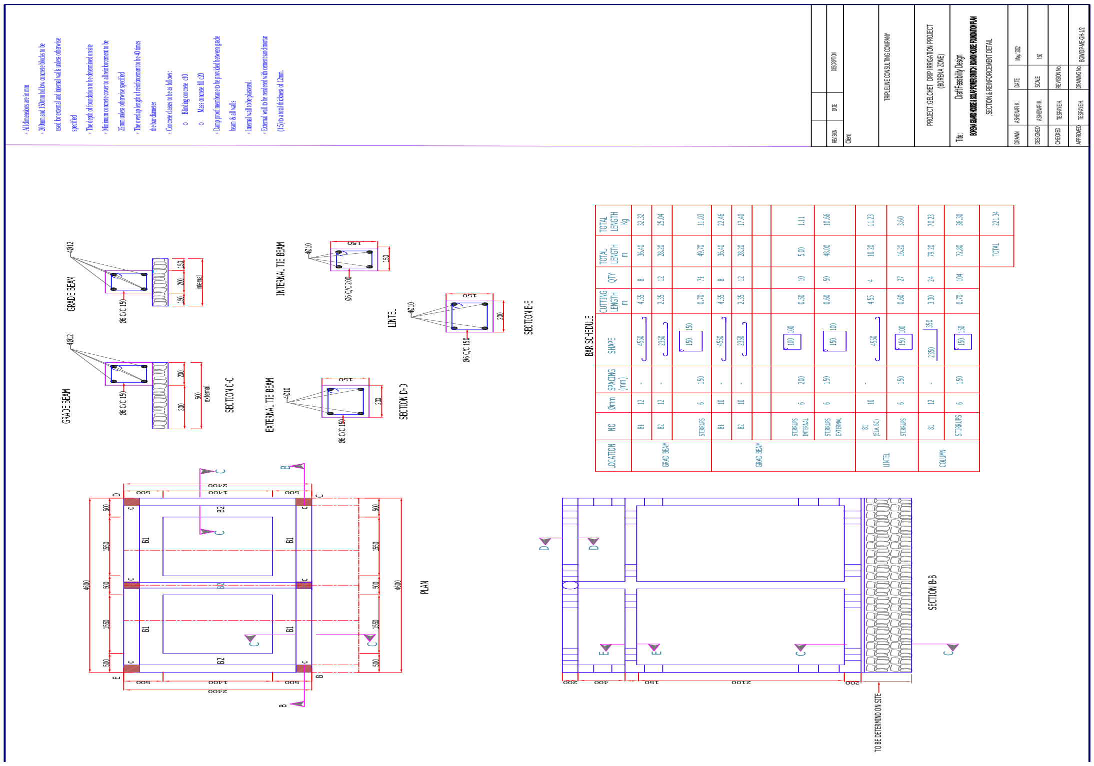
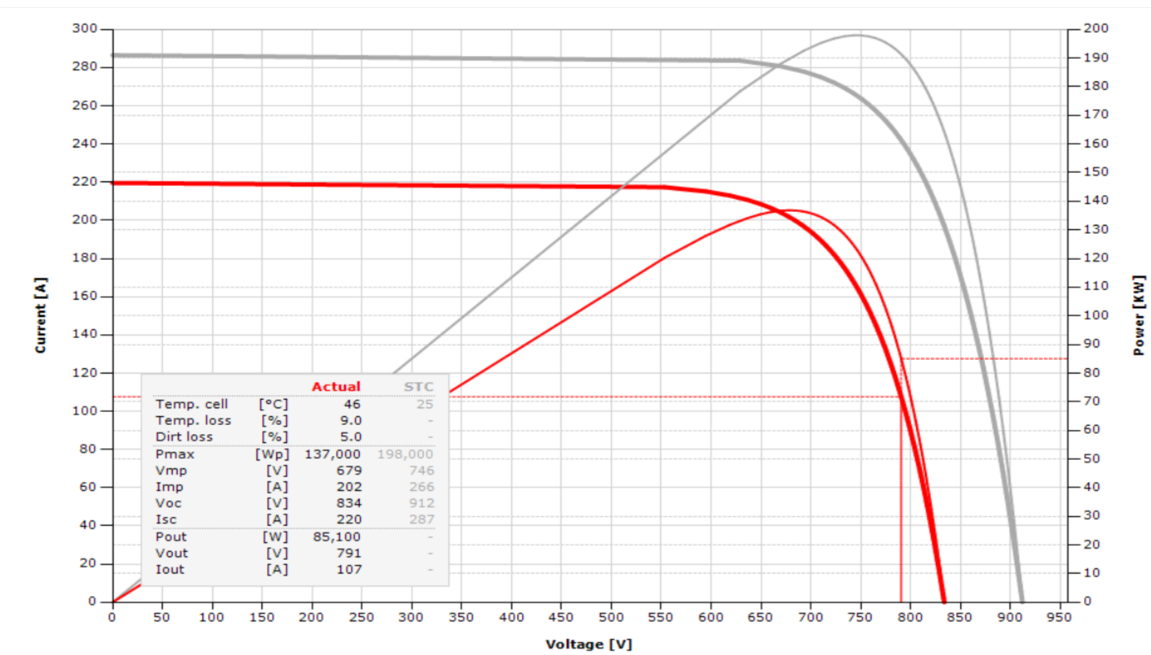


Figure 77 PV Characteristic Data



2.5 Triangulating sizing results

The results generated in designing the solar PV was further triangulated using a proprietary software that is robust for solar system design for water supply and irrigation systems. The software requires base data that best reflects the ground scenario to draw the power requirements and identify any outlier data sets that could have been generated inaccurately.

Accordingly, the following input figures was used

The required inputs for Lorentz Software are:

- Pump Selection........................... Submersible pump in our case (PSK3-7 C-SJ17-7)
- Location...................................... Ethiopia, Borena (4.4˚East,37˚ north)
- Tilt Angle.......................................10 degree
- Water temperature...............................25˚C
- Motor Cable Length 158m
- Total Dynamic head.............................80m
- Required daily output.............................2045m³ (assuming 8hrs pumping)
- Sizing month....................................... July

Individual borehole values was used to calculate the output parameters as shown. Finally, the calculated results are compiled and are prepared in the bill of quantity as shown in the following sections.

Table 40 Summary of the system for the Borena El-dima BH/site

Mode of estimation	PV module (kWp)	Inverter/ controller (kW)	Pump/Motor (kW)	Daily water output(m³/day)
Manual calculation	257	101	79.6	2045
Compass software	197	112.5	75	1905

Annex 2.a. Borehole Hydraulics (attached separately)

KOBO GIRANA

1.1 General Geology

The geology of north and central Ethiopia, which also includes the project area, is dominated by Tertiary volcanic strata underlain by Mesozoic sedimentary rocks. The dominant outcrops on the mountains are fissural basalts with silica varieties. The first geologist in Ethiopia, Branford, 1869 classified the northern Ethiopia volcanic into Ashange and Magdala group. Two Volcanic successions occurred in the period of Paleocene to Miocene, recognized as the Ashangi and Magdala groups.

1.2 Geology of the Valley

1.2.1 Mesozoic Sedimentary Rocks

The geological map of the Kobo-Girana Valley (Co-SAERAR, 1997) shows sandstone unit outcropping near Hara swamp extending to the north and east beyond the boundary of the project area (Figure 79). The sandstone is reported to be characterized by flat topped hills affected with numerous north-south trending faults. This rock unit is composed of horizontal beds of white to pink, medium grained, friable sandstone frequently conglomeratic and with intercalations of limestone or marl.

Weathered aphanitic basalt was observed on top of a faulted block of sandstone. Because of its stratigraphic position and due to the existence of a basalt outcrop on top of it, this sandstone unit is taken as belonging to the upper sandstone formation of the Mesozoic sedimentary sequence.

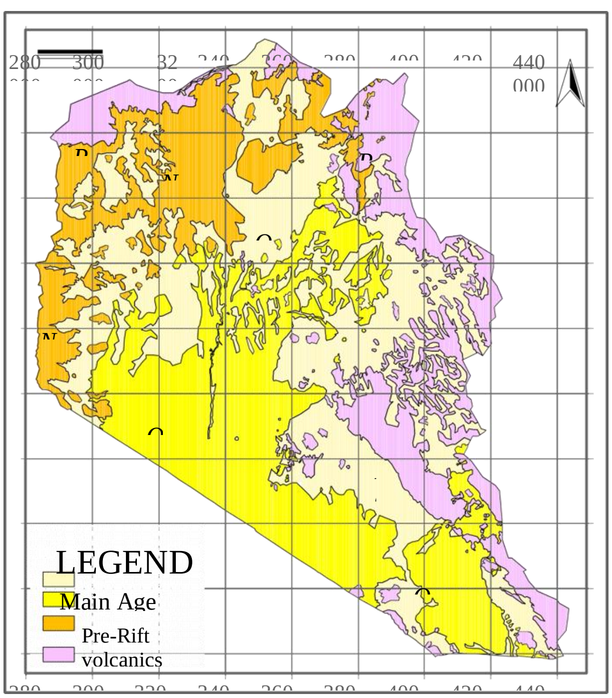


Figure 78 Geology of the Kobo-Girana Basin

1.2.2 Igneous Rocks

The volcanic rocks outcrop on the western and eastern ridges and as erosion remnants at the valley floor. The volcanic rocks of the valley and its surrounding are the Trapean Series especially the Ashangi Group volcanics. These Ashangi Group consists predominantly the thick basalt flow of trachytes and rhyolites interbedded with pyroclastics erupted from fissures. According to COESERAR, 1997, the maximum thickness of this group occurs near Korem upto 1200m. In the upper part, the Ashangi Group becomes more tuffaceous and contains interbeds of lacustrine deposits and some acid volcanics. The basalt rock outcrop in the area includes, olivine, porphyritic and amygdaloidal basalt.

Acidic pyroclasts are found in the north-eastern boundary of the area forming part of the Zobul Mountains1. It consists of tilted beds of ignimbrite and agglomerates with sedimentary (shale) intercalation at the upper part. The ignimbrite is composed of well stratified layers of tuff showing flow banding. Acid volcanic agglomerate contains large fragments of volcanic particles and quartz embedded in acidic tuff.

The Magdela Group volcanic succession is reported to outcrop in Wuchale as Rhyolite overlying the basalt unit. It is characterized by greenish gray, fine grained and compact rock.

Intrusion of granite and syneite outcrop in the volcanic succession in the areas like Garalencha and Keigara close to the Zobul ridge. It forms an isolated ridge upstanding above the surrounding low-lying area, showing mineralogical variations between granite and syenite. It consists of feldspar and varying amounts of quartz and some mafic minerals.

The type and age of these granite intrusions may be similar to those of the Tertiary alkaline massifs occurring on the edge of the Afar Depression and elsewhere. According to Kazmin (1972), these rocks are mainly alkaline riebeckite granites and syenites with ages of 25 to 22 million years.

1.2.3 Quaternary Sediments

The quaternary sediments are all unconsolidated deposits which filled in the graben bounded by the western and eastern volcanic ridges. The source of the sediment is mainly the western ridge from which most of the streams are flowing eastwards into the valley floor. The erosion/transportation from the escarpments and deposition of sediments in the valley flooring is a continuous process to the present as witnessed in the field.

The thickness of the sediment in the valley floor varies from place-to-place owing to the morphology of the deposition basin, the probable shifting of flow channels and the tectonic disturbance that has affected topography of the bed rock.

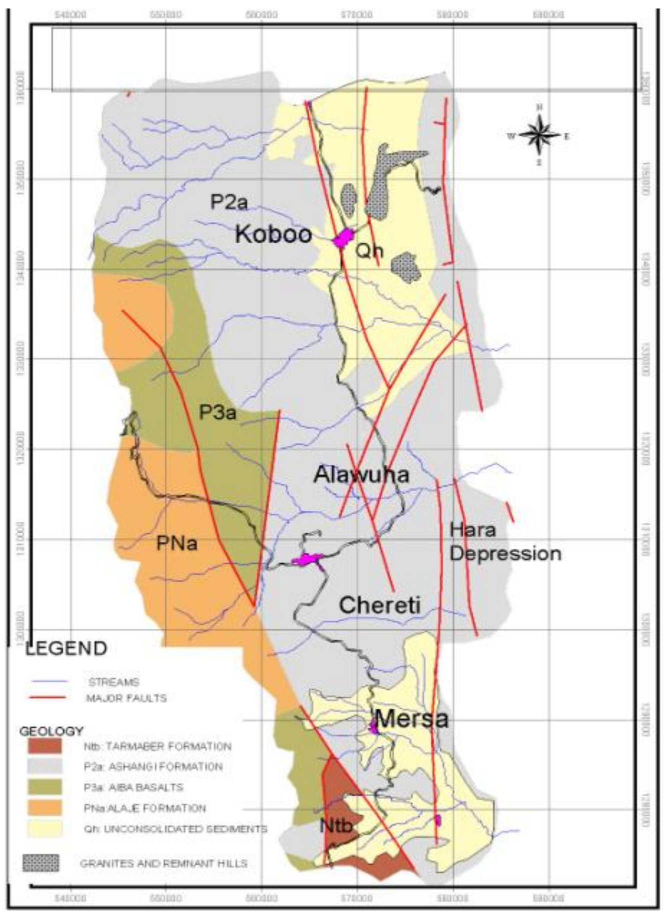
According to the report of the German Consult (1976), the thickness of the sediments in the valley varies from place to place due to differential faulting that affected the graben-floor. The maximum thickness reported to exceed 350 m with the general west to east increase of the thickness. The report further elaborated the deposits in the valley to be lacustrine, alluvial and colluvial.

The lacustrine sediments are composed mainly of alternations of sandy, silty and clayey layers. The existences of a number of swamps in the area are evidences for the presence of clay horizons underlying these swampy areas.The alluvial deposits are composed of boulders, cobbles, pebbles, gravel, sand and silt. While the deposition of the larger materials like boulders, cobbles, and pebbles is restricted to the western part of the graben-floor, the fine materials reach furthest extremes of the area following flood plains of streams. The colluvial deposits are confined to the foot-hill areas in the grabens and are composed of poorly sorted sediments of all sizes.

1.3 Geological Structures

The geological structure of the area is controlled by tectonic events that led to the development of the Rift System (Figure 80). These events are characterized by tensional movements which gave rise to fissural volcanism followed by block-faulting and tilting to form the escarpment zone including marginal grabens. These marginal grabens are narrow elongated depressions bounded on both sides by normal faults facing each other. The eastern and western ridges of the Waja Golesha and Hormat Golina bounding the plain area are characterized by a system of opposite dipping faults oriented parallel to the plateau escarpments.

Figure 79-Geology and structural map of Kobo-Girana Valley



*Source geological map of Ethiopia, 1996

The Waja-Golesha-Hormat-Golina plain area has a length of about 33 kilometres and a width of about 10 to 17 kilometres. The widest basin in the study area reaches to 17 km at Waja-Adis Kigny and the narrowest corridor is about 10 km at Kobo-Gerbi stretch. The eastern margin of this graben is a steep slope fault downthrown to the west about 800 meters as measured from the foot of the hill to the top on the road Kobo-Zobul all-weather roads.

The scarp forming the western edge also has the same amount of downthrows to the east but it is less pronounced due to denudation features and the presence of outliers of the scarp. South of Robit the trend of the westen scarp faults shifts to NNW-SSE narrowing the width of the graben down to 6 kilometers until they finally die out around Indrisamba stream. On the other hand, the eastern scarp faults continue with the same N-S trend up to Hara village, and then die out giving way to a flattened surface that descends gradually into the Afar Depression.

Further to the south occurs the Girana graben bounded in the eastern margin by well-defined steep walled fault scarps and less clear and discrete faults in the western margin. Apart from the major faults defining the margins of the grabens, the escarpment is heavily affected by numerous normal faults with small displacement and short extension and fractures without significant displacement.

An example of such minor fault is the E-W trending Dikala fault on the western scarp of the graben starting just west of Kobo town and extending to the north in ENE-WSW and E-W direction. The throws of these faults are not large enough to be detectable except for one such fault just at the northern boundary of the area with an obvious northward downthrown. These faults continue into the graben-floor under the deposition of sediments.

The E-W fault defining the course of Selenwuha stream on the eastern scarp and other NE trending lineaments to the south of this stream, besides some traces of lineaments found on the graben-floor itself, appear to be the continuation of the cross-¬faults to the east. Other E-W faults and fractures are found elsewhere in the area concentrated particularly on the western scrap north of Robit, determining the course of streams. Another fault line with the slightly different trend of NE-SW was traced crossing the graben-floor in the vicinity of Adis Kigny and Mendefera.

The geophysical studies conducted in the graben by the German Agency for Technical Cooperation also confirms the presence of these cross-faults in the valley. According to the report, geo-electrical resistivity investigations carried out along the axis of the graben indicated the presence of cross-faults and that block-faulting across the graben-floor has given rise to up-lifted and downthrown blocks, so that certain areas in the graben, like the Golesha area, underwent about 100 meters of subsidence.

1.4 General Hydrogeology of Kobo Girana Valley

1.4.1 Regional Set Up

The regional hydrogeological set up of the project area and its surrounding can be summarized as localized graben filling unconsolidated sediment composed of clay, silt, sand, gravel, boulders and pebbles above the Ashangi group volcanics which are intern underlain by Mesozoic sedimentary rocks. The Trapean volcanics and the underlying formation are strongly affected by faulting and displacements prior to the deposition of the quaternary sediments in the grabens and troughs. Regionally the Ashangi volcanics are the most extensive formations above the sedimentary basin.

With regards to groundwater movement and storage, the unconsolidated sediments in the grabens and the sedimentary rock beneath the Ashangi Group volcanics have high potential. The Ashangi volcanics are also moderately productive for rural and small towns water supply in the region as they are good for transmission but with localized flow conduits along the fractures and thin upper fracture zones under the unconsolidated sediments. The groundwater in the Ashangi volcanics in the area can be tapped as springs or shallow wells and due to the poor geomorphologic setup for storing large amount of groundwater it is understood that the aquifers are not promising for high yields at this particular project area. Although localized in occurrence, the unconsolidated sediments are relatively thick with good hydraulic permeability and these sediments get recharge from the weathered part of Ashangi volcanics surrounding the grabens.

1.4.2 Regional Recharge - Discharge Condition

The regional potential groundwater storage and movement is believed to be the Mesozoic sedimentary rock underneath the volcanic succession. The Ashangi Group volcanics are less significant for high yielding groundwater for irrigation. The main water bearing and transmitting formation especially for the irrigation purpose of Kobo-Girana Valley is the thick localized unconsolidated sediment above the volcanic rock. The sedimentary rock under the volcanic rock shows hydraulic connection with the volcanic rocks and unconsolidated sediment at some places in the valley. The connection is manifested through hot springs. The volcanic rock is weathered and fractured in the upper zone of the formation. This weathered zone of the volcanic rock both on the mountains and the plains recharge to the unconsolidated sediment of the valley depending on the slope of the fractured/weathered bedrock.

Therefore, the unconsolidated sediment is recharged mainly as subsurface inflow from the locally weathered and fractured zone of the volcanic rock of the mountains surrounding the plain area. Major groundwater out flow is at the Selenwuha and Golina streams out let to Danakil Depression and Mile-Awash, respectively, in Afar Region. The outlets have perennial flows from groundwater discharge.

Waja cold springs are indicatives of the out flow of groundwater on the plain area and hot springs at Selenwuha and Golina out lets are probably related to the deep-seated regional groundwater stored in the Mesozoic sedimentary rocks under the unconsolidated sediment. The groundwater flowing to the surface at these sites is owing to local fracturing of the formations underlying the sediments.

Static water level data of existing boreholes shows that the ground water table in the graben is often below stream courses in the plain area. At the escarpments and mountain ranges, however, these springs at places are discharging into stream. Moreover, subsurface inflow of groundwater from the upper weathered and fractured zone of the volcanics of the Western Mountain and eastern escarpment to the unconsolidated sediment aquifer contributes to groundwater recharge.

Based on the groundwater potentials in the aquifers, the Kobo ¬Girana valley can be sub divided into two broad aquifer systems:

- The Mesozoic Sedimentary
- The volcanic rock aquifers, and
- The unconsolidated sediment aquifers

1.4.3 The Mesozoic Sedimentary Aquifers

The sedimentary rock aquifer is the regional aquifer system. From regional geological and hydrogeological information, it is expected to be encountered below the volcanic succession. However, the scope of the investigation under this project is confined only into the unconsolidated sediment aquifer. As a matter of fact, the investigation as well as the test drilling was also focused mainly on the unconsolidated sediments in the Kobo and Girana plain sub-basins.

1.4.4 The Volcanic Aquifers

The storage and transmission of groundwater in the volcanic rocks largely depends on type of porosity and permeability formed during and after the rock formation. This group includes various lithological units belonging to different series, but from the hydrogeological point of view, they are grouped together and described here as the volcanic aquifers. Basalt, rhyolite, basic and acidic pyroclastics that comprise ignimbrite, tuffs and volcanic agglomerates are from the bulk of this unit. Due to the prevailed tectonic events in the past, this formation is moderately to highly fractured.

The volcanic rock that forms step and elevated mountainous terrain position has a very limited recharge capacity resulting high surface run off in the Kobo and Alawuha sub-basins. This recharge-discharge condition in the elevated volcanic is revealed by the absence of high yielding springs in the immediate escarpment zones and foot hills bordering the Kobo plain. However, as one goes further to the west the aquifers property of the basalt changes. Several large springs emanate from big fractures and join together to form perennial rivers of the valley.

1.4.5 Unconsolidated Sediments

The unconsolidated sediments of the valley are composed of clay, silt, sand, gravel, pebbles and boulders transported mainly from the western escarpment and deposited in the valley. The thickness of the sediment deposit increases as one move from west to east in the valley. Geological logs of the boreholes and the geophysical surveying results show that the thickness of the sediments of the sub-basins vary from about 300 m in the east to less than 50 m near the mountains to the west. The western part of the valley is characterized by coarse sediments while the deposit becomes finer towards east. At some places like Golesha to Jarota-Addis Kigni Village areas, the fine material is substantially thick on the upper 100 m deposit of the sediment. The lateral and vertical variations in grain composition of the sediment are common every where in the valley attributed to mixing of the proximal and distal deposits following flood and depositional cycles. As a result, the unconsolidated sediment has heterogeneous aquifer both vertically and horizontally.

According to CoASEARAR, 1997, aquifers underlying the Gelana sub-basin show great variations in composition and spatial distributions. In the Mersa plain, coarser sediment of 20 - 30m thickness is overlain by relatively thick fine sediment of 10 - 30m thickness. In the plain area located between Mehal Amba and Girana villages, thickness of the coarser sediment varies from 50m near Mehal Amba and gradually diminishes to few meters around Girana.

1.5 Classification of Basins in Kobo Girana Valley

As an outcome of the study from Kobo Girana Valley Development Project considering general attitude developed on the groundwater potential of the area, Depositional systems, Sediment thickness, Hydraulic conductivity, Water chemistry (TDS) from previous data and Resisitivity values obtained during the field survey, Kobo Gorana Valley divided mainly in two sub basins. A total of 60 production/test wells with 60 observation wells were proposed to drill for test and production in the whole Kobo-Girana valley. From these 60 large diameter wells 40 of them are production and 20 test wells in the whole Kobo-Girana Valley

- Kobo Valley (Hormat-Golina and Waja Golesha sub basins).
- Mersa-Girana (Kobo-Arequaite and Mersa-Girana sub basins)

The observation wells distributed mainly with the test wells and some are allocated for the production wells where testing of well fields is required.

The production wells are concentrated on the topographically surveyed areas for the irrigation scheme. The main objective of the test wells drilling is to produce lithology data and aquifer parameter in fields where no or few drilling activities are carried out previously and where the required data gap is relatively high. The test well data are used in the recommendation of production well drilling.

1.6 Ground Water Well Data and Safe Yields Extrapolation

1.6.1 Kobo Valley (Hormat-Golina and Waja Golesha sub basins)

In Kobo Valley at Hormat-Golina and Waja Golesha sub basins drilled a total of 86 wells. Among these 18 are new wells, whilst 68 of them drilled before 2007. Wells drilled before 2007 was drilled for irrigation of the Kobo valley under the administration and operation of Kobo-Girana Valley Development Project (KGVDP) are mostly for well diameter of 17.5 inch and installation of 10 inch casings. These comparatively larger diameter wells are intended for irrigation and aquifer testing. The average drilling depth of these 41 large diameter production and test wells was 105 m for an average yield of 38 l/s and average drawdown of 23 m. The maximum drilling depth of these wells was 130 m for tested yield of 52 l/s Coba village (WG2) in Waja-Golesha groundwater sub-basin. According to the well completion reports, the average sediment thickness partially penetrated during drilling of the irrigation and test wells is 93 m with the maximum thickness penetrated being 130 m at WG2.

The completion reports of the contractors further showed that most of the wells on the unconsolidated sediment in Hormat Golina and Waja Golesha groundwater sub-basins are only partially penetrated. The maximum transmissivity value calculated in these wells is 1171 m2/day with an average value of 423 m2/day for the Hormat-Golina and Waja-Golesha sub-basins. Wells drilled after 2007 are 18 for well diameter 20 inch and installation of 12-inch casings

Table 41- Kobo-Girna Borehole Characteristics

No.	Well ID	Location X	Location Y	Location (GPS) Z, elevation, m.a.s.l.	Depth (m)	Static Water Level(m)	Discharge (l/s)	Draw Down(m)
1	*WG9*	567405	1354956	1446	105	19.15	30	35.02
2	*WG23*	569685	1354829	1403	167.5	14	47.78	33.78
3	*WG28*	568854	1352624	1425	158	16.38	60	5.08
4	*WG 29*	568000	1353000	1436	137	8.27	60	3.41
5	*WG31*	568574	1354821	1430	150	14.58	24.36	9.78
6	*WG32*	569683	1354829	1420	186	23.09	43.2	16.77
7	*WG33*	569408	1356020	1428	178.7	24.1	51	21.1
8	*WG40*	571293	1356513	1412	202	27.6	40.45	24.33
9	*WG41*	570153	1356181	1421	179.5	19.85	56	13.29
10	*WG42*	569574	1353799	1418	214	22.6	58	1.94
11	*WG 43*	570275	1355009	1418	277	19.62	75	8.5
12	*WG 34*	568670	1356024	1438	156	14.35	52	26.9
13	*HG 5*	571867	1334044		112	20	50	14.3
14	*HG11*	571055	1335915	1437	116.5	14.4	50	20.77
15	*HG13*	571683	1336365	1425	110.6	18.26	50	13.35
16	*HG26*	569380	1339575		152.7	16.7	85	14.5
17	*HG 28*	568066	1340931	1491	170	25.54	55	9
18	*HG 29*	568476	1341101	1488	137	23.56	80	15.6
19	*HG 37 A*	569485	1341610	1475	145	23.85	50	5.91
20	*HG43*	579090	1332043	1375	81	13.3	29	24.71
21	*PHG-6*	571823	1334961	1407	178	20.13	70	5.72
22	*PHG 8*	570553	1334124	1434.097	147	21.27	46.4	16.66
23	*PHG 9*	570085	1333953	1440.327	158	21.94	53.5	5.58
24	*PHG 10*	569560	1334010	1447.831	146	25.3	59.5	5.58
25	*PHG-16*	574874	1331241		99	8.5	25	35.55
26	*ALTW-1*	575506	1314095	1425	218	37.4	52	7.79
27	*ALTW2*	577550	1316613	1395	251	11.82	48	47.23
28	*ALTW-3*	574703	1315873	1422	250	14.58	50	21.18

29	ALPW1	575116	1312965		220	43	53	29.09
30	MGTW-1	574345	1280320	1524	252	23.15	62	11.23
31	MGTW-2	576148	1288640	1491	282	0	57	36.47
32	MGTW3	573821	1277578		251	18.35	25	72.85
33	MGPW1	573583	1280146		200	8.6	72	23.49
34	MGPW2	574158	1290510		258	31.89	64	10.44
35	SWTW2	574602	1300133		250	8.8	60	46.65
36	TG 3	580516	1279739	1394	164	2.63	52	39.27
37	TG 4	581014	1278563	1387	143	0.75	55	36.82
38	PG 4	579579	1279670	1409	126	11.04	30	26.43
39	PG 5	579838	1278511	1405	120	11.7	20	35.82
40	PG 6	581793	1278463	1377	173	0	43	29.41
41	TATW-1	567514	1267867	1588	253	7.92	56.9	14.24
42	TATW-2	567307	1266660	1571	248	14.58	62	21.18
43	HCKTW2	587540	1182638	1450	252	8.32	60	3.27
44	HCKTW3	590050	1185850	1423	260	0	66	28.25
45	HCKTW4	585874	1203916	1459	324	0	60.3	45.35
46	HCKTW5	595255	1173713	1406	310	0	19	134.5
47	Mekoy pw-1	564435	1355542	1484	112	8.32	41.3	15.93
48	Mekoy pw-2	578231	1226297	1470	88	13.08	30	22.56
49	JRTW1	600042	1164989	1461	239	3.13	62	33.05
50	JRTW2	595313	1167092	1490	302	11	50	24.55
51	STW1	603153	1136754	1421	180	3.19	55	28.78
52	STW2	600793	1134590		227	4.56	33	99.26
53	JWTW1	602800	1117220	1180	184.48	0	68	25.7
54	JWTW2	604659	1117744		220	5.69	40	57.61
55	SRTW1	595779	1107850	1346	186	18.4	50	44.88
56	DHBH2	569800	1230107	2446	75	14.2	41	13.45
57	SNBH1	610691	1204682	1192	94.5	7.05	42	8.6
58	GKBH1	569303	1224795	2257	109	0	35	40.32
59	THG 43	579090	1332043	1375	81	13.3	29	24.71
60	TWJ3	569491	1357769	1433	154	16.46	60	7.46

2 BORENA

2.1 General Geology

Main lithostratigraphic units in the project area consists of Precambrian metamorphic and intrusive rocks, Cenozoic volcanic rocks and Recent superficial deposits and cover 17%, 46% and 37% of the area, respectively. These are further subdivided into two or more lithologic unit based on mineralogic composition and texture (Table 42)

Table 42- Main Lithostratigraphic Units

Geologic Age			Formation	Lithology (Symbol)	Description	Area (km2)	Area (%)
PHANEROZOIC	Cenozoic	Quaternary	Recent Superficial Deposits	Qal	Fluvial gravel, sand silt	953	5.3
				Qbs	Black to dark brown silty clay	2769	15.4
				Qrs	Red, brown grey silty sand	2896	16.1
			Recent/post Rift Volcanics	Qgb	Gorahe basalt	218	1.2
				Qsc	Scoria	178	1
				Qlt	Lappli tuff	1679	9.3
				Qsv	Soda Belo Volcanics	91	0.5
				Qbb	Bulal basalt	3374	18.8
		Tertiary	Pre-rift/Syn-rift volcanics	Nuv	Upper volcanics	985	5.5
				Nmv	Middle vlcanics	1002	5.6
				Nlv	Lower volcanics	840	4.7
PRECAMBRIAN	Neoproterozoic		Metamorphic basement	Pgt	Granite	60	0.3
				Pygn	Granite-gneiss complex	555	3.1
				Pqfgn	Quartzofeldspathic gneis s	714	4
				Plgn	Layered gneiss complex	1612	9
				Pgrt	Granulite	154	0.9

2.1.1 Precambrian Crystalline Rocks

The Precambrian crystalline basement is widely distributed underlying prominent mountain ranges as well as low lying hills and relatively elevated flat surfaces in the area. Exposures are commonly continuous on the mountain ranges, ridges and hills, and blocky or fragmental elsewhere. The crystalline basement in the region is made up of quartzofeldspathic rocks of several kinds, mafic gneisses, and very minor metasedimentaryschists and serpentinite.

Inherent heterogeneous intermixing of different rock types on the mesoscopic/outcrop scale could not allow classification of the basement rocks into simple homogenous lithological units. Based on the mineralogical composition, texture and lithological association, the crystalline basement is grouped into five major map units constituting an assemblage of different type of rocks (Table 41). These major map unit groups are Granulite (Pgrt), Layered gneiss complex (Plgn), Quartzofeldspathic gneiss complex (Pqfgn), Granite gneiss complex (Pygn), and Granite (Pgt). Some adjacent map units (example, the Fele and the Gamedu gneissic complexes) most commonly share similar characteristic feature differing only in some minor geological factors. Therefore, it should be noted that the classification scheme and the divisions adopted here is not conclusive.

2.1.2 Cenozoic Volcanic Rocks

The volcanic rocks occupy the western warped plateau and the central plain land stretching from the Segen river in the north to Megado in the south. They occurred as lava flows, pyroclastic deposits, spatter cones, scoria cones and maars, and are dominantly basaltic in composition, and associated minor felsic pyroclastic deposits and phonolites, trachytes, and rhyolites. The stratigraphic, petrographic and geochemical data of previous works and acquired field data in the present study were used to characterize the volcanic rocks exposed in the Borena area and a comparative stratigraphic sequence is presented in Table 43.

In the study area, the alkaline basalts (Taltale) and associated rhyolites and trachyte (10-17 Ma) are exposed in the north-western and north-eastern part. The alkaline basalts and basanites (7-8 Ma) are exposed east of the present project area, (Figure 81).

The tholeiitic basalts (Bulal, OWWDSE, 2008) cover extensively in the central and western part and extend up to Ethiopia-Kenya border (dated between 3.4 – 4.7 Ma, Davidson and Rex, 1980; Takele, 2004; Tesfaye, 2008). It mostly covers the flat lying areas and flanks of ridges. The tholeiitic basalts are more extensive than other volcanic rocks in the Yabello area.

The Quaternary (0.1-0.8 Ma) lavas are extensively occurring in Mega areas in the southeast and around Dilo and Goray localities to the southwest. They are sporadically occurring in the central and northern part of the Yabello area. Exposures of this unit mostly found on the tops as well as slopes of the spatter cones and sometimes occur as composite with the associated pyroclastic deposits in the volcanic centers (craters).

Based on differences in predominant lithology, composition, texture, structure, exposure elevation/thickness, and volcanic association, the Cenozoic volcanic units in the studied area were classified in to eight stratigraphic sequences (Tables 43, Figure 81). These are from bottom to top, lower volcanic sequence (Nlv, V1): alkaline Talta basaltic sequence; Middle volcanic sequence (Nmv, V2): intercalation of basalt, trachybasalt, agglomeratic to scoriaceous trachybasalt and trachyphonolite, and tuff; Upper volcanic sequence (Nuv, V3): intercalation of tuff, ignimbrite, rhyolite, basalt, and trachyphonolite; tholeiitic Bulal basaltic sequence (Qbb, V4), intercalation of trachyte, trachyphonolite, tuff and pitchstone (Qsv, V5), intercalation of xenoliths bearing alkaline basalts/basanites and lapilli tuff and ash (Qlt, V6), Scoria and scoriaceous basalt sequence (Qsc, V7), and Goray basaltic and agglomeratic sequence (Qgb, V8).

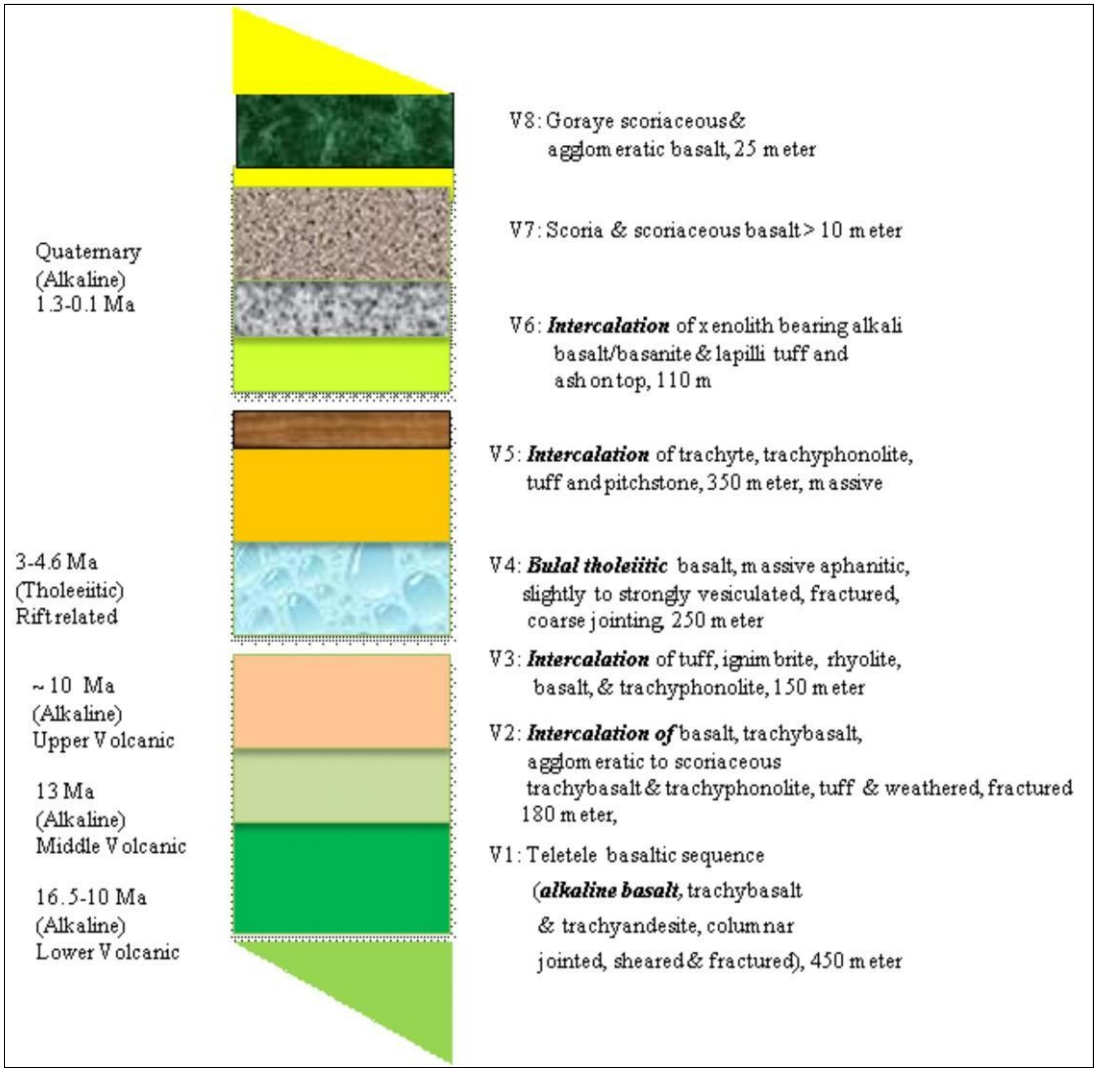
Table 43-Volcanic sequences in Yabello area compared with data from Davidson, 1983 and others

Taltale & Bulal plains (Davidson,1983; references therein)	Amaro & Yabello areas (as compiled from, Tesfaye, 2008; Takele,2004; WoldeGabreil, 1994)	This study (Bedru Hussien & Kurkura Kabeto)
Qv, QHv basalt	Stage 5: Amaro: Bobam-Nechsar (Alkaline basalt & trachybasalt) Yabello: Alkaline basalt/basanite, 0.8 -0.1 Ma & 1.9 - 0.3 Ma	V8: Goraye scoriaceous & agglomeratic basalt (xenolith bearing) V7: Scoria V6: Intercalation of xenoliths bearing alkali basalt/basanite and lapilli tuff and ash on top V5: Intercalation of trachyte, trachyphonolite, tuff and pitchstone
Nb, Bulal basalt	Stage 4: Tholeeiitic basalt, 3.6 – 4.7 Ma	V4: Balal basalt, massive aphanitic, slightly to strongly vesiculated basalts and fractured at places
	Stage 3: alkaline basalts and basanites, Arero, east of Yabello, 8.2-6.7 Ma	V3 Arero, east of Yabello, 8.2-6.7 Ma
NMhp, Phonolite, 13Ma		
NMv: Salic flows & Pyroclastic rocks Basalt	Stage 2: Trachyte, phonolite 10-13 Ma,	V3: Intercalation of tuff, ignimbrite, rhyolite, basalt, and trachyphonolite
	Stage 2: Alkaline basalt, trachybasalt & trachyandesite 10.8 and 16.5 Ma	V2: Intercalation of basalt, trachybasalt, agglomeratic to scoriaceous trachybasalt and trachyphonolite, and tuff
(NMs: Surma basalt) NMt: Taltale basalt, 20.3 Ma		V1: Teletele basaltic sequence (alkaline basalt, trachybasalt & trachyandesite, columnar jointed, fractured)
	Stage 1: the Amaro tholeiitic basalts; (2) the overlying Amaro rhyolitic tuff; 39-35 Ma	
Crystalline basement		

2.1.4 Recent Superficial Deposits

As is the case elsewhere in southern Ethiopia, the superficial deposits occupy the plain-land in the area and covers 37% of the project area (Table 42). The unit is represented by red-greyish brown sandy soil (Qrs), dark-brown/black soil (Qbs), a variety of gravel, sand silt deposit (Qal) and greyish/brownish white calcretes and ferricretes (e.g., HaileMeskel and Fekadu, 2007; Solomon and Amanti, 1999; OWWDSE, 2006; 2011; Likisa, 2012).

Figure 80 Summarized Volcanic Sequences of the Project Area



Summarized volcanic sequences of the project area. (On the left of the columnar section the general chemistry and age of sequences are given and on the right of the section volcanic sequence intercalations, thickness and specific features are given. The section is not scale. The top cover is alluvial, lacustrine and elluvial deposits).

2.2 Hydrogeology of Borena area

From the investigation of geology and geomorphology, hydrology, water point inventory, test wells drilling, hydrogeochemistry & isotope hydrology and the field verification of hydrogeological works made so far, hydrogeology and aquifer extents of the general project area is broadly outlined below. Furthermore, we have used the work of OWWDSE (2011), which is very recent and being compiled from different previous studies made at different time, to extract the hydrogeology and aquifer extents of the study area specifically for those areas including east and central part of the project areas where the current geophysical survey and test well drilling did not cover.

The overall hydrogeological configuration of the project area is mainly controlled by the geomorphological, structural setup and lithological formations. The Ririba Rift system is the main prominent regional structure in the area that resulted in creating different geomorphologic settings. The variations in the aquifer distributions and the groundwater flow system are the result of structural and lithological differences over the project area. The volcanic rocks are the regional aquifers with variable hydraulic capacities.

The porous media forming aquifer in the area is the weathered and fractured basalt unit designated as “Bulal Basalt”. This rock unit is aphanitic to vesicular textures exist with intercalations of scoria/scoraceous basalt unit over larger part of the project area, and at suitable geomorphological positions with adequate thickness to store and transmit groundwater. This Bulal type of basalt forms the main promising aquifer of the area.

Except at few localities where it rests directly over the basement and forms localized aquifer, the alluvial deposits in the area acts only as transmitting media to the lower Bulal and Taltale lower aquifer.

In the entire project area, the volcanic rocks rest over the basement rock that acts as impermeable bottom unit of the region that helps groundwater storage within the overlying Bulal and lower Taltale formations. However, the most top weathered part of this basement unit could also bear groundwater and considered as bottom parts of both Bulal and Lower Taltale aquifer. This was confirmed that in most of the test wells where basement traced and the upper weathered and fractured basement is fully penetrated high groundwater is observed with respect to the other test well where no basement rock reached; the Mermero case is the exception.

Bulal basalt contains appreciable amount of groundwater within its fractures. It covers the largest area occupying the low lying plain areas of Gelchet, Wobok, Horbate, Memero, Gobso, Sarite, and Megado where the existence of promising groundwater has been confirmed by test well drilling.

Works done to define the extent and geometry of this target aquifer formation (Bulal Basalt) over large part of the project area shows that its saturated thickness ranges from 20 m to 160 m with an average of 60 m. The thickness of the un-saturated section of the unit ranges from 92 to 118 m with an average of 126 m. The total thickness of the Bulal basalt section over large part of the area so far explored is in the range of 140 to 250 m with an average of 185 m. However, within this general domain, the total thickness of this Bulal basalt in the Sarite plain is about 336m, which was not penetrated during the previous investigation phases. On the other hand, the thickness of this basalt at and near Meremero localities is more than 482m. It was still not possible penetrating the full section of Bulal basalt and thus it will be verified during the pilot well field drilling program. The actual total thickness of lower Taltale basalt is also variable from place to place. It varies from 188m (Bule Denbi Test well) to more than 500m (Lega Anga tests well). In general, the Taltale basalt thickness increases from west to east wards for the project area.

The groundwater flow pattern of the project area depicts the convergence of flow lines from the parts of eastern and western land blocks towards the rift center, as it ultimately flows southwards towards the Ethio-Kenyan border along the rift zone. Groundwater is discharged from the area in the form of small springs, evaporation from shallow soil storage, boreholes abstractions and flows through permeable structures and aquifer formations towards general south. Groundwater out flows to deeper horizons along the major fault zones, open fractures and volcanic centers (maars) is anticipated to be a significant phenomenon in the area, apart from flows within the general aquifer media.

Depth to water strike ranges from 42 m in the locality of Taltale to 167 m, b.g.l in the area of Wobok/Dambala Dara. For yields determinations, all the recent ten deep wells drilled at different sector of the project area are properly tested (4.7l/s-50l/s). From the preceding investigation works in this area (2007-2010), only small capacity wells have been properly tested (3-14 l/s), while the rest did not furnish yield data due to narrowness of the well diameter that could not accommodate larger diameter submersible pump. In general, the safe yield of the aquifers in the area ranges 3 l/s to 60 l/s. Thus, in this project program, the optimum yield determination of the Bulal aquifer was made using proper pumping test analysis so as representative and reliable hydraulic parameters more or less derived for the numerical modeling purpose so that now it is possible to develop numerical modeling for the project area, which is now finalized.

In general, in the work of OWWDSE (2007-2011), determinations of aquifer parameters were made only for the low capacity aquifer zones of the area, due to the un-completed pumping test works. According to this work the Transmissivity and specific capacities of low yielding aquifer horizons is in the range of 4.42-398 m2/d and 0.1-1.25 l/s/m, respectively. Since these determinations apply only for low-capacity zones (low Transmissivity), cannot represent the entire project area. Plotting of the Transmissivity map of the project area and calibrations of the modeling work to be conducted requires representative more pumping test results from the rest of the high yielding aquifer systems. Accordingly, ten test wells were drilled with large diameter and thus appropriate submersible pump was used to determine the required hydraulic parameters. The Transmissivity and specific capacities of aquifer horizon is then modified and in the range of 3.1m2/d – 6665 m2/d and 0.05- 24.54 l/s/m, respectively. This was recorded at Lega Anga and Melka Sadeka sites respectively, which are located at recharge and discharge areas of the project.

Table 44- Borena Borehole Characteristics

No.	Well ID	Location X	Location Y	Location (GPS) Z, elevation, masl	Depth (m)	Static Water Level(m)	Discharge (l/s)	Draw Down(m)
1	*NBTW-6*	290068	487279	908	441	46.83	71	59.25
2	*NBTW-5*	300532	510052	1000	470	17	50	50.86
3	*NBTW-12*	337939	454121	740	256.9	78.53	46	85.73
4	*NBTW-8*	389315	520647	1252	302	104.3	41	128.11
5	*NBTW-9*	360943	505273	1121	186	112	40	113.63
6	*BH2WF1V1*	389741	520258	1241	301	101	31.8	93.49
7	*Utalo WF1V6*	389603	520504	1252	284	102	28	107
8	*Utalo WF2V2*	385739	525759	1258	295	101	28	127
9	*NBTW-11*	338613	505449	950	173	92	27.2	125.24
10	*NGW-2*	362488	507038	1124	218.7	130.47	22	157.72
27	*NBTW-10*	359028	542560	995	602	96.5	18	165.97
19	*NBTW-1*	311927	557149	1307	282	34	17.72	115.14
11	*Bokku-moyale*	464747	428688	1243	92	37.3	16	43.87
12	*kella qufa*	421636	583984	1493	70	13.2	15	18.2
20	*NBTW-7*	310921	475280	873	403	109.45	15	175.45
21	*GW2*	362519	506349	1130	181	95	15	124.32
22	*GW4*	361707	505679	1125	187	98	15	120
23	*GW3*	358637	506621	1132	204	94	14	129
28	*Mexi*	452994	407754	1205	70	2	14	16
13	*Dusse#2*	497468	498425	1107	145	16.7	13	23.33
14	*Boku-moyale*	464747	428688	1123	92	37.3	13	43.87
24	*NGW-1*	362521	507901	1136	204	132	13	172.07
25	*NBTW-3*	305256	548785	1232	416	45	11.11	128.93

26	*NBTW-4*	305869	526340	1097	492	48.6	10.19	140.43
15	*Dusse#3*	497471	498434	1109	127	16.1	8	44.75
16	*Gollole*	338312	566152	1121	158	32	8	54
17	*Cholkasa*	408298	550547	1550	83	25	7	40
18	*H/Samaro*	439393	449249	1396	88	38.43	6.3	63.93
29	*Gaale*	452446	458161	1105	100	8.35	6	66.54
30	*Marmaro*	306345	522346	1056	400	67	6	214
31	*Kafara*	458155	538061	1374	138	38.7	5.6	71.7
32	*Dida Xuyura*	413526	547756	1536	80	12	5	30
33	*Romso*	425075	447473	1580	70	36	5	38.7
34	*NBTW-2*	313602	545518	1351	500	75	4.7	181.4
35	*WDW2*	351284	495846	1011	215	133.48	4.2	148.01
36	*Melbana*	437300	434226	1385	100	21	4	31
37	*Dolollo hola*	406927	540254	1587	75	37	4	47
38	*Eloye*	378680	548496	1390	84	35	4	59
39	*Haro bake*	412311	550859	1521	72	18	3	42
40	*NGW-3*	363480	506842	1134	197	132.34	2.8	171.43

2.3 Aquifer Systems (Aquifer Classification and Characterization)

Aquifer classification of the project area is done using available data. During previous studies of OWWDSE 2011, three classes of aquifers were identified. However, using the previous studies as base this work classified the aquifers into five classes. Accordingly, these classes of aquifers have been identified based on their aquifer characteristics, lithological nature (texture, jointing and fracturing), and geomorphological setup and the effect of the secondary structures. Accordingly, where there is available aquifer test data (pumping test) aquifer parameters are derived which enabled grouping of different rocks to one aquifer class depending on the similarity of the Transmissivity. Further, the classification is based on the rock nature in which the rocks are whether intergranular or consolidated hard materials are identified first. The size of the aquifer is also taken into consideration.

2.3.1 Extensive Fractured Volcanic Aquifer with High Productivity

This aquifer class is extensive with several drilled wells in this section and have fully penetrated the aquifer section. The recently drilled boreholes; NBTW-5, NBTW-8, NBTW-9, NBTW-10, NBTW-11 and NBTW-12 were drilled in this aquifer class. The max depth drilled was 602 m (NBTW-10), which has intercepted the basement rock and total basal thickness is 236 m. The top superficial alluvial deposit is 194 m thick while the bottom layer is 172 m thick Gneiss. This borehole is tested with 18 l/s and the aquifer parameters derived show Transmissivity of 8.74 m2/day. The water quality result of this borehole shows a TDS value of 1416 mg/l.

The Bulal Basalt favors groundwater recharge and movement due to the highly vesiculated, fractured and jointed rock structure with very wide aperture up to 70 cm. However, as results of tests for water quality of few boreholes in this formation/aquifer indicates, the high TDS value is attributed to the dissolution of carbonate infilling materials (travertine). Further, the thermal groundwater has dissolution effect increasing the salinity of the groundwater in the direction of groundwater flow. For instance, during pumping test of the test well NBTW-10, the water temperature showed that it is thermal with 40 0C, indicative of the deep fracture effect contacting deep heat source (volcano).

Other borehole (BTW-6B) drilled to the depth of 294 m downstream was tested with 9.3 lit/sec has an increased TDS up to 4160 mg/l. The temperature however is only 35 0C which is probably due to its shallow depth compared to borehole NBTW-10.

Test wells drilled at Megado/Albor area, which is located in eastern extreme of the project area are with the depth of 214 m (BTW-4A) and 109 m (BTW-4B), respectively. Both wells penetrated through fractured basalt and vesicular/scoraceous basalt. Their SWL is about 75 m, and borehole BTW-4B was provisionally tested with 22 lit/sec for 1.5 hour with no or little drawdown. The later borehole has partially penetrated the basalt while the former one struck the basement rock (gneiss). This area is one of the places where the groundwater flow merges and exits from the boundary of the project as well as the country, and therefore it is one of the high potential zones on which detail geological and hydrogeological needs to be conducted at well field scale. Within a short distance of about 12 km to the northwest BTW-1 was drilled to the depth of 210 m at Furole locality. It penetrated through alternating layers of scoraceous basalt and fractured basalt with only 2 m thick clay soil at the top. The SWL of this borehole is 85 m and was tested with 3.8 lit/sec. The water quality result indicated that it has very high TDS groundwater up to 5500 mg/lit. The TDS of BTW-4A on the other hand is relatively lower up to 1239 mg/lit. Therefore, the above contrasting result of the boreholes within a few distance intervals might attributed to the presence of barrier formation or structures that prevents groundwater mixing. Hence, detail study on the surrounding rocks, maars, geological structures and geomorphological setup for the source of high TDS and its dynamic controls will be carried out in the detail 1:50,000 scale map for the well field investigations.

BTW-10 and NBTW-11boreholes are drilled in the central project area along Ririba main fault to the depth of 161 m and 174m respectively. Both have the same with a SWL of 91 m. But, the optimum yield observed in NBTW-11 is 27.2l/s while a discharge of 19 lit/sec pump capacities observed in BTW-10. It penetrated through the alluvial deposit up to 38 followed by fractured and weathered basalt, vesicular basalt and scoria to the depth of 140 m. The rest bottom section is gneiss.

NBTW-12 borehole is drilled to the depth of 256.9m in the outlet of this aquifer class at Melka Sadeka locality, about 15km southwest of Goray town. The optimum yield measured here is 46l/s against 7.2m drawdown. At this site the maximum Transmissivity and hydraulic permeability was determined; 1380m2/day and 17.1m/day respectively. Thus, this site was confirmed that the Ririba main fault has great role on occurrence, movement and storage of groundwater. On the other hand, one borehole (NBTW-8) was drilled almost at the recharge area on the eastern plain of the main Ririba fault. In this well an optimum yield of 42l/s and 23.81m draw down was observed. The depth of the well is 304m of which the bottom 48m is crystalline basement rock. In the preceding work, there was one dry well (BTW-5) drilled to the depth of 112m just at downstream of this high yielding well. On one hand, the high yielding well is located at the highland plain near to the basement boundary; recharging region. Thus, such high yielding and dry well within the same geologic set up needs special attention further research work on the particular area of Utalo.

There are more boreholes drilled in this aquifer class in the central of the project plain. For instance, WDW-1, WDW-2 and BTW-8 at Wobok/Dambala Dara locality near or along stream channels. The lithological information obtained from these wells show that alluvial deposit overlies the various volcanic rocks including basalt with varying degrees of weathering and fracturing and scoria. All the wells reached the basement rocks (gneiss and granitoide). Well depths are 215 m at WDW-1 and BTW-8 while 171 m at WDW-2. The SWL is deeper at WDW-2 and BTW-8 which reach up to 153 m and 167 m, and they are tested with 4.2 and 3 lit/sec, respectively while SWL is only 120 m and discharge of 14 lit/sec is attained at WDW-1. The Transmissivity derived from these wells is high up to 476m2/day at WDW-1 and is very small up to 14m2/day at BTW-8.

Most of the wells are swarming the area around Gelchet. Groundwater flow at this point is east-west. An increasing well yield is observed from BTW-3 and Gobso wells with 3 lit/sec to GW-1, GW-2, and GPW-2 with 17, 15 and 12 lit/sec even for relatively shallow drilled depths. The yields of boreholes of Gelchet boreholes are low only up to 4 lit/sec (e.g. BTW-3, Goboso, BTW-8 and WDW-2) where the groundwater flow amount is small. That means the groundwater is controlled both by lithology and structure, takes a round route following a constricted area along Gelchet valley north of Kenchero, finally making its destiny along Ririba rift. As it is shown on the Hydrogeological map (Figure 82), the Wobok-Dillo boreholes are situated outlying in the south of the groundwater flow lines indicated missing most of the flow so that low yield is encountered with respect to Gelchet area that lies along the main groundwater flow lines. Further, it is located nearby the gneissic Kenchero Mountain, which is less affected by geological structures where as that of Gelchet area is structurally highly affected.

BTW-9 drilled at Gocha locality for 250 m recovered basalt of various degrees of weathering and fracturing throughout its whole section, with massive basalt at various depths. During drilling circulation loss was encountered at the depths of 30 m and 82 m probably due to the presence of fractures. The SWL is 82 m and it was tested with 7.5 lit/sec. Downstream along a different stream channel, BTW-11 was drilled at Wobok locality to the depth of 237 m, and it penetrated through fractured and weathered basalt and vesicular basalt which are at certain depths separated by massive basalt. Only thin clay soil probably reworked from the weathering of tuff is found at the top and bottom of the well. Here the SWL is indicated to be 143 m and it was tested with 6 lit/sec. This area is characterized by the presence of massive basalt at depth which plays the role of limiting the storage of water, and these two boreholes show that the Bulal basalt varies both in its lithological characteristics and hydrogeological nature in yielding water.

NBTW-5 and BTW2 were drilled in Mermero locality to the depth of 472m and 141 m respectively with 18m of SWL at both wells. The lithological log description shows that the thickness of alluvial deposit constituted of coarse and medium gravel is 62 m followed by massive basalt and varying degree weathering and fracturing of basalt underneath. The most thickness of the volcanic is basalt, scoria and ignimbrites. These boreholes have not intercepted the basement rock so that its maximum thickness in this specific locality is not known yet. It is indicated that the main water strike is 79 m, and may be the gravel has only little water. The aquifer parameters are derived for the large diameter deep wells (NBTW-5) and are 510m2/d of Transmissivity and 3.02m/d hydraulic conductivity. The optimum yield obtained in this well is about 50l/s contained by drawdown of 33.86m.

2.3.2 Extensive Fractured Aquifer with Moderate to High Productivity

The lower volcanics (Taltale basalt), the middle volcanics, the upper volcanics, Soda Belo volcanics and Gorahe basalt are grouped into this class of aquifer. The characteristic situations with the indicated rocks are that they mostly occupy elevated area except for the lower Taltale basalt which dominantly occupying the plains of Taltale area that dissected by west-east trending nearly parallel lineaments followed by intermittent streams. Further, the fractures in these rocks are dominantly veined by calcite that retards groundwater storage and movement that is confirmed particularly at north of Bule Denbi area whereby spring manifestations are observed at the contact of the lower volcanics with the basement rocks.

There are no or few shallow boreholes drilled in these rocks, and it was considered initially of this class of aquifer to be with low to moderate productivity. However, the recently drilled test well at Bule Denbi/Taltale locality (NBTW-1) penetrated through the lower volcanics of the Taltale basalt to the depth of 208 m and the basement rock (gneiss) up to 282 m. This borehole was fully tested for 72 hours with an average of 20 lit/sec. This indicates that although most of the nature for this rock is dominantly not suitable for defining it as high productive aquifer, a good deal of water could be tapped from these rocks locally with a provided conducive environment (as with this borehole). The water quality analysis result shows that the water is soft and relatively fresh with TDS result of 454 mg/l. There are also other two test wells drilled in this aquifer, at Elkune (416m) and at Laga Anga (502m). The first one is located in the center of Taltale basalt plain whereas the second one is located nearly at the surface water divide of Segan sub basin and Balal sub basin. The optimum aquifer yield observed from pumping test is 11.11l/s and 4.7l/s respectively.

This aquifer is fracture controlled that some of the boreholes drilled at Elkune (BH-74) to the depth of 183 m, Birindar to the depth of 125 m, and Dhaka Kala to the depth of 200 m are with relatively low discharge with 4.67 lit/sec, 4 lit/sec and 1 lit/sec, respectively probably due to limitation of groundwater storage and movement within the rock primary matrix. Detail borehole information of these wells is not available. Borehole drilled in the Soda Belo volcanics (Sarite/Gewisa Borehole) has given only a yield of 3.25 lit/sec.

2.3.3 Local Inter-granular Aquifer with Moderate Productivity

This class of aquifer is restricted to river or stream channels and alluvial fans. As described in detail in the geological section of the geology report (Volume-II), they are not significantly thick and they reach up to 6 m thickness over most of the plains. These aquifers form shallow groundwater which could yield to hand dug wells and springs where there is massive contact rock beneath. Otherwise, they only act as transmitting media to the aquifer underneath.

However, this aquifer is thick in the northeast of Gelchet potential site as observed in Harewayu borehole that is drilled to the depth of 150 m with alluvial deposit of about 125 m thickness, which was also indicated to be buried river channel. And its SWL is 54 m and the yield is 9 lit/sec. The high hardness of the water tapped from this borehole is attributed from the presence of high sulphate which is either from dissolution of travertine or calcite minerals in the basalt.

In general, this aquifer system is alluvial deposits exist mainly along the river channels and flood plain areas. In most of the areas, their thickness ranges from about 2 m to 40 m, while in the borehole sections at the localities of Mermero, Brindar and Harewayu thicknesses 65 m up to 125 m were recorded. The thick depositional environments are believed to be zones of old river channels. Gradation of the deposit from clay and silt to coarse sand and gravel at their bottoms gives it to possess moderate to good permeability. However, the unit forms localized aquifers only when it rests over the basement unit. Over the volcanic, since the underlying basalt formation is highly fractured and permeable together with the position of its saturated zone below the sediment and rock contact, groundwater could not be stored in the alluvial. Therefore, here it acts as infiltration media to the underlying Bulal aquifer.

2.3.4 Extensive Intergranular Aquiclude with Leaky and Low Productivity Aquifer

The superficial deposits and/or the Elluvial soils grouped under this system have fine sand and clay content which makes it to possess poor permeability and has no hydrogeological significance. This covers an extensive area overlie the high yielding aquifer of the Bulal basalt act as transmitting media to the underlying aquifer, and they also play the role of confining it. Borehole logs show that basalt is found at certain depth below this deposit, and due to their difference in their lithological characteristics (origin, texture, fracturing, etc.) these deposits are classified to separate group.

There are many boreholes penetrating through the surface exposed lithology, but the water strike depths indicate for most of them that the main aquifer is basalt. The role of this aquifer class is generally as transmitting media and/or aquiclude. Most of the underlying basalt aquifer in the plain lands show low groundwater storage is observed where it is less affected by geological structures, whereas high groundwater storage is observed where dominant interconnected structures prevail underlying this class. Therefore, this class can be treated as Aquiclude with Leaky aquifer.

2.3.5 Regional Aquiclude with Localized Aquifer in Fractured and Weathered Profile of the Basement Rocks

Due to its inherent poor permeability, basement rocks are generally known to be non- aquifers. However, at localities where the rock mass is intensively fractured and weathered, or along open fault zones connected with recharge sources, it can form localized shallow aquifer system. Though it lies in outlier of the study boundary, Dubluk area can be mentioned as example. Within and adjacent to the considered volcanic aquifers, the important role of the basement unit is as bottom boundary to the Bulal and Taltale lower aquifer acting as regional aquiclude, to block the deep vertical percolation of groundwater and hence helps storage within the overlying basalt and in the top weathered basement. However, the most upper thin weathered portions of the basement below the Bulal and Taltale lower basalt could bear groundwater and can be included to contribute to the main volcanic aquifer that was confirmed from the recent test wells drilled at, Utalo, Gelchet, Liso/Ririba, Melka Sadeka, Sarite and Bule Denbi sites.

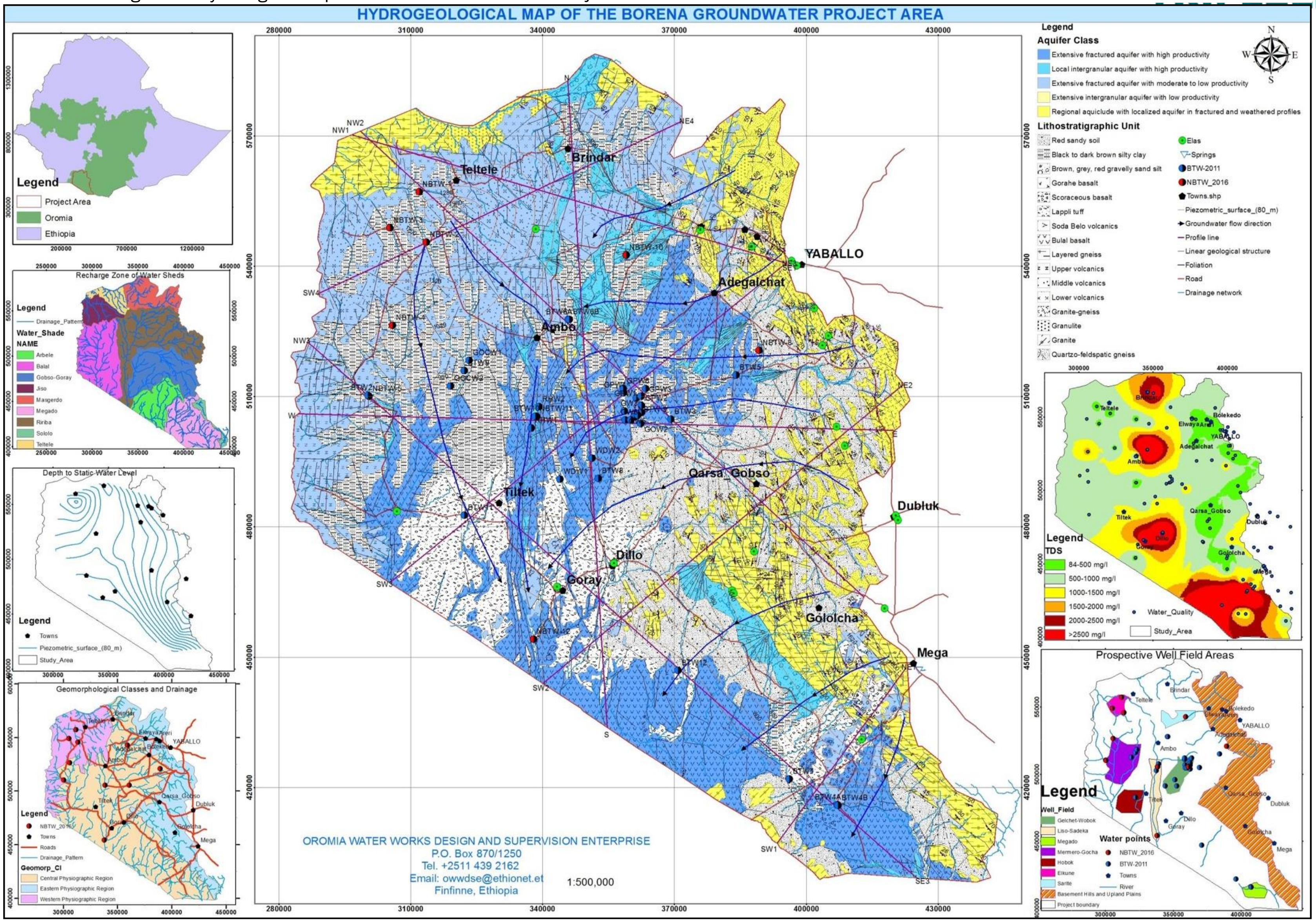
The hand dug wells are found only on the weathered portion of the layered gneisses specifically in the northeastern portion of the area based on the available data since these rocks act as massive aquifuge holding the water at top. It is therefore, expected that the groundwater is found at shallow depth acting as groundwater recharge zone for aquifers lying in low-lying areas. That is groundwater flows through the top weathered layer and fractures basements that gradually deepen to the lower elevated volcanic aquifers as indicated with imaginary groundwater flow directions from Utalo via Gelchet to Ririba Rifts. The Hydrogeological map and hydrogeological profiles along several profile lines are shown in figure 82.

2.4 Groundwater Occurrence and Movement

Different studies made in the area prior to the groundwater potential assessment of south and southwest of Yabello town have indicated that groundwater exists within alluvial deposits, weathered and fractured volcanic rocks, weathered and/or fracture zones of basement rocks. However, the study conducted by OWWDSE (2007-2011) shows that substantial amount of water stored in thick fractured or jointed Bulal basalt directly overlying the crystalline basement rock. This leads to the current project work and thus occurrence of very high groundwater potential in the volcanic of Bulal basalt and Taltale basalt was confirmed.

The groundwater flow pattern of the project area depicts the convergence of flow lines from the parts of eastern and western land blocks towards the rift center, as it ultimately flows southwards towards the Ethio-Kenyan border along the rift zone (Likissa, 2012 and OWWDSE, 2011). The respective hydrogeological profiles in Figure 82 shows that the depth to the groundwater surface (piezometric surface) is deep at the margins following topography, but relatively shallower at the center which is also due to effect of confinement of the aquifer. Groundwater is discharged from the area in the form of small springs, boreholes abstractions and flows through permeable structures and aquifer formations towards general south. Groundwater out flows to deeper horizons along the major fault zones, open fractures and volcanic centers (maars) is anticipated to be a significant phenomenon in the area, apart from flows within the general aquifer medium.

Figure 81-Hydrological Map of the Borena Groundwater Project Area



Annex 4: Groundwater Balance Analysis

1.0 GENERAL

The recharge potential of groundwater depends on a variety of factors, including precipitation volume and variability, surface water run-off and the transmissivity of sediments (and therefore the rock types). Therefore, knowledge of the geological and hydrogeological regimes is decisive in the planning of groundwater development. The recharge potential of groundwater can be estimate

The Groundwater balance is defined by the general hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrologic cycle. The rate of Change of Water storage is the Inflow minus outflow. A ground-water system consists of a mass of water flowing through the pores or cracks below the Earth's surface. This mass of water is in motion. Water is constantly added to the system by recharge from precipitation, and water is constantly leaving the system as discharge to surface water and as evapotranspiration. Hence, to understand the rate of storage to the ground, the recharge amounts and discharge has to be evaluated and/or estimated.

Recharge estimation methods are made via indirect techniques due to several reasons such as; heterogeneity of land mass, rock type, data availability amongst other factors. Among the several recharge estimation methods, the Darcy Approach is widely used for the Hydrogeological areas when relatively sufficient data is available and has been applicable for this study in the Kobo Girana Valley. There have been numerous research and studies conducted at the Kobo Girana valley which have generated relatively reliable data and thereof estimating Groundwater recharge can be treated using the Dracy approach.

However, for the Borena region, the Direct Precipitation Recharge Method was used to infer on the recharge amount mainly because of the limited data availability in the region[105]. Furthermore, the IPCC WGI Interactive atlas was used to for temporal and spatial analyses of trends and changes in key atmospheric and oceanic variables, extreme indices and climatic impact-drivers (CIDs). The direct precipitation recharge method uses surface water data such as rainfall infiltration, run off from the adjacent basement hilly regions and accordingly calculate the ground water recharge that percolates along the regional fault and or fracture systems. Direct infiltration of rainfall to the surface of alluvium/elluvium over the plain area is not the major component of recharge to aquifers as these are fine silty clay at the top with very low permeability. However, the thick alluvial deposits along the old river channels identified in annex 3 Geology and Hydrogeology would contribute to the substantial rate of recharge during the flood seasons.

2.0 KOBO – GIRANA GROUNDWATER BASINS

The distribution of the aquifers of the sediment basin in the Kobo Girana valley under consideration is treated separately inorder to generate a robust data analysis and accurate groundwater potential estimation. The assumption applied is that the movement of the groundwater is confined within each sub-basin confined in the sediment aquifers of the Kobo Girana valley. This assumption has limitation in undermining the possibility of inter-sub basin hydraulic connection in terms of recharge from the uplands and from underneath weathered volcanic formations which is believed to be negligible from the practical point of view.

[105] Gebrechorkos, Solomon & Bernhofer, Christian & Hülsmann, Stephan. (2020). Climate change impact assessment on the hydrology of a large river basin in Ethiopia using a local-scale climate modelling approach. Science of The Total Environment. 742. 140504. 10.1016/j.scitotenv.2020.140504.

2.1 Waja Golesha Sub basin

The Waja Golesha sub basin bounded from west by the western ridge from the south by Mendefera-Key Gara hills and from north it is in hydraulic connection with the Alamata plain and from east by Rama-Zobul ridge, the eastern escarpment. Geomorphologic ally the sub basin gets surface waters of Dikala Wenz from west, runoff from Key-Gara and Rama-Zobul ridge from east and direct precipitation into the plain area. The outlet of the sub-basin is the E-W faulting of the Western/Lasta plateau to Rama ridge at Selen Wuha together with the northern Raya valley on its northern boundary to Mehonie area.

2.2 Arequaite-Gerbi Sub Basin

Current investigation showed that the Area from Kobo Town to Gedemyu from south and Kobo-Zobul all-weather road to Mendefera-KeyGara from the north and Zobul ridge to the east is a closed sub-basin. In this area no hydraulic connection with the sub-basin Hormat Golina is detected. Both surface and sub surface drainage divide between Hormat Golina and Arequaite-Gerbi sub-basin from the southern side is the Kobo-Gedemyu path.

2.3 Hormat Golina Sub Basin

The Hormat Golina sub basin encompasses part of the Kobo Town, all the drainage area of Hormat and Golina rivers before they leave the Valley into Danakil Basin. This sub basin is bounded by Alawuha sub-basin from the southern side, the western mountains from western side and extension of Zobul ridge on the eastern side. The outlet of this sub basin is the Golina stream formed through the E-W fracture/fault line running from Weldia-Lasta Plateau to Zobul ridge.

2.4 Mersa-Giran Sub Basin

This sub basin drains the western mountains of Mersa and Girana and leaves through the Gelana river to Mille/Awash basin.

2.5 Delineation of Groundwater Potential Well Fields

Analyzing the geology and geometry of the land in each sub basins and the existing data on groundwater showed that the groundwater potential for irrigation and water supply source in Kobo valley is grouped into three forms, namely:

a) High potential area, which includes the Waja Golesha plain area mainly wellfields WF1, WF2, western part of WF3, WF4, the Hormat-Golina interfluves area which includes WF7, WF8 and southern part of WF6
b) Moderate potential area both in quantity and quality of groundwater which includes eastern part of WF3 in Waja Golesha
c) Poor groundwater potential area which encompasses the Kobo-Gerbi-Arequaite area (WF5) northern part of WF6 and the area north of Kobo town in Waja Golesha sub basin. The groundwater potential map is depicted in Figure 82.

2.6 Recharge Estimation

The investigation and previous data study indicated that the major recharge zones in the valley are sub-surface inflow from the western escarpments and ridges and recharge from direct infiltration from the runoff along river channels and remnant hills in the valley. Moreover, the Waja-Golesha and Hormat Golina sub basins are areas of focus. Kobo-Gerbi area is delineated as poor groundwater potential zone.

2.6.1 Darcy Approach

This approach considers groundwater flux through a flow width perpendicular to the general gradient of groundwater flow. The annual discharge of this groundwater can be estimated using the following formula.

$$Q = 365 * T * B * I$$

Where Q, T, B and I denote discharge (m^3/year), Transmissivity (m^2/day), hydraulic gradient (-) and groundwater flow channel width (m) respectively. Inserting the specific values into the above formula, gives the annual flow of groundwater in each sub basin. Using this approach, the annual flow/recharge in Hormat Golina including the Kelkeliti area is determined to be 41.1 MCM and that of Waja Golesha 31.2 MCM. The summary of recharge determined by Darcy Approach is tabulated in Table 45.

Table 45-Summary of Darcy Approach recharge estimates of Waja Golesha and Hormat Golina sub-basins

No	Sub-basin	Flow width, m	Flow line length	Delta in Water table elevation along the flow line	Slope of GW along the major flow line	Average Transmissivity	Flow in MCM
1	Hormat Golina						
1.1	Kelkelite	2,680	8,000	150	0.0188	400	7.3
1.2	Hormat and Golina	14,000	13,000	155	0.0119	600	36.5
2	Waja Golesha	13,000	14,000	118	0843	600	24.0
	Total from flow approach						67.8

2.6.2 Recharge Area Separation

According to different studies[106], [107], the estimated recharge through the river channel of main rivers (Golina, Hormat, Kelkeliti and Gobu) to be 6.26 MCM and from runoff of remnant hills 0.6 MCM. However, the current investigation showed that no recharge from rivers to the groundwater rather the groundwater feeds the river. Therefore, no recharge component from rivers is considered in this report and a 20 hour per day pumping regiment is considered to stretch the estimatation conducted and to ensure that high level of climate variability is accounted for in to the future, thus landing at very conservative MCM figures. Other water balance studies that have been conducted in the same area which account for recharge element from the rivers with 8 hours of pumping per day and using MODFLOW modelling software estimate the ground water reserve at 95 MCM and 83 MCM for Hormat Golina and Waja Golesha respectively[108].

Another recharge source to the plain area is direct infiltration from precipitation mainly during torrential rainfalls. The annual precipitation determined from Hydrology report of the same project is about 800 mm. In this study the annual infiltration rate is taken to be about 5% (40 mm) of the precipitation. The

[106] Tafesse, Nata & Nedaw, Dessie & Woldearegay, Kifle & Gebreyohannes, Tesfamichael & Steenbergen, Frank. (2015). Groundwater management for irrigation in the raya and kobo valleys, Northern Ethiopia. 8. 1104-1114.
[107] Adane, Getahun. (2014). Groundwater Modelling and Optimization of Irrigation Water Use Efficiency to Sustain Irrigation in Kobo Valley, Ethiopia.
[108] Adane G.W, Groundwater modeling and optimization of irrigation water use efficiency to sustain irrigation in Kobo V alley, Ethiopia (2014), Thesis Master of Science, UNESCO-IHE Institute for Water Education, Delft.

surface area of the plain area of Waja-Golesha and Hormat Golina sub-basins is 165 and 231 km^2, respectively. Therefore, the direct infiltration on these sub basins is estimated to be 9.24 MCM for Hormat-Golina and 6.6 MCM for Waja-Golesha.

In conclusion, the total recharge in Waja-Golesha and Hormat-Golina sub-basins of Kobo valley is estimated to amount 84.24 MCM.

2.7 Recharge-Discharge Balance of the Kobo Girana Valley

a) The general mass balance principle implies that inflow is equal to outflow at equilibrium condition. The annual recharging amount is expected to be discharged.
b) The draft hydrology report of Kobo valley under this same project estimated annual runoff at Golina outlet to be 61.8 MCM. This outlet includes the flows from Hormat and Kelkeliti rivers which eventually feed to the Golina outlet.
c) The Gobu stream feeds the Waja Golesha plain. The annual runoff determined for this stream is estimated as 44 MCM at the upper part and disappears in the plain downstreams.
d) According to the Feasibility Hydrology Report 1999 by CoSAERAR as cited in GES, 2003 Hydrogeological Appraisal Report, the infiltration rate of Gobu to the subsurface is 20% of the runoff which is 8.8 MCM.
e) According to the water table map shown in previous section produced under this project for Waja Golesha sub basin the groundwater flows to Selenwuha out let direction. The Waja-Golesha wellfield discharges to Slenwuha direction along a 6 km flow boundary. The transmissivity and water table gradient values at the boundary are the same as for the Waja-Golesha plain. Hence, the flux/discharge from Waja-Golesha to Raya Valley equals about 14 MCM. The remaining about 21 MCM runoff from Gobu is balanced by evapotranspiration and partly used in the groundwater abstraction for community water supply and irrigation. The flow from Dikala stream disappears in the plain north of Kobo around the Garalencha catchment. This amount is considered in the flux width during recharge estimation of Waja-Golesha sub basin.
f) Currently, out of the estimated annual recharge of 84.24MCM, 75.8 MCM or 89 percent of the water is discharged through Golina outlet as surface water and through Raya boundary as subsurface outflow. The difference of 8.44 MCM or 11 percent of the recharge amount that is captured on the surface is being utilized by the community during the study period.
g) A 2.5% annual population increase projection was used to incorporate the community water demand, which will be increased to 14 MCM in 20 years or 16 percent of the current recharge amount and not tapping into the reserve. Therefore, the net groundwater recharge within Waja Golesha and Hormat Golina sub basin will be 70.24 MCM (hence, the difference between 84.24 MCM and 14MCM is 70.24 MCM)

2.8 Groundwater Reserve in Kobo Valley

The total subsurface water reserve is a function of saturated thickness and storage coefficient/specific yield. The aquifer system is generalized into water table aquifer of the sediment. The average saturated thickness is 139 m in Waja-Golesha and 107 m in Hormat Golina sub basins.

The groundwater reserve is computed applying the following formula.

$$V = Sy * A * H$$

Where V, Sy, A and H denote reserve (m), specific yield (0.1 for kobo valley), surface area of the aquifer (m2) and saturated thickness (m) respectively.

The groundwater reserve in Waja Golesha and Hormat Golina sub basins is summarized in Table 46.

Table 46-Static Condition Groundwater reserve in Kobo valley

Sub basin	GW potential area (km²)			Average saturated thickness (m)	Ground water reserve (MCM)
	High	Moderate	Total		
Waja-Golesha	65	20.6	85.6	139	1,189.84
Hormat Golina	96.3	30.7	127	107	1,358.9
Total	161.3	51.3	212.6		2,548.74

2.9 Conclusion

Based on the availability of the groundwater from the reserve and the recharge and the amount that is discharged to the surface and extracted for irrigation purposes, the following assumptions have been applied;

- The radius of influence and well interference is nil as the distance between the 60 boreholes considered for this project and the additional 176 boreholes is beyond 500 meters.
- Annual groundwater abstraction has been assumed 50 liters per second for all 60 wells (0.26 MCM per well) when extracted for 8 hours pumping rate per day and a period of six months/annum.
- Considering a total number of 60 wells in the Kobo Girana valley targeted for this purpose, a total of 15.6 MCM of ground water will be extracted per annum from a total recharge of amount of 84.24 MCM
- Thus at the current rate, also considering the amount extracted by the community, which is 8.4 MCM/annum in addition to 15.6 MCM/annum for the irrigation system, a total amount of 24 MCM of ground water will be extracted per annum leaving a net discharge of 60.24 MCM to the surface.
- Considering a 2.5% population increase, linear extrapolation of the water demand of the community will increase to 14 MCM/annum in 20 years. While this approach does not put into consideration of increased water demand as a result of improved livelihood and income, based on this approach, the total amount of ground water extracted will increase to 39.4 MCM/annum, still leaving a net amount of 44.84 MCM as a runoff to the surface.
- The water balance study based on baseline scenarios and putting the implementation of this project into consideration thus estimates that a net 48.84 MCM will be available as a run-off without tapping to the existing ground water reserve of 2,548.74 MCM, which will remain the same after 20 years, the life of this project.

3.0 BORENA - GROUNDWATER BALANCE

Due to data limitations prevailing in the Borena region, an alternative method called "Environmental isotope hydrology" analysis was used in the Borena region to identify three recharge mechanisms. These are direct precipitation recharge, regional groundwater recharge and/or fast selective recharge from intensive rainfall and flash floods recharge mechanisms, Likissa Fanta (2012), unpublished MSc Thesis.

$$\mathbf{GWrch = Rt - Q\ surt - ET\ t \left(\frac{+}{-}\right) SWt}$$

Where

- GW_{rch} = *recharge to the groundwater*
- R_t = *rainfall depth that occurred within time t*
- Q_{surt} = *surface runoff depth that occurred within time t*
- ET_t = *Evaporation Rate to the atmosphere*
- SW_t = *soil moisture retained or released within the time t*

In arid and semiarid regions similar to the study area, application of water-balance is more difficult than in humid regions because precipitation is frequently and slightly different from actual evapotranspiration; small errors in these two components thus cause large errors in recharge estimates. In addition, the area is a fractured terrain and structurally controlled where using Darcian method is not applicable to determine recharge. Thus Recharge estimation requires proper understanding of the mechanisms of flow and the interactions of ground and surface water nexus.

The major component of water balance in surface and groundwater recharge estimation is the amount of precipitation occurring on the land surface, the amount of water absorbed back to the atmosphere and the amount held with the soil pore space. The amount of water held in the soil pore space is either taken up by plants or freely draining to the underlying soil strata.

3.1 Groundwater recharge estimation

Groundwater recharge estimation for Borena area was made using widely applicable models that can estimate hydrological elements such as surface runoff, sediment yield, and groundwater recharge. The common models are Hydrologic Simulation Program Simulation FORTRAN (HSPF), Surface Water Modelling (SWM), Agricultural Nonpoint Source Pollution (AGNPS), the Agricultural Nonpoint Source Watershed Environment Response Simulation (ANSWERS), and Soil Water Assessment Tool (SWAT), where the underlying difference lies on the intended purposes and data availability.

For the purpose of water balance studies in the Borena region to use ground water for irrigation purposes, the SWAT (Soil Water Assessment Tool) model is practical. SWAT models generate long term computationally efficient watershed model with the capacity to estimate surface runoff, evapo-transpiration, soil moisture and percolating water (part of groundwater recharge) in the presence of limited climate data, land use and soil data. The model is suitable for the Borena scenario to generate a soil water balance model.

After setting up the model using the weather data, land use and soil data of the study area, the model default values on curve number has been edited based on theoretical values. One of the major sources for spatial variability of runoff in watershed scale modelling is the soil physical characteristics. With availability of all the required land use and soil parameters, the model was set up and the spatial and temporal pattern of the annual soil moisture depth (mm), annual surface runoff depth (mm) and annual groundwater recharge depth (mm) was estimated.

3.1.1 Sub basin analysis

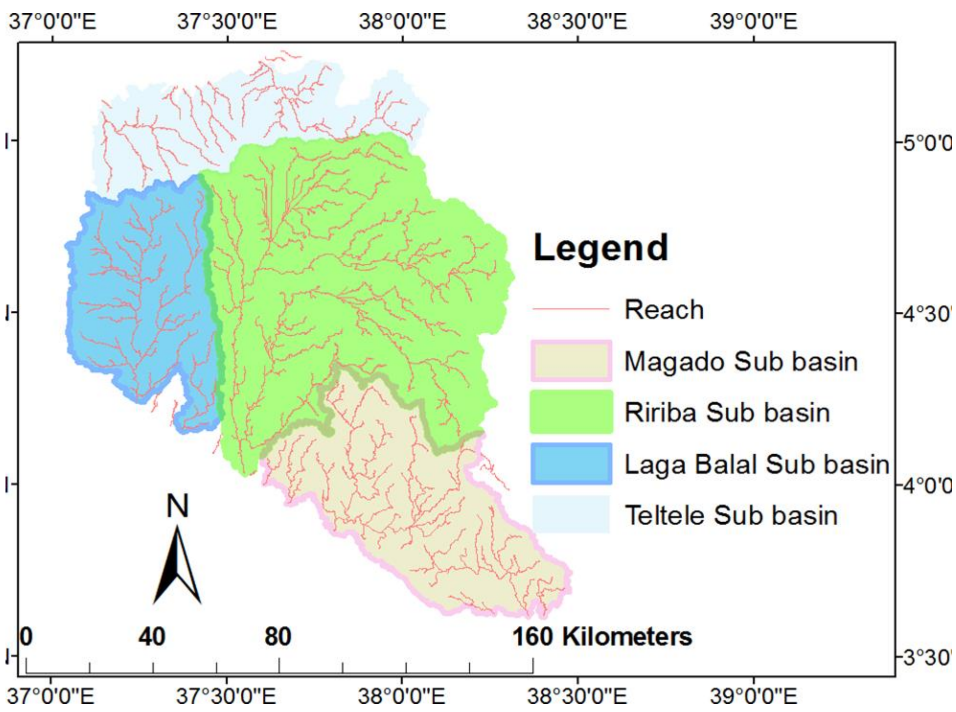
In order to estimate the hydrological characteristics, the entire study area was divided into sub basins. The land areas with similar land use and soil type within the sub basins were thus further sub divided in to two or more land units called Hydrologic Response Unit (HRU)s. The HRUs are the basic building units for study and analysis of hydrology including surface runoff and groundwater recharge.

The SWAT model was thus run to estimate the basic water balance component (surface runoff, Evapo-transpiration, soil moisture and groundwater recharge). The entire study area was divided in to 664 small catchments with each unit being considered for analysis based on dominant hydrologic response unit (HRU). Four major sub-basins (Laga Balal, Taltale, Ririba, and Magado) have been delineated for analysis purpose, (Figure 83). The size of the sub-basins has been calculated,

Table 47 – Size of the Sub-basins

S/No	Name of sub-basin	Area(Km2)	% of the study area
1	Laga Balal	2,839.70	16.77
2	Ririba	7,282.60	42.97
3	Magado	4,189	24.72
4	Taltale	2,635.90	15.55
Total		16,947	100

Figure 82- Borena Area Sub basins



The interaction between the atmospheric, surface and subsurface flow phenomena has been considered for instantaneous soil moisture variability and thus the monthly moisture excess or deficit is hard to summarize from the result of physically (semi) based models including SWAT2005. Thus, priority has been given in determining the major water balance components which are independent soil physical characteristics. These components are the RF, PET, ET, RO and RCHRG.

The variability of the water balance components including recharge rate is not limited only to spatial aspect, but significant variability has been observed on temporal scale. In the area, maximum recharge is reached in months of April, October and November which has direct correlation with occurrence of rainfall.

Table 48-Monthly Hydrological Water Balance Components

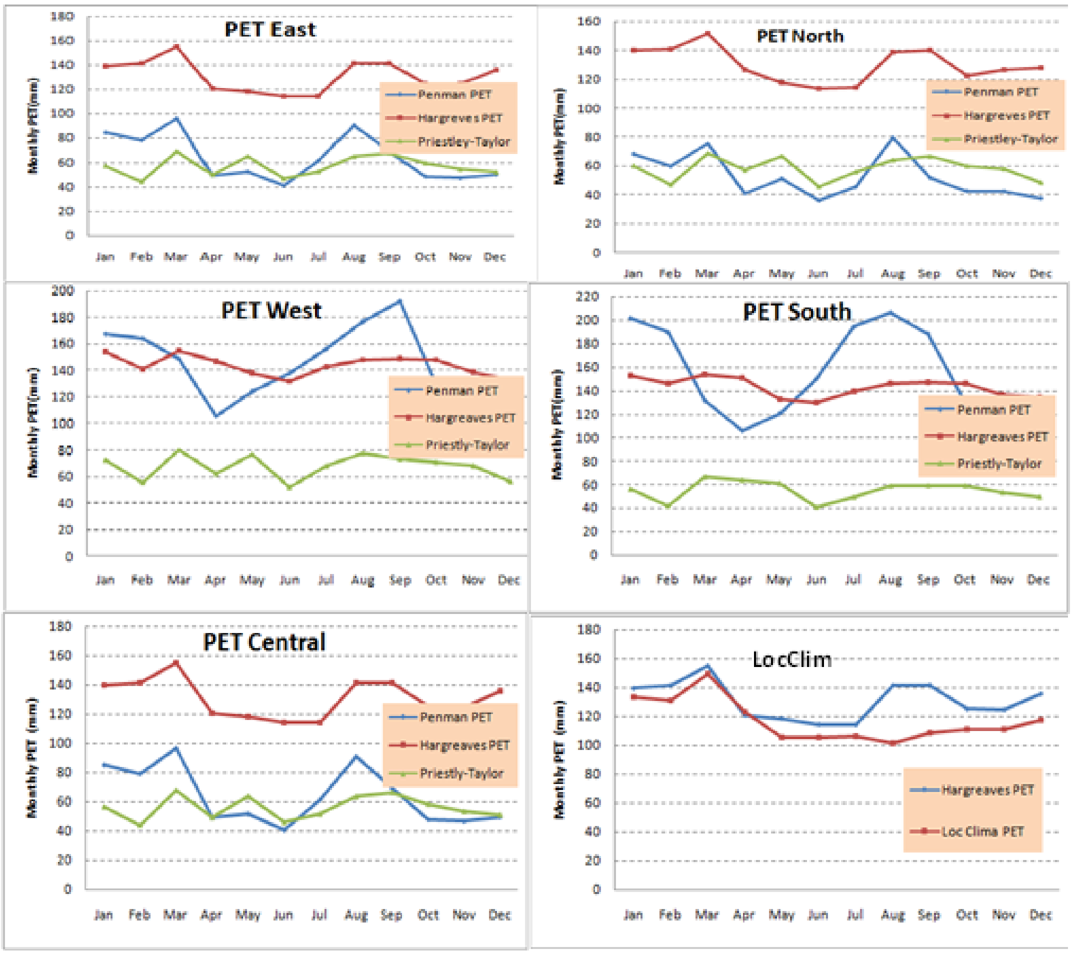
Sub basin	Month	RF	PET	ET	RO	RCR G	Sub basin	Month	RF	PET	ET	RO	RCR G
Laga Balal	Jan	1.1	161.9	18.7	0.0	0.0	Magado	Jan	23.6	164.7	20.7	0.1	0.0
	Feb	0.5	139.3	13.9	0.0	0.0		Feb	43.3	155.5	11.4	0.0	2.1
	Mar	33.4	139.5	45.0	0.0	0.2		Mar	75.3	139.1	53.8	2.1	0.0
	Apr	89.9	58.8	48.4	1.0	10.0		Apr	158.	66.5	35.7	16.8	8.2
	May	98.4	83.6	62.9	2.7	7.3		May	93.9	79.4	45.2	3.9	0.5
	Jun	6.8	110.8	39.6	0.1	0.0		Jun	30.6	86.7	43.4	0.0	0.0
	Jul	11.2	122.8	21.6	0.0	0.0		Jul	34.1	86.0	41.6	0.0	0.0
	Aug	16.9	154.2	27.4	0.0	0.0		Aug	21.9	172.5	32.6	0.0	0.0
	Sep	20.9	201.7	27.7	0.4	0.1		Sep	20.0	181.0	15.6	0.0	0.0
	Oct	128.	86.2	45.1	3.1	9.5		Oct	92.0	81.6	20.3	3.1	5.2
	Nov	38.8	93.3	50.7	1.0	2.0		Nov	66.7	79.9	23.0	0.2	2.0
	Dec	62.4	297.3	66.5	2.0	5.5		Dec	27.0	263.5	25.6	0.0	0.0
	Total	509.	1649.	467.	10.3	34.5		Total	688.	1556.	368.	26.3	18.2
Ririba	Jan	10.6	178.1	18.1	0.1	0.1	Taltale	Jan	36.1	165.5	18.0	0.0	0.0
	Feb	3.3	158.2	8.4	0.0	0.0		Feb	56.2	150.1	17.1	0.0	0.0
	Mar	73.9	134.0	45.2	0.9	8.4		Mar	85.6	186.0	27.4	0.7	0.0
	Apr	130.	67.3	43.1	6.2	20.6		Apr	158.	80.9	45.3	6.1	4.7
	May	100.	89.5	51.0	2.0	14.6		May	85.7	126.6	63.0	12.4	1.3
	Jun	25.3	99.5	45.3	0.4	2.8		Jun	47.4	133.3	50.0	0.1	0.7
	Jul	18.6	97.6	31.2	0.0	0.4		Jul	31.3	95.3	30.4	0.1	0.1
	Aug	3.9	173.2	19.2	0.0	0.1		Aug	28.2	182.8	38.0	0.6	0.1
	Sep	57.7	166.2	32.6	4.5	9.1		Sep	56.0	126.6	27.5	0.6	0.5
	Oct	65.1	76.8	32.6	1.1	9.4		Oct	84.8	75.4	36.4	6.8	0.6
	Nov	50.9	84.4	26.8	3.7	7.2		Nov	51.7	93.8	35.2	3.6	3.0
	Dec	8.5	257.2	29.5	0.3	1.7		Dec	29.2	167.4	37.6	9.7	1.2
	Total	548.	1581.	382.	19.2	74.5		Total	751.	1583.	425.	40.7	12.2

3.2 Analysis of Evapo-transpiration

For the evapo-transpiration component of the water balance, the model has three options for calculating potential evapotranspiration, namely the Hargreaves method, Priestley- Taylor method and Penman-Monteith method.

The potential evapo-transpiration computed by the three methods described above have been extracted from the model for the North(N), Eastern (E), Western(W), Southern (S) and Central (C) part of the study area. The computation result has been shown in Figure 84.

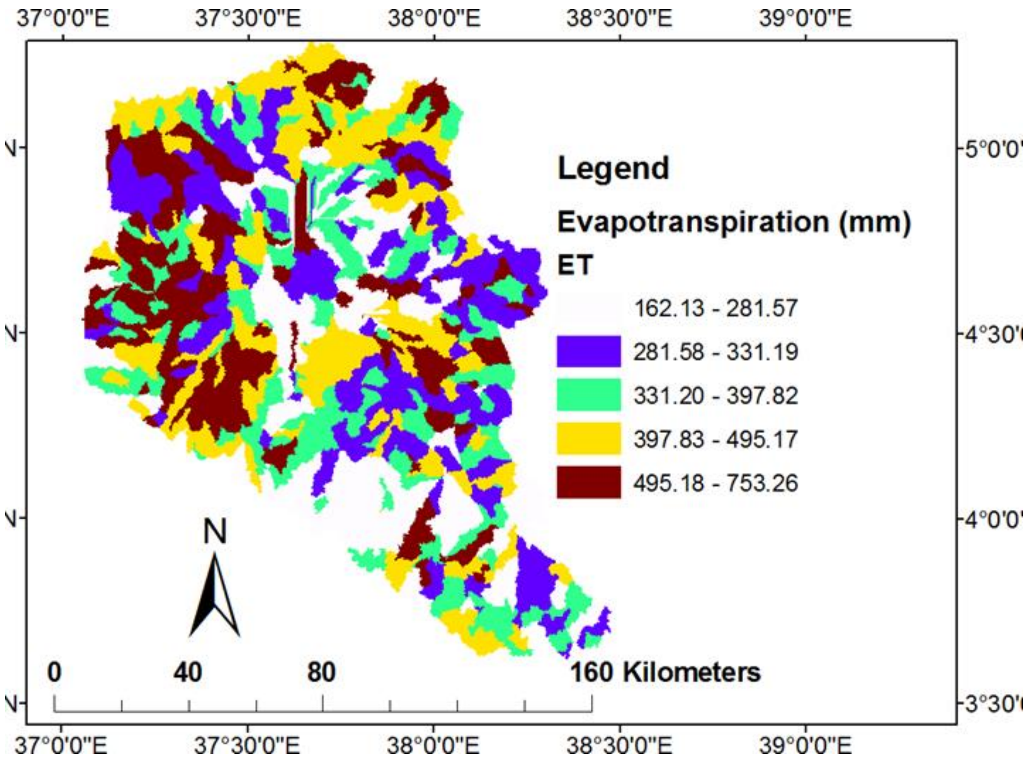
Figure 83 - Comparison of PET values estimated by different methods



The graph indicates that the PET value estimated by Penman-Monteith and Priestly- Taylor method under estimated as compared to the Hargreaves method. The under estimation could be probably due to the data limitation related to latent heat of vaporization and net radiation where these two parameters were not taken in to Hargreaves. Moreover, the average PET values extracted from New_LocClim-1.10 indicate that the PET value of the Hargreaves method is reasonable as compared to the other two methods.

Hence, the Hargreaves method has been selected to compute the monthly and annual PET value. The evapo-transpiration has been computed based on the PET value determined and the soil moisture availability. Beside that the plant canopy cover plays major role for the determination of the evapo-transpiration. The canopy cover determines the transpiration from leave area which is related to the Leave Area Index (LAI) with appropriate empirical relation considered in the model. The evaporation from the soil layer has been computed in due consideration to the difference between the soil field capacity and wilting point where these inputs are derived from the soil physical characteristics. Thus, the transpiration from the canopy cover and soil moisture evaporation has been computed and the result has been displayed on the following Figure 85 and Table 49 below.

Figure 84- Results of Transpiration from the Canopy Cover and Soil Moisture Evaporation



The average potential Evapo-transpiration and the Evapo-transpiration of the major sub- basins has been estimated and summarized in table 49. As described on the above paragraph, the ET value has been taken after the dynamic soil moisture condition and vegetation cover (canopy).

Table 49-Annual PET and ET Values of the Sub basins of the Study Area

Sub-basin	PET (mm)	ET (mm)	Min Elev. (m)	Max Elev. (m)
Taltale	1583.09	425.20	821	1566
Laga Balal	1649.75	467.23	737	1300
Ririba	1579.87	382.42	660	1718
Magado	1557.34	368.34	667	1667

3.3 Soil Moisture

The surface runoff is another crucial component of water balance equations. After setting up the model using the weather data, land use and soil data of the study area, the model default values on curve number values has been edited based on theoretical values. One of the major sources for spatial variability of runoff in watershed scale modelling is the soil physical characteristics.

SPAW ((Soil Plant Air Water), Saxton et al, (1986)) is a model capable of simulating daily hydrologic water budgets of agricultural landscapes. The model has soil water characteristics as one of its components. The soil water characteristics, soil texture (percentage of sand and percentage of clay) and percentage of organic carbon content is pushed as input for the model. The basic mathematical background of the model is Saxton and Rawls 2006 equations, developed from extensive laboratory analysis on the national soil characterization database United States Department of Agriculture (USDA). The data extracted from FAO soil database were used in SPAW model to determine the additional soil parameters required by SWAT2005 model. For the major sub basins of the study area the following soil types were found to be dominant and selected in the model application and temporal pattern of the annual soil moisture depth (mm), annual surface runoff depth (mm) and annual groundwater recharge depth (mm) has been estimated figure 86.

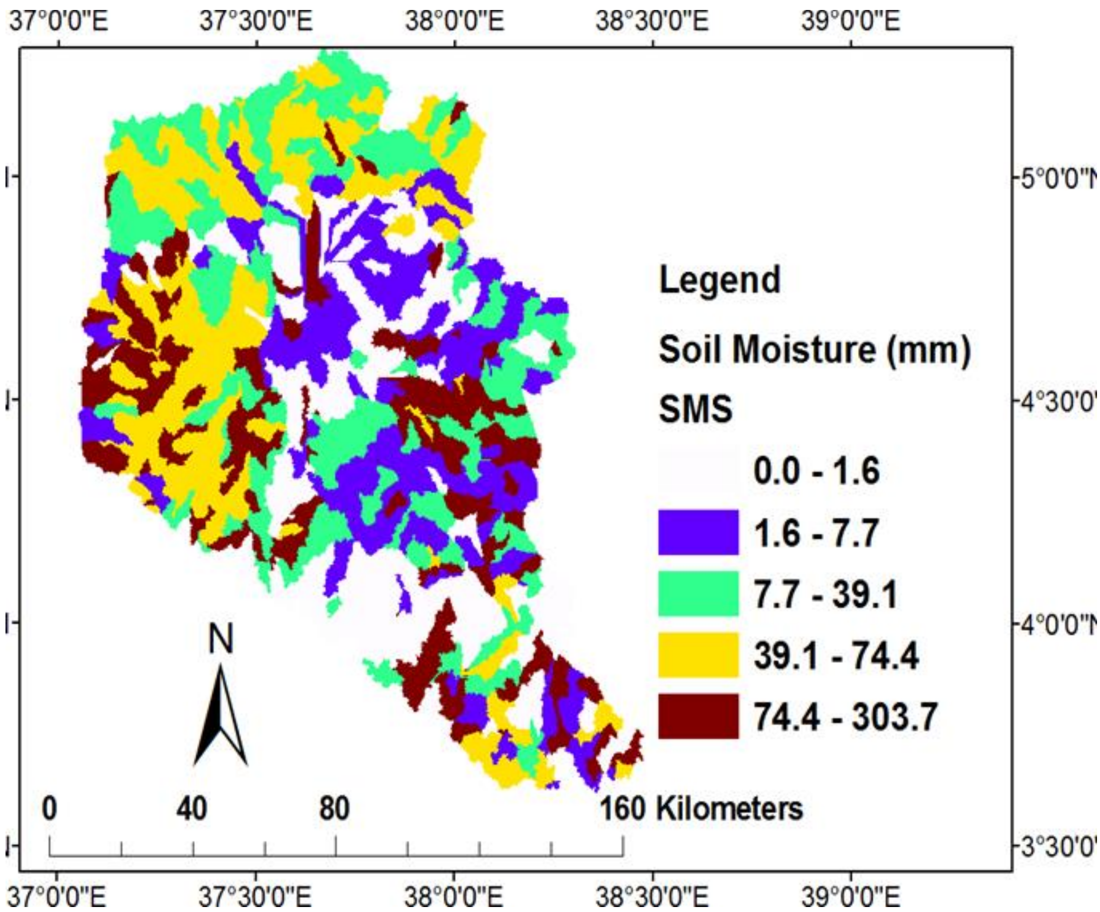
Table 50 Basic physical characterstics of dominant soils

S. No	Soil Name	F.C %	K (mm/hr.)	AWC cm/cm	B.D (g/cm3)
1	Leptosols	26.9	11.21	0.1	1.5
2	Chromic Cambisols	35.5	2.03	0.12	1.46
3	Calcic Solentez	33.6	4.02	0.14	1.45
4	Calcic Fluvisols	26.0	9.74	0.13	1.56
5	Calcic Vertisols	25.7	10.35	0.11	7.8

Where:

- *F.C = Field capacity*
- *K = Saturated hydraulic conductivity*
- *AWC = Available water content*
- *B.D = Bulk density*

Figure 85-Soil Moisture Classifications in mm Depth



3.4 Surface Runoff

The SCS (US Soil Conservation Service) method explained in detail in annex 4.a. and used to calculate the surface runoff component of the water balance in the Borena region (Figure 87). To compute the surface runoff depth using the SCS method; CN is the major parameter to be used in the SWAT2005 model, the paramters and equations have been provided in annex 4.a. The SCS curve number is a function of soil permeability, land use and antecedent moisture condition. The soil permeability and the soil available water content are provided for the model through soil database input components. The provided soil available water content is used to estimate the antecedent soil moisture condition. Similarly, the curve number (CN) is estimated for the respective area of land use pattern and different hydrologic soil groups. The land use map and soil maps, along with their corresponding database are provided as an input for the model.

Figure 86-Runoff classifications in mm depth

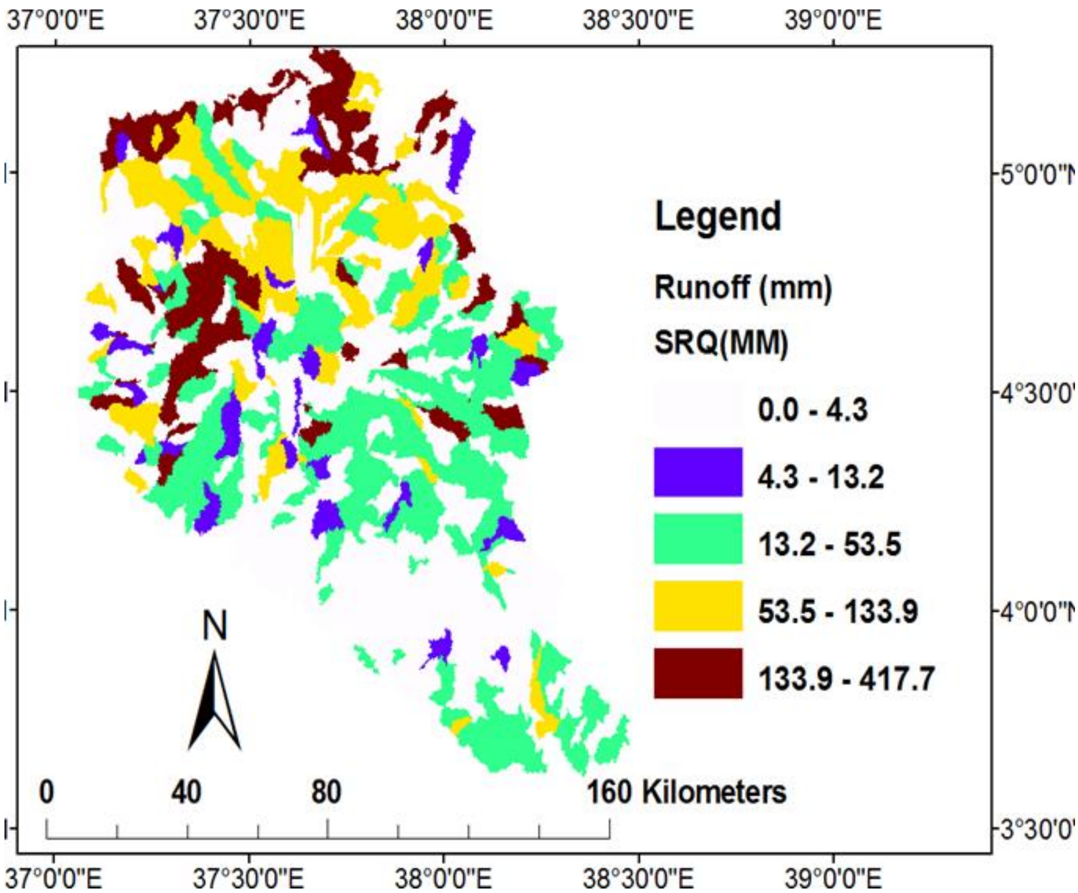
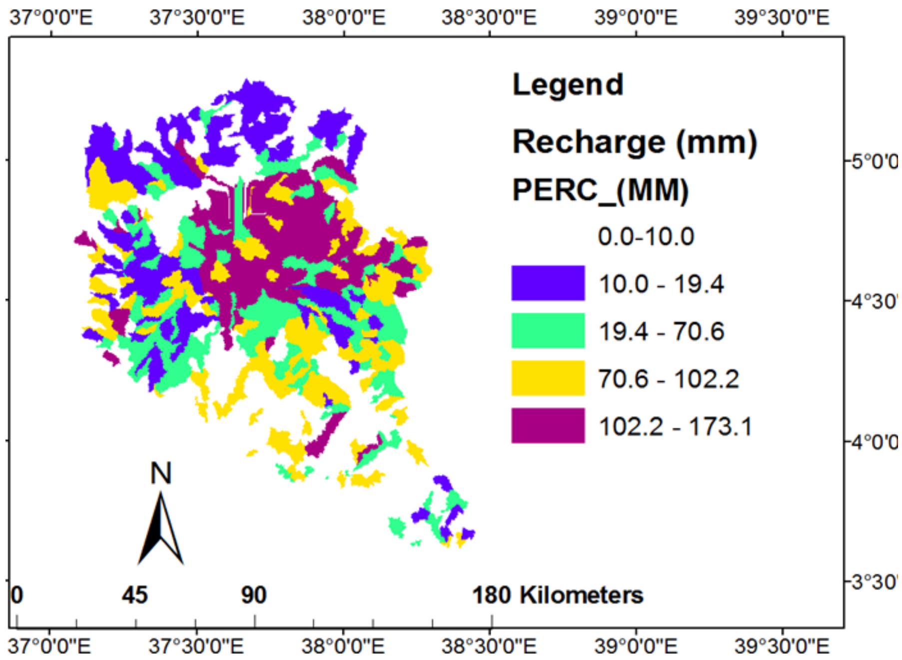
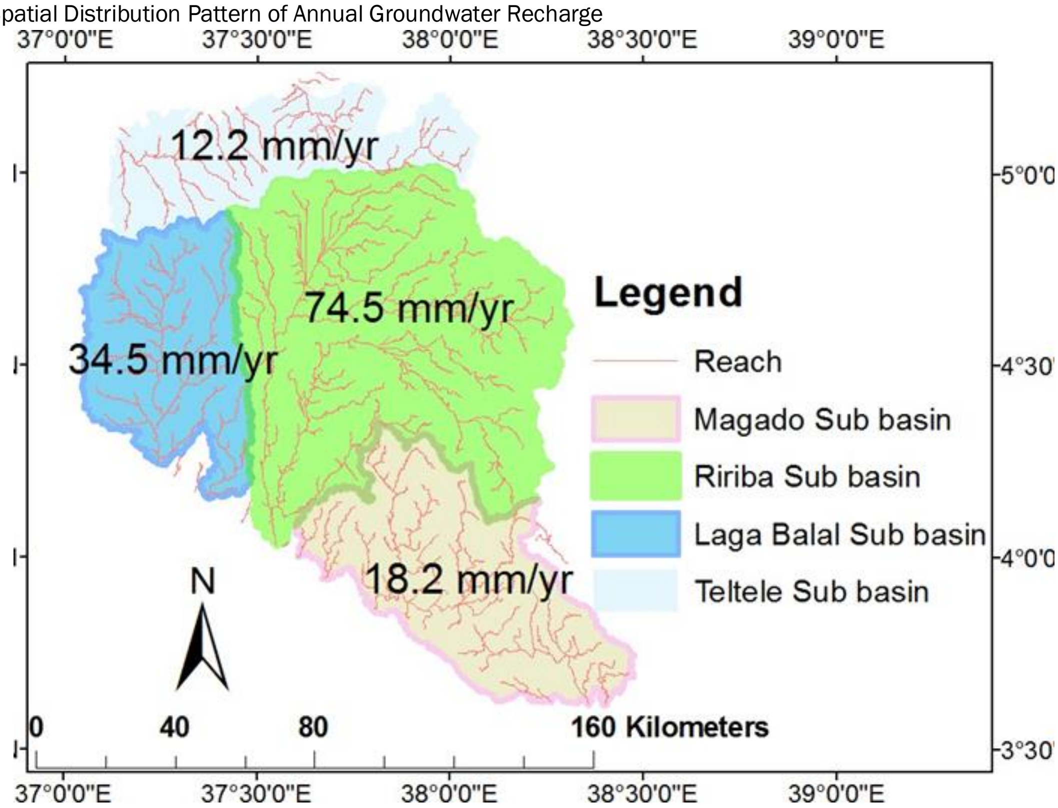


Figure 87-Spatial Distribution Pattern of Annual Groundwater Recharge in mm



After providing the required input to the model, the percolation which is major source of the groundwater recharge has been estimated. The spatial and temporal distribution pattern of the recharge in Borena area has been computed (Figure 88). The distribution of the recharge depth over the four major sub-basins has been computed (Figure 89).

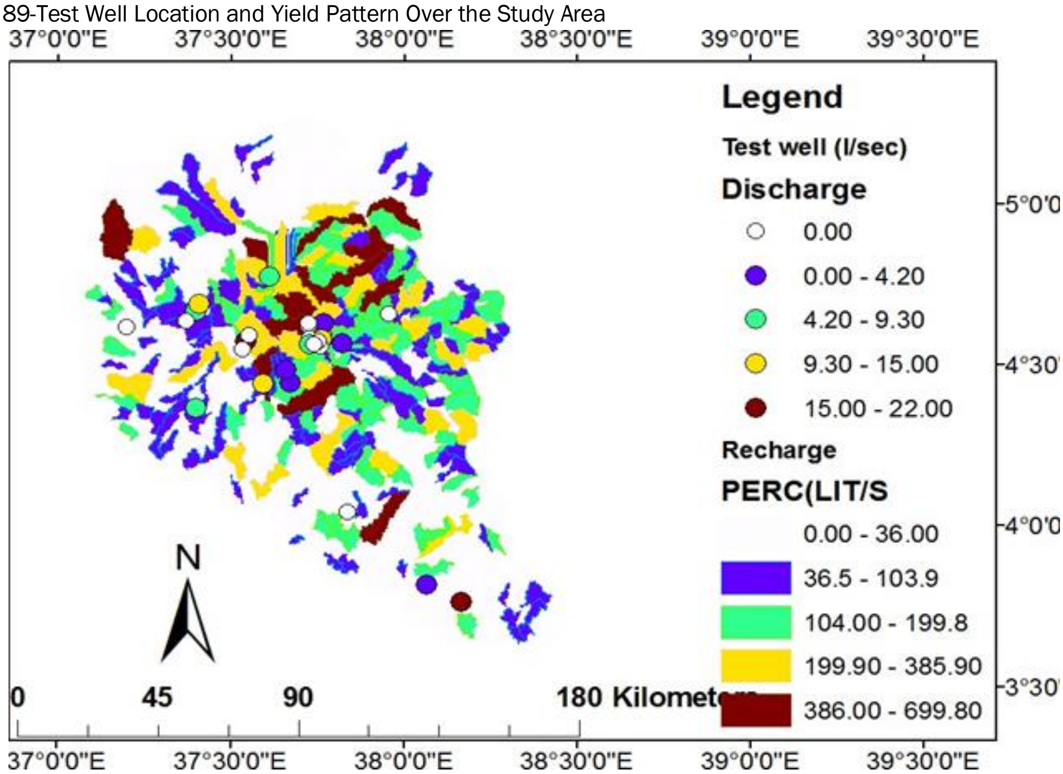
Figure 88-Spatial Distribution Pattern of Annual Groundwater Recharge



For the sub-basins, similar to the recharge depth, the recharge magnitude in litre per second has been estimated on the assumption that the specified recharge depth occurs during the rainy season. As indicated in rainfall analysis of the area, the area receives monthly rainfall depth of more than 20mm for about seven months. The 20 mm has been taken as threshold for percolation to take place on assumption that, the soil water holding capacity is fulfilled at rainfall depth of less than 20 mm. For the dominant soils in the study area, the water holding capacity is less than 20 mm and it has been used as basis to fix the threshold for percolation to occur. Accordingly, the recharge rate (lit/sec) for each catchment has been estimated and the spatial distribution pattern of the study area are shown on figure 90.

The test wells result obtained up to the preparation of this report has been used to compare the model estimation result with the well yields. Figure 90 shows the pattern of the test wells location and their discharge (yield). As it can be seen from the same figure, the model also showed minimum recharge or the adjoining catchment has minimum recharge areas where the test wells have minimum yield,. Inversely, at points where there is less recharge but relatively higher yield is observed (in Magado Sub basin), the neighbouring catchment has higher recharge. The yield from the test well might be from the direct recharge over the catchment or the recharge from the adjoining catchment. Hence, the test well yields can be correlated with respective catchments they are located in the neighbouring catchments where they receive lateral flow.

Figure 89-Test Well Location and Yield Pattern Over the Study Area



The average recharge rate for the major sub basins has been computed from the individual watersheds recharge. The result has been summarized on the table 51.

Table 51-Summary result of recharge for individual sub basins

S.No	sub-basin	Area(Km2)	% of the study area	Average annual	Average total annual recharge (mm³),
1	Laga Balal	2,839.70	16.76	34.52	98.03
2	Ririba	7,282.60	42.97	74.50	542.55
3	Magado	4,189	24.72	18.6	77.92
4	Taltale	2,635.90	15.55	12.21	32.18
	Total	16,947	100		

3.5 Discussion

Based on the table above, the recharge depth has been used to classify the entire study area into different recharge class. The classification has been made based on natural breaks approach where five recharge classes can be clearly seen. The recharge class for the major sub-basins of the study area has been tabulated as shown in table 52.

Table 52-Recharge Distribution Over the Sub-Basins of the Study Area

S.No	Sub-basin name	Recharge class	Average depth(mm)	Sub-basin Area (km2)	% of the sub-basin
1	Lega Belala				
		102 - 173	116.57	128.27	4.52
		70.6 – 102	82.57	403.22	14.20
		19.4 – 70.6	43.61	697.38	24.56
		00001 – 19.4	11.15	879.02	30.96
		0	0	732.81	25.81
2	Taltale				
		102 - 173	115.30	55.79	2.12
		70.6 – 102	80.63	245.79	9.32
		19.4 – 70.6	41.27	255.46	9.69
		00001 – 19.4	8.15	1399.34	53.10
		0		679.52	25.78
3	Ririba				
		102 - 173	130.0	1834.94	25.20
		70.6 – 102	85.5	1550.1	21.30
		19.4 – 70.6	45.7	1326.8	18.21
		00001 – 19.4	14.6	399.2	5.48
		0	0	2170.94	29.81
4	Magado				
		102 - 173	0	0	0
		70.6 – 102	99.6	37.3	3.92
		19.4 – 70.6	49.7	81.9	8.62
		00001 – 19.4	11.45	97.32	10.24
		0		733.89	77.22

Thus, the net balances of the indicated annual values were suggested as the return flow component. Both the return flow and the surface runoff were assumed to flow out of the study area.

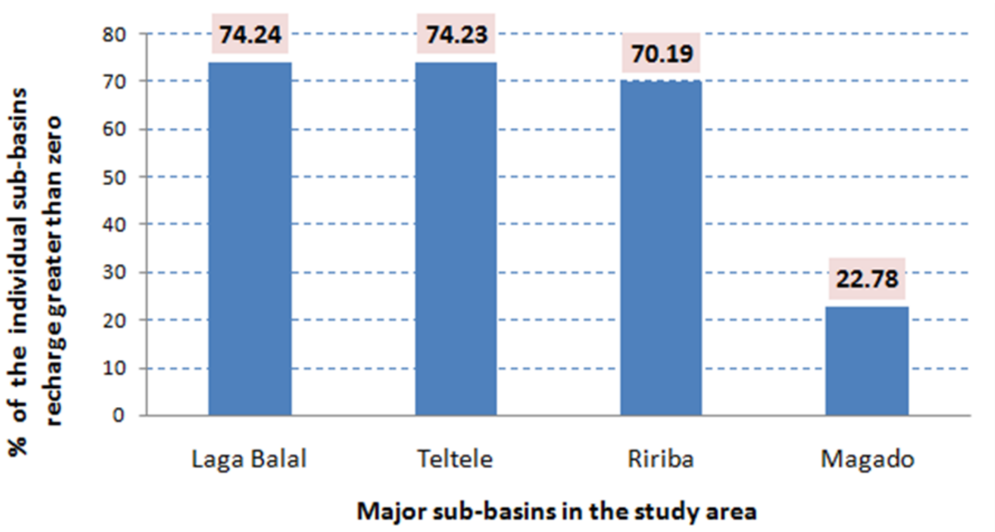
Table 53 Summary of sub basins water balance

Sub basin	RF (mm)	Eta(mm)	RO(mm)	RCHRG(mm)	Return Flow (mm)	Total surface outflow (mm)
L.Balal	509.1	467.8	10.3	34.5	0	10.3
Magado	688	368.8	26.3	18.2	274.7	301
Ririba	548.5	382.9	19.2	74.5	71.9	91.1
Teltele	751.1	425.9	40.7	12.2	272.3	313

3.6 Conclusion

The areas of the individual sub-basins which have recharge depth greater than zero has been summarized and shown on figure 91. The graph shows Laga Balal, Taltale and Ririba sub-basins have recharge greater than 10 mm for greater than 70 percent of their area coverage. Besides that, as it can be clearly seen from table 52, Ririba sub-basin has the maximum proportion (42.9 percent) of its area to gain maximum discharge (70.6 mm to 173 mm) as compared to the other sub basins. The percentage of the recharge class over the entire study area has been analyzed. More than 50 percent of the entire study area receives recharge rate of less than 20 mm whereas about 48 percent of the study area receives recharge rate of greater than 20 mm reaching the maximum of about 170 mm. The comparative analysis of the result has been summarized on figure 91.

Figure 90 Area coverage of each sub-basin with significant recharge rate



The study area has been divided in to four major sub basins which vary significantly in their area coverage. Ririba sub basins covers 42.9 percent of the entire study area while Magado, Laga Balal and Taltale sub-basins each covers 24.7, 16.7 and 15.5 percent respectively. From the groundwater recharge study, Ririba sub basin has the largest recharge rate of 74.5 mm/year followed by Laga Balal sub basin which has recharge rate of 34.5 mm/year. These two sub basins are portion of the study area have a relatively higher groundwater potential.

This study thus clearly shows the trend of the spatial variability of the most likely recharge rate with the minimum and maximum possible magnitude for the individual watershed level. Temporal pattern of the monthly recharge rate for the four major sub basins has also been considered which forms the basis to identify the peak recharge period and critical (minimum) recharge period of the year.

The SWAT model based on the empirical result of water balance result thus shows that there is a ground water outflow of a total 715.50 mm from the Borena basin. This shows that a new outflow of ground water in the Borena basin exists, where the recharge values being “outflow” is a reflection of saturation of the available ground water reserve.

A study titled "*Water Resource Assessment of a Complex Volcanic System Under Semi-Arid Climate Using Numerical Modeling: The Borena Basin in Southern Ethiopia*[109]" has conducted an assessment of groundwater potential in the basin, its spatial distribution and factors controlling its movement using numerical groundwater modeling. Accordingly, the result of the model estimated the ground water rechared into the basin amounts to 542 MCM /year, of which 367 MCM/year is provided by superficial recharge.

Based on the availability of the groundwater from the reserve and the recharge and the amount that is discharged to the surface and extracted for irrigation purposes, the following assumptions have been applied;

- The radius of influence and well interference is nil as the distance between the 40 boreholes considered for this project as well as existing 176 boreholes is beyond 500 meters.
- Annual groundwater abstraction has been assumed at an average 20 liters per second for all 40 wells (0.10 MCM per well) when extracted for 8 hours pumping rate per day and a period of six months/annum.
- Considering a total number of 40 wells in the Borena basin targeted for this purpose, a total of 4.15 MCM of ground water will be extracted per annum from a total recharge of amount of 524 MCM/annum. This will leave a net recharge of 519.85 MCM/Year.
- Note that the Borena basin is a basaltic Aquifer, which is intensely fractured, resulting in strong connectivity within the hydrogeologic system. Thus, as opposed to ground water being reserved in the Kobo Girana valley within the Aquifers, in Borena it flows within the fractures and very difficult to estimate the ground water reserve.
- However, the amount of ground water extracted from this project is 4.15 MCM or 0.8 percent of the recharge amount. This explicitly shows that this project will only be using water from the superficial recharge and not tap into reserve of the ground water aquifer system. Thus amount of ground water that will be extracted from this project is thus only 0.8 percent of the recharge value.

[109] Razack M, Furi W, Fanta L, Shiferaw A. Water Resource Assessment of a Complex Volcanic System Under Semi-Arid Climate Using Numerical Modeling: The Borena Basin in Southern Ethiopia. *Water*. 2020; 12(1):276. https://doi.org/10.3390/w12010276

Annex 4.a: United States Soil Conservation Service (SCS) Method

1.0 BACKGROUND

This technique was developed by the U.S soil conservation service. For calculating the rates of runoff the method requires the same basic input as the Rational Method, namely; drainage area, runoff factor (in different form than Rational Method), time of concentration and rainfall depth. The SCS approach, however, is more sophisticated in that it considers also the time distribution of rainfall, initial rainfall losses to interception and depression storage, and infiltration rate that decrease during the course of a storm. The SCS methods produce the direct runoff for a storm by subtracting infiltration and other losses from the total rainfall. A rainfall-runoff relationship is used to separate total rainfall into direct runoff, retention and initial abstraction utilizing the following equations:

1.1 Data Managing

On the basis of the command area block are taken from the project office, then generated river and catchments characteristics by Arc GIS extension of Arc Hydro, the sub-catchments nearby the site are delineated and the relevant characteristics has been derived as shown in Table 54 below. The catchment characteristics like land cover, Hydrologic soil group were found from the GIS Section of Ministry of Agriculture (Core ETHIO-GIS Data Sets, based on CSA Census data of 2008) and updated the land cover from recent Google earth image see Figure 93 below.

1.2 Time of concentration

The time of concentration, Tc, is an index of lag frequently used to define a catchment's response time. Time of concentration is the time taken for runoff to travel from the hydraulically most remote point of the catchment to the point of outlet.

The time of concentration was computed considering part of the flow as Overland Flow and the remaining as Defined Watercourses flow. As most of the catchments are relatively big, the channel flow dominates in many of the sub-catchments. Therefore partitioning the time of concentration is unlikely to improve the result of the discharge estimation. However, we have Overland flow is the type of flow that occurs in small, flat or in upper reaches of catchments, where there is no clearly defined watercourse.

1.2.1 Calculation of the Time of Concentration for Overland Flow

Overland flow is the type of flow that occurs in small, flat or in upper reaches of catchments, where there is no clearly defined watercourse. Run-off, then, is in the form of thin layers of water flowing slowly over the fairly uneven ground surface. The kerby formula is recommended for the calculation of Tc in this case. It is only applicable to parts where the slope is fairly even.

$$\mathbf{Tc} = \mathbf{0.604}\left(\frac{\boldsymbol{CvL}}{\boldsymbol{S}^{0.5}}\right)^{0.467}$$

Where:

- Tc = time of concentration (hours)
- Cv = roughness coefficient of land use of cultivation = 0.2[110]

[110] ERA Drainage Design manual 2013

- L = hydraulic length of catchment, measured along flow path from the catchment boundary to the point where the flood needs to be determined (km) =7.12km.

$$S = \left(\frac{H}{1000\ L}\right)(m/m)$$

Where:

- S = Slope of the catchment
- H = height of most remote point above outlet of catchment (m)

1.2.2 Time of concentration for defined water course

$$Tc = \left(\frac{0.87L^2}{1000\ Sav}\right)^{0.385}$$

Where:

- L = hydraulic length of catchments, measured along flow path from the catchment, boundary to the point where the flood needs to be determined (km)
- S_{av} = average slope (m/m)

$$Sav = \left(\frac{H0.85L - H0.10L}{1000 * 0.75L}\right)$$

- H 0.10L = elevation height at 10% of the length of the watercourse (m)
- H 0.85L = elevation height at 85% of the length of the watercourse (m)
- L = length of watercourse (km)

1.3 Curve number

As described on the Figure 92 below the hydrologic soil group of crossing structure sites catchment , land cover and land use and its curve number (CN) is summarized in Table 54 below. The curve number (CN) is an index expressing a catchment's storm flow response to a rainfall event.

Table 54 Parameter of Crossing Structure points catchment prepared for SCS method

Cross drainage Name	East	North	Catch Area	Length of Drainage	Fall	River Channel Slope	TC	SCS CN	Potential Infiltration (S)	Initial Abstraction (la)
	UTM	*UTM*	*km2*	*Km*	*m*	*m/m*	*Hr*			
BD-CD-1	312152.8	557152.7	125.65	38.13	615	0.129	2.41	72.9	94.5	18.9
EI-CD-2	305402.6	548682.3	0.67	1.81	140	0.179	0.20	73.0	93.8	18.8
EI-CD-3	305188.0	548621.3	130.56	18.08	238	1.179	0.58	62.0	155.7	31.1
EI-CD-4	305104.9	548689.1	1.34	10.48	123	2.179	0.30	72.0	98.8	19.8
HO-CD	311128.2	475264.3	29.47	16.91	97	3.179	0.38	77.0	75.9	15.2
LA-CD_1	313658.9	545415.8	1.20	0.87	62	4.179	0.03	78.0	71.6	14.3
LA-CD_2	313636.5	545406.5	78.79	6.87	536	5.179	0.16	62.0	155.7	31.1

Mer_CD-1	300264.1	510318.9	19.47	6.87	536	6.179	0.15	67.0	125.1	25.0
MS_CD	337927.2	454482.5	3145.14	128.10	775	7.179	1.30	72.0	98.8	19.8
EAL-CD	293491.1	487992.4	72.04	14.03	605	8.179	0.23	75.0	84.7	16.9

1.3.1 Rainfall Runoff equation

A relationship between accumulated rainfall and accumulated runoff was derived by SCS from experimental plots for numerous hydrologic and vegetative cover conditions

$$\mathbf{Q} = \frac{(\boldsymbol{P} - \boldsymbol{Ia})^2}{\boldsymbol{P} - \boldsymbol{Ia} + \boldsymbol{S}}$$

$$\mathbf{S} = \mathbf{25.4} * \left(\frac{\mathbf{1000}}{\boldsymbol{CN}} - \mathbf{10}\right)$$

Where:

- Ia = 0.2S

From these, the resulting equation is derived:

$$\mathbf{Q} = \frac{(\boldsymbol{P} - \mathbf{0.2}\boldsymbol{S})^2}{\boldsymbol{P} + \mathbf{0.8}\boldsymbol{S}}$$

Where:

- Q = accumulated direct runoff (mm)
- P = accumulated rainfall (potential maximum runoff), (mm)
- S = Potential maximum retention (mm)
- Ia = initial abstraction (mm)
- CN = runoff curve number

Figure 91 Soil type of the crossing points catchments for Borana ground Water irrigation command

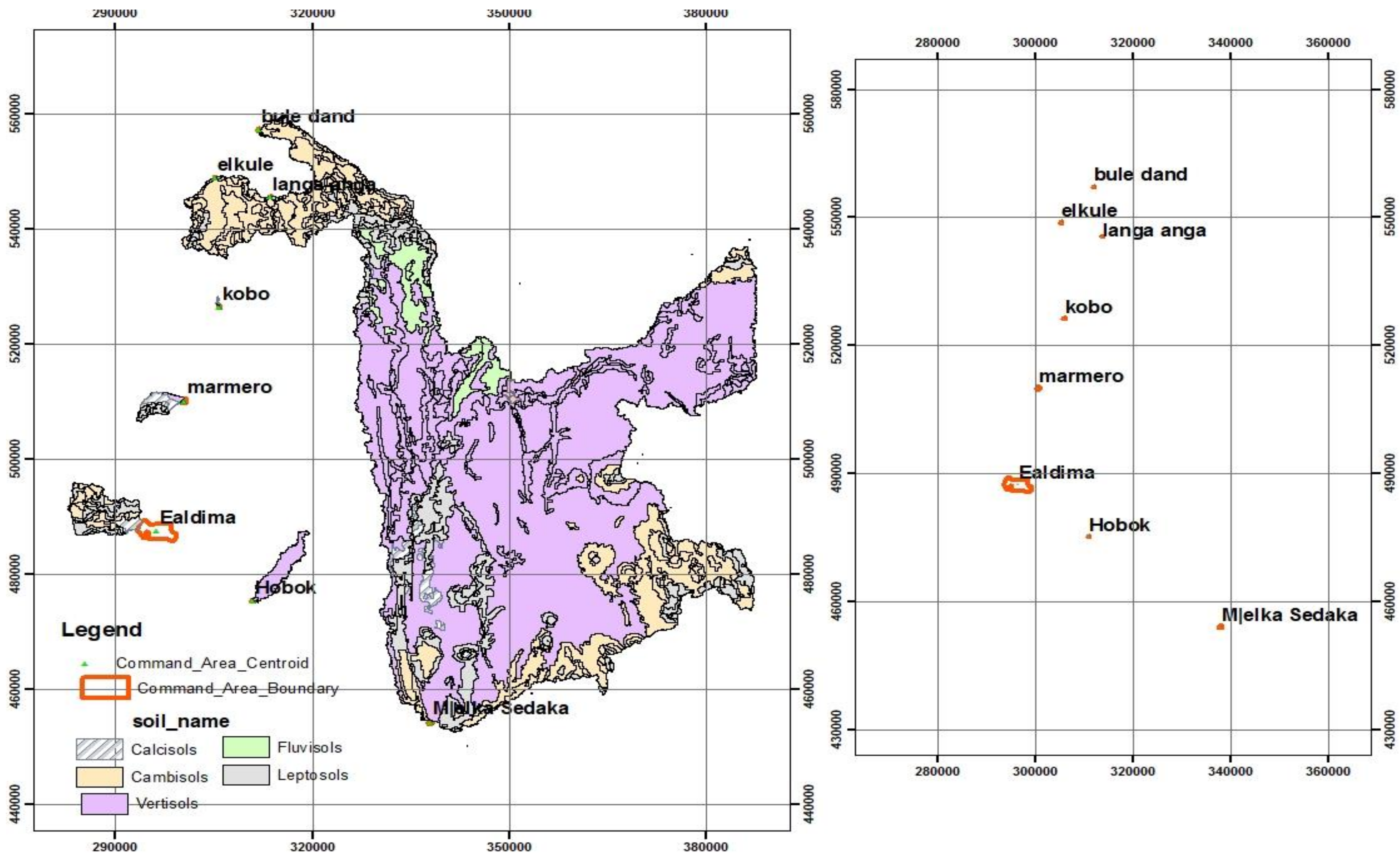
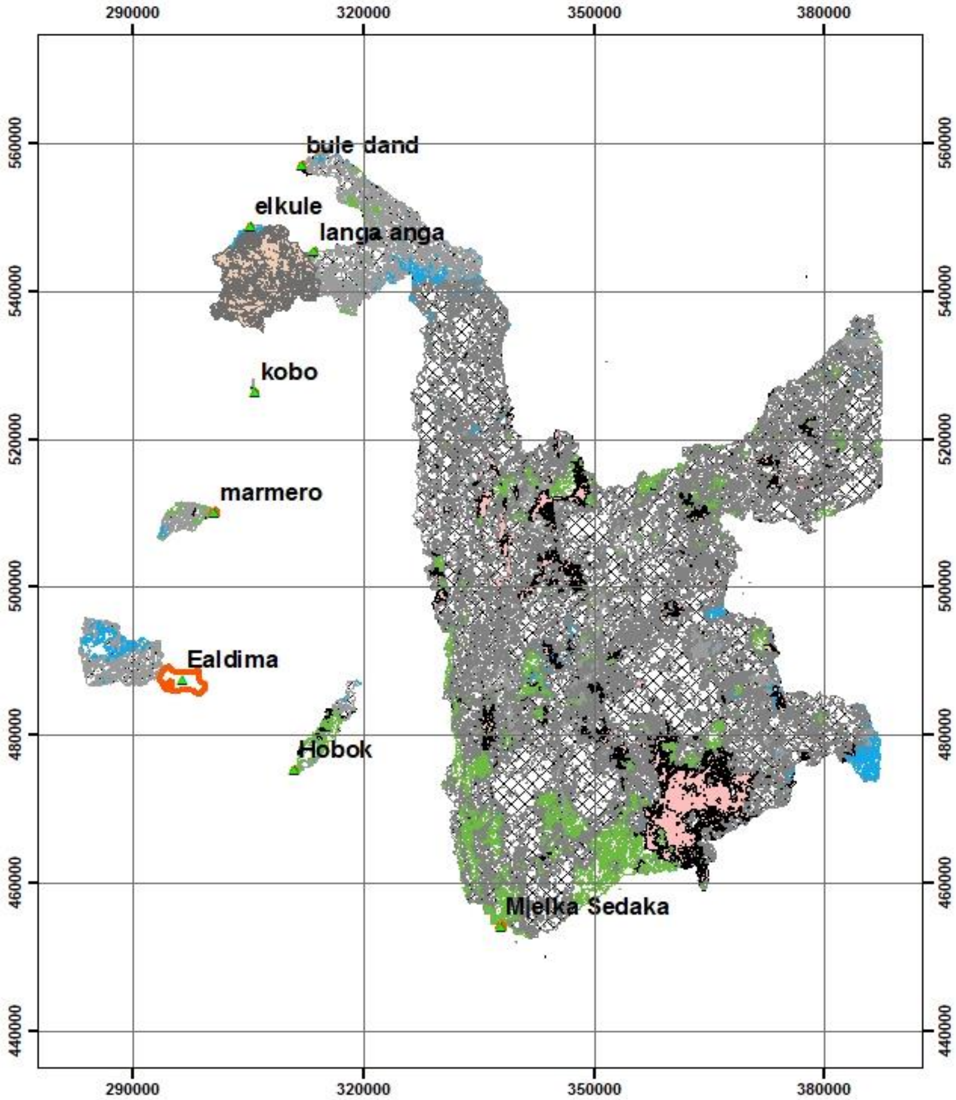
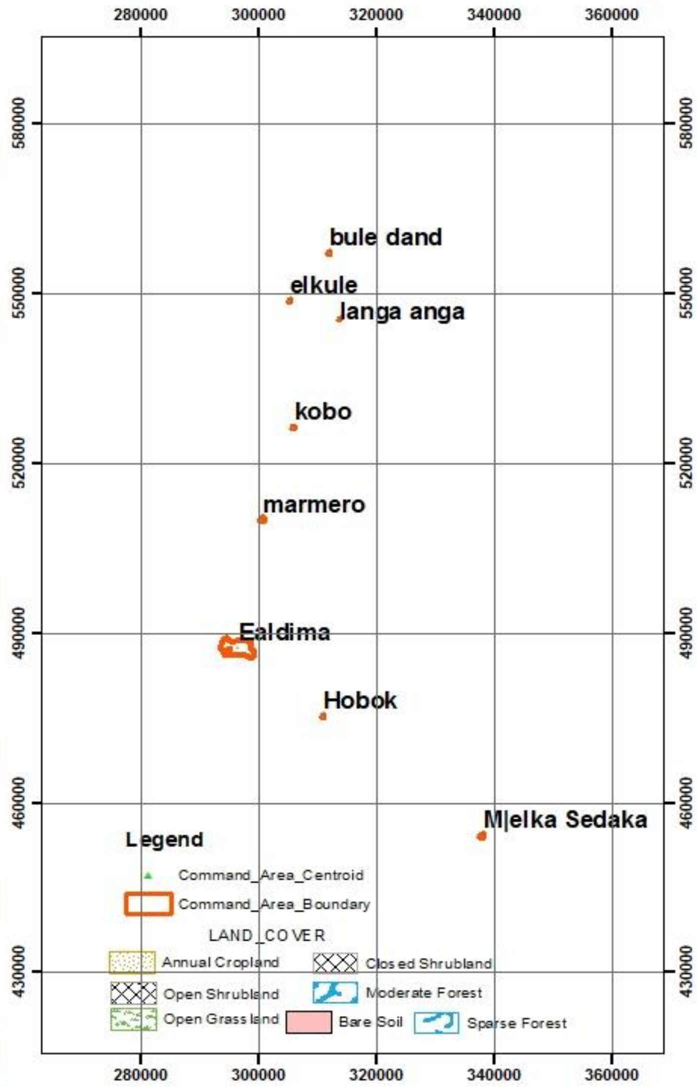


Figure 92 Land use/ land cover of the crossing points catchments for Borana ground Water irrigation command





1.3.2 SCS Method peak discharge equation

The calculation of peak discharge by SCS techniques is based on the triangular unit Hydrograph (UH) concept.

$$\mathbf{Qp} = \frac{\mathbf{0.2083}\ \boldsymbol{AQ}}{[(\mathbf{0.6Tc}) + (\boldsymbol{Tc})^{0.5}]}$$

Where:

- Qp = Peak discharge (m^3/s)
- A = Catchment Area (km^2)
- Q = Storm flow depth (mm)
- Tc = Time of concentration (hr.)

Table 55 The value of maximum storm (mm) in 24 hrs for different years returns period

Cross drainage Name	East	North	Catch Area	Design Discharge				
	UTM	*UTM*	*km²*	*Q5*	*Q10*	*Q25*	*Q50*	*Q100*
BD-CD-1	312152.8	557152.7	125.653	108.7	152.9	215.6	264.4	315.4
El-CD-2	305402.6	548682.3	0.670	2.4	3.3	4.7	5.7	6.8
El-CD-3	305188.0	548621.3	130.576	94.3	156.3	252.2	332.5	419.9
El-CD-4	305104.9	548689.1	1.342	3.6	5.1	7.3	9.0	10.8
HO-CD	311128.2	475264.3	29.468	54.0	71.1	89.7	101.6	112.4
LA-CD_1	313658.9	545415.8	1.196	13.5	17.4	22.5	26.5	30.6
LA-CD_2	313636.5	545406.5	78.788	132.6	212.3	332.0	432.3	540.6
Mer_CD-1	300264.1	510318.9	19.467	33.5	52.2	80.1	102.7	127.6
MS_CD	337927.2	454482.5	3145.143	1318.4	1855.6	2482.7	2904.5	3285.6
EAL-CD	293491.1	487992.4	72.041	113.6	153.1	197.7	226.9	252.9

Where:

BD= Bule dand, El= Elkune, Eal = Ealdana , Ko=Kobo, LA=Laga anga, Mer=Mermero, Ho= Hobok , MS= Melka Sedeka.

1.3.3 Rational Method peak discharge equation

There are seven crossing drainages which have less than 0.5 sq.km as seen in Table 56 and 57 below.

$$\mathbf{Q = 0.278\ CIA}$$

Where:

- Q = peak discharge (m^3/s)
- C = runoff coefficient related to land slope
- I = Intensity of storm event of duration 6 min (mm/hr)
- A= Drainage area (km^2)

Table 56 Parameter of Cross Drainage Works of Borana Ground water irrigation command by rational method

Catch name	Catch Area	Easting	Northing	Tc	Freq. Factor					Runoff coef.
	Km²	*UTM*	*UTM*	*Min*	*C_{f5}*	*C_{f10}*	*C_{f25}*	*C_{f50}*	*C_{f100}*	*C*
BD_CD-2	0.313	311994.5	556928.3	236.3	1	1	1.1	1.2	1.2	0.3
BD_CD-3	0.260	311912.0	556918.5	13.4	1	1	1.1	1.2	1.2	0.3
El-CD-1	0.373	305434.7	548789.7	16.6	1	1	1.1	1.2	1.2	0.3
KO-CD	0.461	305826.5	526506.5	15.9	1	1	1.1	1.2	1.2	0.3
LA_CD_3	0.283	313485.7	545530.6	10.2	1	1	1.1	1.2	1.2	0.3
Mer CD-2	0.197	300169.0	509953.6	9.3	1	1	1.1	1.2	1.2	0.3

Table 57 Design floods for Cross Drainage for Borena ground water irrigation command

Cross drainage Name	East	North	Catch Area	Design Discharge				
	UTM	*UTM*	*km²*	*Q5*	*Q10*	*Q25*	*Q50*	*Q100*
BD_CD-2	311994.5	556928.3	0.313	0.3	0.3	0.5	0.9	1.9
BD_CD-3	311912.0	556918.5	0.260	1.5	2.9	4.1	6.7	18.5
El-CD-1	305434.7	548789.7	0.373	1.9	3.7	5.2	15.6	62.4
KO-CD	305826.5	526506.5	0.461	2.1	2.4	3.0	3.6	3.9
LA_CD_3	313485.7	545530.6	0.283	1.8	2.0	2.6	3.1	3.3
Mer CD-2	300169.0	509953.6	0.197	1.1	1.6	1.7	2.5	20.7

Where:

BD= Bule dand, El= Elkune, Eal = Ealdana , Ko=Kobo, LA=Laga anga, Mer=Mermero, Ho= Hobok , MS= Melka Sedeka.

Annex 5: Implementation schedule (attached separately)

Annex 6: Project budget and detailed budget plan (attached separately)

Annex 7: Methodology to Determine Crop Water Requirements

1.0 CROP SELECTION

Before projecting appropriate cropping pattern or crop productions, crop selection criteria and procedure were established based on the situational analysis of the command site and policy frame works. Generally, crop selection criteria and procedures for a specific irrigation project depends mainly on physical, socio-economic and priorities indicated in the policy and strategic frameworks of the country. For both seasons of the irrigation development project plan choice of crops depends mainly on national and regional priorities/strategies, national policy issues, pastoralists and agro-pastoralists preference, edaphic factor, crops response to irrigation, existing socio-economic situation, expected profitability, expected factors of production, and other risks and opportunities were considered.

Crops selected for the Kobo Girana irrigation site thus anchored on foreign currency earning potential, food security, employment generation, increase household income, agro-processing, agro-ecological suitability, and yield potential and amount of water consumption. Based on these selection criteria; sesame, groundnut, tomato, peppers, and green beans ranks first followed by cotton, orange, and onion. Banana, papaya and sorghum ranks third. Finally sugarcane comes the least in the category. Considering the above selection criteria and stakeholders' preference crops that ranks first to third are selected. The ultimate goal of the project is to meet stakeholders' preference and attain sustainable development through production of surplus (high value cash crops) for local and foreign market. Hence, based on the selection criteria sorghum, sesame, cotton, groundnut, papaya, orange, coffee and banana are selected during wet season crops while onion, industrial tomato, pepper, green beans, papaya, orange, coffee and banana for dry season as shown below.

1.1 Cropping Intensity Kobo Girana irrigation site

Table 58-Proposed Growing Period and Cropping Calendar of Kobo Girana

No.	Wet season crops		Dry season crops	
	Crop types	Area (%)	Crop types	Area (%)
1.	Sesame	20	Tomato	25
2.	Cotton	25	Onion	30
3.	Sorghum	15	Pepper	15
4.	Maize	10	Green beans	10
5.	Ground nut	10		
6.	Papaya	5		
7.	Banana	5		
8.	Sweet orange	5		
9.	Avocado	5		
	Sub Total	100		80
	Total	200 (With all year-round crops)		

No.	Crop name	Land preparation	Planting/sowing date	Total LGP (Days)
A	Wet season crops			
	Sesame	April-May	June1-15	120
	Cotton	April	May 10-20	150
	Sorghum	Late March	April 15-30	150

	Maize	Late March	April 15-30	120
	Groundnut	March -Apr	May 15-30	140
	Papaya	April –May	June 16-25	300
	Banana	April-June	July 1-15	300
	Sweet orange	May-Aug	Sept 1-15	3-5years
	Avocado	May-Aug	Sept 1-15	3-4years
B	Second season crops			
	Green bean	End of Oct-1st Nov	Nov 16-25	90
	Tomato	Oct	Nov 5-16	125
	Pepper	End of Sept. -1st Oct	Oct 26-nov15	130
	Onion	End of Oct – 1st Nov	Nov 20-30	120

1.2 Cropping pattern

a) Criteria like climatic factors, the physical, chemical and biological characters of soil have direct influence on crop and livestock feed production. Therefore, under the irrigated agriculture, with assured availability of water, the efforts are made to select the most economical, high yielding and irrigation responsive crops, which fit well in the production system with high degree of input use efficiency mainly water and supporting sustainable agricultural production since water is the major scarce and critical factor of agriculture, crop and livestock production. Generally, the following factors have been considered as the prominent factors for irrigated and rainfed farming in the project target areas:

b) Agro-climatic and soil condition: The target project area is found in low-land area where climate and soil types are suitable for diversified crop production including cereal crops, pulse crops, fruit crops and forages. Cereal crops like maize and lowland wheat; vegetable crops like onion and tomato; fruit crops including mango and banana; forages like Sudan grass, buffel grass, Panicum antidotele, guinea grass/Panic (Panicum maximum), alfalfa and Rhodes Grass and that can adopt the climatic and soil conditions of the area were proposed. Moreover, most of the target program areas of the soil vary from sandy loam to heavy clay which is highly suitable for diversified crop production in combination with the application of integrated soil management. The only major critical factor in the project area for crop production is surface water scarcity and soil factor which should be resolved by the proposed irrigation water source and soil management actions respectively.

c) Food and feeding requirement and farmers' preference of crops: Unlike Dillo Woreda, currently, about 82%, 9%, 4.6% and 4% of the total cultivated land area are cultivated for producing cereals, vegetables, root and tuber crops and fruit crops respectively in Teltele Woreda for food and cash requirement[111]. However, of the total population of Teltele Woreda, about 47.7% of them are supported by World Food Program and Productive Safe net program. Similarly, of the total population of Mermero and Elkune kebele about 42.5% and 41.7% of Mermero kebele and Elkune kebele are supported by Productive Safe net program[112]. The preferences of pastoralists and agro-pastoralists and proposed pasture and crops are originated from livestock feed demand, food demand and better market price and storability of cereals for long time. Moreover, cereal crops are

[111] ECDSWC, 2021. The Federal Democratic Republic of Ethiopia: Irrigation Development Commission, Study and Design of Borena Groundwater Irrigation Development Project: Final Feasibility Report on Agricultural Planning and Irrigation Agronomy Studies. Addis Ababa, Ethiopia

[112] ECDSWC, 2021. The Federal Democratic Republic of Ethiopia: Irrigation Development Commission, Study and Design of Borena Groundwater Irrigation Development Project: Final Feasibility Report on Agricultural Planning and Irrigation Agronomy Studies. Addis Ababa, Ethiopia

not only selected for their food value but also their aftermath for livestock feed value since the local community is undertaking mixed farming, crop and livestock production. The crop aftermath and residue of maize and wheat are used for livestock feed in the target areas. For this reason and other interrelated criteria, recommended irrigated crops are cereals (maize and lowland wheat), and pulses and crops.

d) Government policy and strategy priorities: Food security is the first priority of the government of Ethiopia in the past two decades. The government of Ethiopia considers intensifying and commercialization of agriculture as the sole option to challenge poverty and food insecurity levels in rural Ethiopia. Wheat is one of the strategic crops in Ethiopia, because of its role for food security, import substitution and supply of raw material for agro-processing industry. Hence, Ethiopian Water Resource Management Policy [113] states that, irrigation is meant to improve food security through the implementation of small, medium and large-scale interventions. The policy also outlines that efficient and sustainable management of water requires management that combines federal level alignment with regional level.
e) For Market Purpose: - Onion, tomato, mango, banana and forages are a potential candidate crop both for cash and food purposes. Even though, these crops are not widely cultivated in the target command site they are well adapted and potential crops for purpose of market.

Employment opportunity and possibility of crop rotation: The selected crops engage more labour and unskilled labour and experience of smallholders' farmers for food, market, fodder and soil fertility management.

Agro-Processing Industries: Wheat crops are the potential candidate crop suitable for agro-processing purpose. The bi-product from the agro-processing plants could be used as important livestock feed source and hence could play an important role to integrate crop production with livestock production which is a major enterprise in the target area. In general, lowland wheat crops are also suitable for irrigated production in target area. Currently, there are one flour agro-processing industries in Yabelo nearby Yabalo town.

Cropping system is an important component of any farming system representing cropping system used on a farm and their interaction with farm resources and other farm enterprises and available technology, which determine their makeup. It is the yearly sequence of crops grown and the spatial arrangement of them and fallows in a given area. It is formulated with a view to obtain maximum crop production under a given situation. Two cropping patterns/seasons, each for first season (wet season) and second season (dry season) irrigation are proposed for the project to be adopted by the pastoralists and agro-pastoralists of project area. Crop rotation is also necessary to give due consideration with regard to cultivation of different crops in order to avoid growing crops of the same species repeatedly on the same land. This helps to avoid the building up of serious soil borne pests, weed and diseases. Hence, including legumes is highly important for crop rotation and land resource management and this report includes legumes with the project condition where the soil and the agro-ecology is high suitable.

Table 59 Crop Pattern the Borena Project

Crop categories	Seasons	
	First season	Second season
Cereals	Lowland wheat and maize	Lowland wheat and maize

[113] Ministry of Water Resource (MoWR), 1999. Ethiopian Water Resource Management Policy. Addis Ababa.

Pulses	Haricot bean	Haricot bean
Vegetable	Onion and tomato	Onion and tomato
Fruits	Mango and banana	Mango and banana
Forages	Grasses and legumes	Grasses and legumes

Table 60 Cropping Intensity Borena irrigation sites

No.	First season crops		Second season crops	
	Crop types	Area (%)	Crop types	Area (%)
1.	Lowland wheat	15	Lowland wheat	15
2.	Maize	15	Maize	15
3.	Onion	7	Onion	7
4.	Tomato	4	Tomato	4
5.	Haricot bean	5	Haricot bean	5
6.	Mango	2		46
7.	Banana	2		
8.	Forage	50		
9.	Grass	45		
	Legumes	5		
10.	Sub Total	100		46
	Total	200 (With all year round crops)		

1.3 Proposed Operational Crop Calendar with Project

The operational crop calendar of the irrigation project was proposed based on primary and secondary data collected from project Woreda and kebeles during the feasibility study, climate data particularly the rainfall pattern and distribution based on the selected meteorology station, discussion results from experts, agro-pastoralists, farmers, and stakeholders of the irrigation sites.

Table 61-Proposed Cropping Calendar of each irrigation sites

No.	Crop name	Land preparation	Planting date	Harvesting date	Total LGP (Days)
A	First season crops				
	Lowland wheat	Jan-Feb.	March 1st	June 1st	110
	Maize	Jan-Feb.	March 1st	June 1st	100
	Onion	Jan-Mid Feb.	Mid Feb.	End of May	100
	Tomato	Jan-Feb.	March 1st	End of June	120
	Haricot bean	Jan-Feb.	March 1st	June 1st	90
	Mango	Nov-Jan.	Feb. 1st	End of Jan.	365
	Banana	Nov-Jan.	Feb. 1st	End of Dec.	330
	Forage grass	Nov-Jan.	Feb. 1st	End of Jan.	365
	Forage alfalfa	Nov-Jan.	Feb. 1st	End of Jan.	365
B	Second season crops				
	Lowland wheat	Mid-June-July	Aug. 1st	Nov. 1st	110
	Maize	Mid May-June	July 1st	Oct. 1st	100
	Onion	Mid May-June	July 1st	Oct. 1st	100
	Tomato	Mid May-June	July 1st	End of Oct.	120
	Haricot bean	Mid May-June	July 1st	Mid Oct.	90

1.4 Soil and crop water requirements

The water requirement of a crop is mainly depending on climate, the type of crops cultivated, crop intensities, base period, reference ET, crop coefficient, conveyance losses (soil types, subsoil water, method of irrigation, ploughing methods, etc., also affects the crop requirement. Under the same condition different crops require different amount of water and the quantities of water used by particular crop vary with its stage of growth. Initially during seeding, sprouting and early growth a crop uses water at a relative slow rate. The rate will increase with growth of crop reaching the maximum in most crops as it approaches flowering and then decline towards maturity.

Crop water requirement is the water required by the plants for its survival, growth, development and to produce economic parts. This requirement is applied either naturally by precipitation or artificially by irrigation. The crop water requirement varies from place to place, from crop to crop and depends on agro-ecological variation and crop characters. Crop water requirement is the depth of water needed to meet the loss through evapo-transpiration of diseases free growing in large fields under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment.

$$\mathbf{ETcrop = ETo\ X\ Kc}$$

Where:

- ETCrop = Crop Water Requirement
- Kc = Crop coefficient
- Eto = Reference Evapotranspiration

The computation of Crop water requirement requires the data of Reference Crop Evapo-Transpiration, crop growth stages, crop coefficient and effective rainfall.

1.5 Reference Crop Evapo-Transpiration (Eto)

Reference crop evapo-transpiration is the rate of evaporation from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground with no shortage of water. The only factors affecting Eto are climatic parameters. As a result, Eto is a climatic parameter and can be computed from weather data (i.e., temperature, humidity, wind speed, sunshine hour). Eto expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors.

The Reference crop evapo-transpiration (Eto) for the project will be calculated by modified Pen man-Monteith method using CROPWAT 8.0 software. The long-term climatic factors/data will be considered from the nearest meteorology station will be considered and will be used for the calculation of Eto by using temperature (minimum and maximum), humidity, wind and sun shine hour as input for both Raya-Kobo and Borena project sites.

1.6 Length of Crop Growing Stage

There are four main growing stages of a crop during its growth period where water requirements vary i.e., the seasonal use of water by plants will be determined by their stage of growing. Since during the vegetative stage consumptive use continues to increase. Flowering occurs near and the peak of consumptive use of water. The fruiting stage is accompanied by a decrease in consumptive use until the transpiration essentially ceases during the latter part or the formation of dry fruits.

1.6.1 Crop Coefficient (Kc)

The effect of crop characteristics on crop water requirement is given by the crop coefficient. It represents the relationship between reference (ETo) and crop evapo-transpiration (ETcr) or ETcr = Kc x ETo

Values of crop coefficient given are shown to vary with the crop, its stage of growth, growing season and the prevailing weather conditions. The Kc for a given crop changes over the growing period as the groundcover, crop height and leaf area changes. Four growth stages are recognized for the selection of Kc: initial stage, crop development stage, mid-season stage and the late season stage. Therefore, the crop coefficients will be taken from yield responses to water, FAO irrigation and drainage paper 33, the table of crop coefficient (kc) of different growth stages.

1.6.2 Effective Rainfall

Effective rainfall is the proportion of rain, which is stored in the root zone and therefore be available to the plants. Rainfall which percolates beyond the root zone or is lost to the plants through surface run off is not effective, in that it is not available for plant growth.The effective rainfall will be calculated using the CROPWAT 8.0 software and the method for CWR (effective rainfall) calculations will be dependable rain (FAO/AGLW formula). Several factors influence the proportion of effective rainfall and these may act singly or collectively and interact with each other. These factors are rainfall characteristics, land slope, soil properties, ground water characteristics, management practices, crop characteristics, carry over soil moisture, seepage and percolation will also be considered.

Moreover, the texture of the soil and other soil characteristics pertaining to total available soil moisture (FC-WP) (mm/m), maximum rain infiltration rate (mm/day), maximum rooting depth (cm), initial soil moisture depletion (as % of TAM) and initial available soil moisture (mm/m) will be considered.

1.6.3 Irrigation Depth (D)

Depth of irrigation (d), including application losses, applied to the soil in one irrigation application and which is needed to bring the soil water content of root zone to field capacity in mm will also be considered based on field application efficiency and inputs:

$$\mathbf{(d)} = \frac{\mathbf{(p\ X\ Sa)\ X\ D(mm)}}{\mathbf{Ea}}$$

Where:

- p = fraction of available soil water

- Sa = total available soil water mm/m soil depth
- D = Rooting depth, m
- Ea = application efficiency, fraction

1.6.4 Irrigation Interval (i)

The irrigation schedule or days interval between two consecutive applications will be determined with simple formula or by using the cropwat software.

$$i = \frac{(p.sa).D}{ET\ crop}$$

Where

- i = Irrigation interval
- p = fraction of available water (%) … given
- sa = Total available soil moisture (mm/m).
- D = Rooting depth (m), tabulated reference
- ETcrop (ETc) = Crop water requirement

1.6.5 Irrigation Efficiency (E)

Not all water taken from source to be used for irrigation reaches its destination and used by plants. Part of the water is lost during transport through the canals and the fields. The remaining part is stored in the root zone and use by plants. In other words, only part of the water is used efficiently, the rest of the water is lost through Conveyance efficiency (Ec), Field canal efficiency (Ed), and Application efficiency (Ea). Accordingly, the overall irrigation efficiency (Ep) will be Ec x Ed x Ea.

1.6.6 Water application efficiency (Ea)

It is the percentage of applied irrigation water stored in the soil and available for consumptive use by the crop. Field losses consist of surface run off and deep percolation. The purpose of irrigation is to replenish the available moisture in the root zone depleted by evapotranspiration. The application of the least amount of water required to bring the root zone moisture content up to field capacity is considered as efficient irrigation. Therefore, field application efficiency will be considered in crop water requirement.

1.6.7 Net and Gross Irrigation Requirements

Net irrigation requirement (IRn)

It is a depth of water needed to bring the soil moisture level in the effective root zone to field capacity from the soil moisture. The net irrigation requirement does not include losses that are occurring in the process of applying the water. IRn plus losses constitute the Gross Irrigation Requirement (IRg). It will be calculated by using the relationship between crop water requirement (ETcr) and effective rainfall, i.e., Net irrigation requirement = ETcr – Effective rainfall.

Gross irrigation requirement

The total quantity of water used for irrigation is termed as gross irrigation requirement. It includes net irrigation requirement and losses in water application and other losses in the conveyance system due to seepage, evaporation, etc. and will be computed as follows:

$$\text{Gross irrigation requirement} = \frac{\text{Net irrigation requirement}}{\text{Overall project efficiency}} \text{X100}$$

Agricultural crop and forage production projection is an important output of the agronomy feasibility study that explains the potential of the project to meet the anticipated objectives. Moreover, the crop yield projection will be used as a major input for financial and economic analysis that determines the feasibility of the irrigation development project. Since, the yield incremental rate per year could vary depending on the genetic potential of the proposed crops and farm management efficiency.

The major assumptions required to develop appropriate annual yield increment based on the local conditions of the project area and objectives of the project and considered as follows:

1) Performance of existing crop productivity of the proposed crop without project intervention,
2) The yield achieved through improved practices in the project area,
3) Farmers' experience and capacity to practice improved irrigated farming and use of improved agricultural inputs,
4) Comprehensive technical support from Zone, Woreda and kebele agriculture and natural resource office experts,
5) The effectiveness of agricultural input supply system and availability of effective credit facility and
6) Farmers' commitment to adopt and practice the proposed improved agronomic activities and crop farm management.

Regardless of the irrigation water source and land, in the project area where there are active beneficiary involvement and a relatively better level of improved technology application on some crops, the optimum yield could be achieved within a shorter period. In the context of the Raya-Kobo and Borena irrigation development with intensive extension support, the optimum yield for annual crops might be attained in 3-4 years. In the case of tree fruit perennial crops, the year could be extended to 6-8 years.

Annex 8: Methodology to Determine Livestock Water Requirements

1.0 GENERAL

Water requirement by livestock appears to reflect individual and specific herd characteristic. Such differences are reflected in the herds respective abilities to withstand dehydration and in their demand for free water. As the demand of the individual animal for water is variable, only average estimates of water requirements in a specific climatic environment are generally indicated (Tables 62 and 63)[114].

Table 62-General guides to water intake of different class of animal

Class of livestock	Daily water requirement		
	gallons/day	Litre/day*	average Litre/day*
Beef cows	7–12	26 - 45	36
Dairy cows	10–16	38 - 61	49
Horses	8–12	30 - 45	38
Sheep and goats	1–4	4-15	9
Chickens	8–10/100 birds	30 - 38/100 birds	34

Assumed by 1gal.= 0.26417*liter

Table 63-Estimated water requirement and voluntary intake of livestock under Sahelian conditions1

Species	TLU2	Mean live weight	DM Intake	Wet season air temperature (27oC)		Dry cold season air temperature (15–21oC)		Dry hot season air Temperature (27oC)	
				TRW	VWI	TRW	VWI	TRW	VWI
				Litres/day					
Camels	1.6	410	9	50	15	37	35	50	50
Cattle	0.7	180	5	27	10	20	19	27	27
Sheep	0.1	25	1	5	2	4	4	5	5
Goats	0.1	25	1	5	2	4	4	5	5
Donkeys	0.4	105	3	16	5	12	11	16	16

TWR= Total Water requirement, VWR=Voluntary water intake

1) Voluntary water intake has been calculated from the water requirements by assuming a water supply from the plants corresponding to: 70 to 75% of moisture content of the plants during the wet season 20% of moisture content of the plants during the dry and cold season 10% of moisture content of the plants during the dry and hot season.
2) TLU = Tropical livestock unit is equivalent to an animal of 250 kg live weight on maintenance.

The water requirement of domestic animals varies between species, between breeds or varieties within species and between individuals within breeds. For example, heavy western breed cows have a higher water intake (60 to 90 litres/day) than zebu cows (25 liters/day with 350 kg live weight[115] . This requirement is expected to

[114] Sileshi, Z., Tegegne, A. and Tsadik, G.T., 2003. Water resources for livestock in Ethiopia: Implications for research and development. Integrated water and land management research and capacity building priorities for Ethiopia, 66.
[115] King 1983

increase due to the increase in livestock population and envisaged improvement in productivity (milk, meat, eggs). Improvements in the dairy sector, for example, will require additional water for milk production and sanitary management[116]. Therefore, the amount of available water can determine the amount and type of animals to be included in the proposed project.

The water demands of sheep, goats and camels are not as high as those of cattle. Water requirement increases with growth, and with increases in productive processes such as lactation and egg laying. Lactating cows consume more water to cope with the water excreted with milk than cows of similar weight fed on maintenance level.

Water requirements also largely vary according to other factors such as food intake, quality of the food and air and water temperature. Water consumption increases with increasing dry matter intake and increasing temperature. Bos taurus cattle weighing 450 kg and eating 10 kg dry feed per day drank 28, 41 and 66 litres of water per day when the temperature is 4, 21 and 32°C, respectively[117].

Smith[118] stated that water should be always available especially in arid and semi-arid areas, where getting green feed is difficult. Therefore, water availability should assume both for feed production, stock drinks and hygiene. In case of drinking water requirements, we have to:

- Estimate the daily water requirements for the class of livestock in the period
- Estimate supplied water – quantity and quality.
- Construct or maintain suitable watering points.

If either the water supply or feed is less than required by the livestock to be carried throughout the year, then there should be need to destocking plan (sell, agist or move) before animal welfare becomes a deteriorated and mass loss of livestock occurred like that happened in Borena in 2021.

Good quality livestock water characterized by having:

- Salinity within the acceptable range for the animal type and condition
- Water pH between about 6.5 (acid) and 8.5 (alkaline)
- Freedom from toxic elements and chemicals
- No contamination with toxic algae or putrid materials
- Temperature below the body temperature of livestock

The daily water requirement of livestock will be calculated using the average estimates of water requirements in a specific climatic environment. In this regard, a minimum average daily consumption of 25 liters of water per TLU[119] will be used to assume total livestock water requirement of the project

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[116] Sileshi, Z., Tegegne, A. and Tsadik, G.T., 2003. Water resources for livestock in Ethiopia: Implications for research and development. Integrated water and land management research and capacity building priorities for Ethiopia, 66.

[118] Smith G, 2021. Livestock water requirements and water budgeting for south-west Western Australia accessed https://www.agric.wa.gov.au/small-landholders-western-australia/livestock-water-requirements-and-water-budgeting-south-west

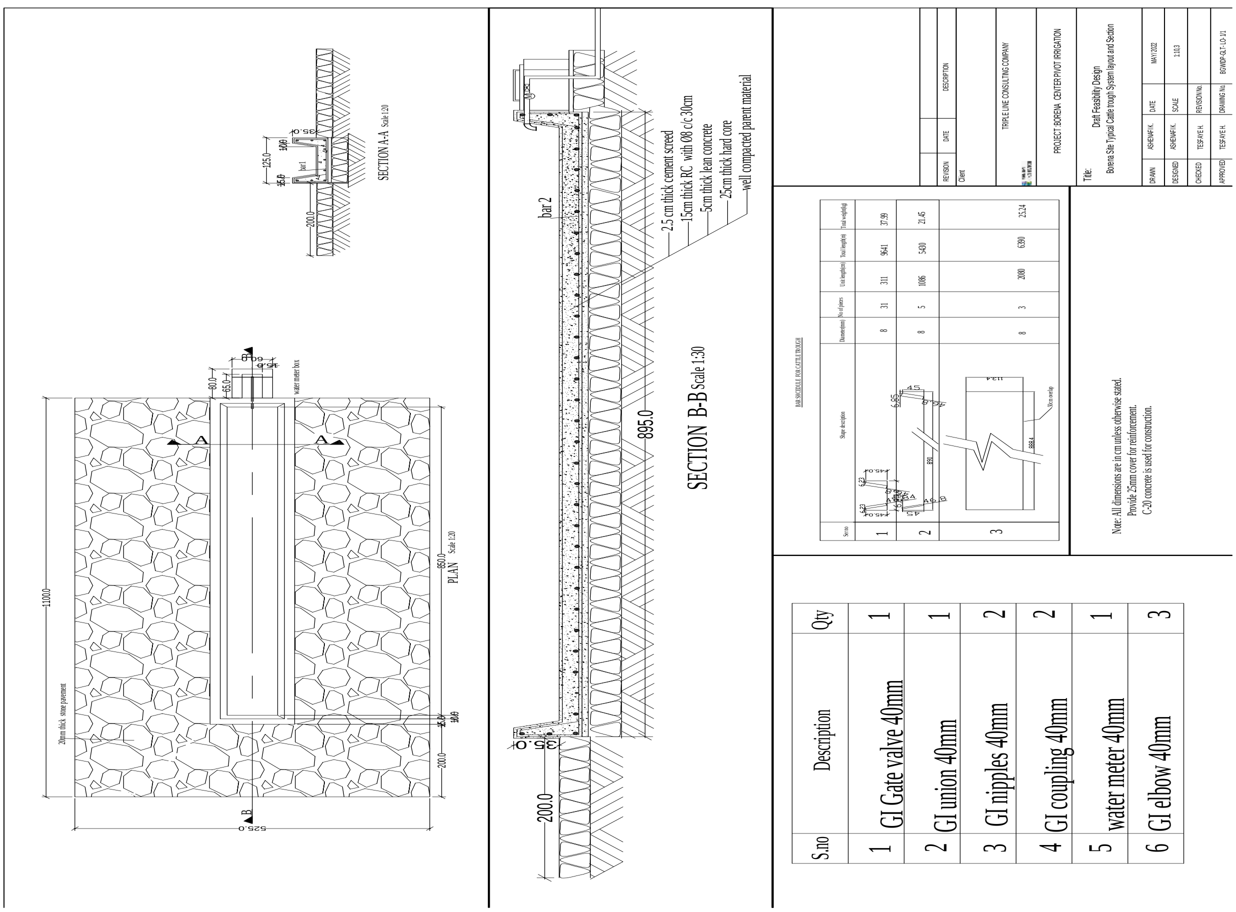
[119] Sileshi, Z., Tegegne, A. and Tsadik, G.T., 2003. Water resources for livestock in Ethiopia: Implications for research and development. Integrated water and land management research and capacity building priorities for Ethiopia

beneficiaries. Therefore, the amount of available water can determine the amount and type of animals and in turn the number of beneficiaries to be included in the proposed project.

Based on previous experience of ECDSW (2021), if there will be settlements to the vicinity of the water points, the recommended amount of livestock size per household will be 10 TLU. Accordingly, the minimum livestock drinking water requirement per day per household will be 250 liters. Furthermore, water for sanitary purpose including cleaning of both the farms, the animals and personnel that manage the livestock.

In association with water point and forage development interventions, there should be animal health service to tackle the risk of water-born livestock diseases that comes across the water points and irrigation line.

Figure 93 Cattle Through plan and section



Annex 9: Current and Past Initiatives undertaken in Kobo Raya Valley and Borena

1.1 Kobo Girana Irrigation Development

The Kobo Sub-basin where pressurized irrigation project is located between 12° 18' to 11° 56' N latitude and 39° 23' to 39° 47' E longitudes. Administratively, it is located in the northern Wollo Zone of the Amhara National Regional State, Kobo Woreda. It is found at a distance of 50 kms from the zone town Woldia and 410 km from the regional town, Bahir Dar. The total area of the sub-basin is estimated to be 1439 km2 of which 29 percent is flat plain and the remaining is either mountainous or hilly. The location map of both valleys is shown in the Figure 1. According to Metaferia Consulting Engineering (MCE)[120], the development of agriculture in the valley as well as in these Woredas are greatly affected by the adverse environment, rapid population growth, poor farming practices, shortage of farm lands, low crop yields and shortage of animal feed are identified as major constraints for the population of the project area. As a result, food supply is frequently in short supply and crop produced is below the requirement of the currently residing population in the project area. Hence, the study was aimed to reverse the harnessing effect of the current situation on the available resources of the area through the development of irrigation 23,000 hectares of land.

Ground water resource is believed to be the huge water resource in the project area. Based on the hydrogeology studies and current aquifer tests conducted on the project, a safe yield for 100 production wells has been determined. The safe yield of the wells varies between 15 l/s to 100 l/s with exception of a few, where the safe yield is ≤ 10 l/s. These wells are 8 in number and as per the financial and economic analysis carried out during the beginning of this project for these low-yield wells, irrigation development is not found feasible. In addition, 3 wells of phase-I are also included and designed since the safe yield data has been prepared lately in this year with the ground water modelling report. Therefore, this document covers draft detailed engineering design of head works at the wells as well as the irrigation distribution systems for the 92 production wells of phase-III, and 3 phase-I wells.

The supply system for distribution lines is developed through direct pumping of water from the well while the irrigation system design is prepared based on the location of the wells/reservoir, assessment of topographical map and the availability of total discharge from each sources The irrigation system is interchangeable drip and sprinkler systems in which pressure adjustment valves are installed to use both systems on the given plots of land as per the demand of the farmers. Drainage networks are also provided to safely remove the excess rainfall from the irrigation plots and protect the plots from the upland catchments flood during rainy season.

1.2 Alewuha Kobo Ground Water Irrigation Project

Alewuha-Kobo irrigation project is found in Amhara National Regional State, North Wollo Zone, Raya Kobo woreda and within 022 kebele. The site is located about 32 km from Kobo (Capital of Raya Kobo woreda). The geographical coordination of the command area lies at approximately 577974.667 - 577339.079UTM East longitudes and 1316792.926 - 1316414.432UTM North latitude and an elevation range of from 1390 - 1411 meters above sea level (masl).

[120] Metaferia Consulting Engineering PLC. (MCE), 2008. Girana Irrigation Agronomy Study report. Addis Ababa, Ethiopia.

In the project area, the main bottle neck for the successful crop production is the nature of uneven distribution rainfall. The rainfed agriculture is mainly based on kiremt rainfall. In the project area, the longer rainy season (kiremt) occurs from June to September and sometime ends in late August. During this time of span some crops are grown despite the fact that there are frequent moisture stresses towards the end of the rain season. Depending on the climatic factors, i.e., late or early start of kiremt rainfall, the cultivated land coverage or cropping pattern vary from year to year. As altitude governs the temperature, rainfall and types of crops that can be grown, the project area is suitable for the production of mid-to lowland crops. The major crops grown in kebele 022 where the project site is found includes: sorghum, teff, maize, chick pea, etc.

According to the study report, taking the estimated ground water and land potential of the valley in one hand and method of irrigation to be used on the other hand in to account, the project is planned to develop on net command area of 36ha of land.

1.3 Galchet smallscale irrigation Pasture development project (2017)

Galchet smallscale irrigation project is geographically situated at 360944.142 E and 505276.718 N UTM in Dillo woreda in kenchero kebele. The main source of irrigation in the project area is groundwater borehole. The project site is located at about 20 kms away from Dillo woreda capital town. The project is aimed to increase livestock productivity in the area through cultivating a new pasture or improving an existing natural pasture adapted for the area with maximum productivity of 2.5tone/ha on targeted areas of 48ha of land size. Currently, the project is developing the pasture on 24hectares of land with Rhodes grass, Panicum maximum, Buffel grass and Panicum antidotele . In addition to these, more than 30,000 livestock and more than 15,000 households were benefited.

The absence of Perennial River in the target area negatively plays great role for expansion of both traditional and modern irrigation schemes. However, Groundwater based forage development irrigation project were initiated by Oromia pastoralist area Development commission on Galchete irrigation command site and the study was prepared by Oromia Irrigation Development Authority and Oromia Water Works Design and Supervision Enterprise (OWWDSE).

However, experience of irrigation is not known in Borena zone particularly in targeted project sites, since, the targeted irrigation sites of Borena groundwater is at least 50km from the nearest irrigation site. Galchet small-scale irrigation project is producing pasture on about 24ha and the small areas of farmland are currently irrigated by local farmers with drip irrigation method by using water from boreholes with generator pump and due to damage of pumps and incomplete structure it is working beyond its potential. Therefore, the development pasture on Galchete may be used as a benchmark for getting experience for each targeted sites of the community through arranging the field visit program.

1.4 Borena Groundwater Irrigation Development Project (2021)

The Borena Groundwater Irrigation Development Project is located in Teltele and Dillo Woreda, Borena Zone, in Oromia National Regional State. This project was submitted to ECDSWC in response to the invitation for Consultancy Services of detail feasibility and design by Irrigation Development Commission. The Development of Groundwater Irrigation Project aims to establish different types of multipurpose water infrastructures for ensuring sustainable water supply for crop and forage irrigation development and drinking water for livestock particularly for pastoral communities. It proposes measures and technologies in order to address irrigation based agriculture development and the integration of optimum crop-livestock and forage production on net command area of 3,270ha irrigable land. Thereby, promoting increased and sustainable production of livestock feeds, food crops, high value and market oriented irrigated crops, which in due course of time could be linked to agro-processing industries for value added chains[121].

The target project comprises five kebeles; Goray and Hobok Sigirso kebele in Dillo Woreda; and Elkune, Mermero Kobo and Mermero Kelo kebele in Teltele Woreda. The project site is located in seven sites, the Elkune, Bule Danbi, Mermero and Kobo irrigation sites are located in Teltele Woreda whereas the Eldima, Melka Sadeka and Hobok irrigation sites are located in Dillo Woreda. The project sites were selected because of the amount and distribution of rainfall in the area is very low intensity, sometimes high intensity with short duration, highly erratic and it is not reliable for successful crop production in both "Meher" and "Belg" rainy season and therefore full-fledged irrigation water source is highly important for crop and forage production in both seasons.

1.5 Raya valley Agricultural Development Project

A feasibility study report study document prepared by water works design and supervision enterprise-WWDSWE (the present Water and Energy sector of Ethiopian construction Design and supervision Corporation (ECDSWC) in 1998. Volume III Agriculture of the study revealed that Raya valley is considered to be livestock potential in terms of high population and adaptability of the livestock to the harsh environment they're existed. It suggested that the productivity of livestock can be improved by proper breeding selection using selected bull or artificial insemination. The study report also added the breeding program has to be complemented with improved feeds and nutrition as well as health service delivery, market linkage of the output products and capacity building training.

Furthermore, the Raya area possess different agro ecology and suggested Livestock improvement, poultry and beekeeping projects for highland midland and lowland agro ecological zones[122]

1.6 Kobo Raya Valley Pressurized Irrigation Project (Phase III)

The Kobo-Raya Valley Pressurized Irrigation Project is located in the southern part of Tigray National Regional State between latitudes 12^{o} 16'N and 12^{o}55'N and longitudes 39^{o}22'E and 39^{o}53'E. The project site is approximately 600km far from Addis Ababa and 150km from Mekelle.The project is planned for development of the agricultural land around 100 production wells drilled in Raya valley through the implementation of Interchangeable Drip and Sprinkler Irrigation Systems by pumping ground water from these wells.

The project area is spread over in two Woredas, i.e. Alamata and Raya Azebo Woredas. Because of their geographical proximity, the agro-climatic conditions in both the areas are similar and therefore same MDD is considered both these Woredas.

[121]ECDSWC, 2021. The Federal Democratic Republic of Ethiopia: Irrigation Development Commission, Study and Design of Borena Groundwater Irrigation Development Project: Final Feasibility Report on Agricultural Planning and Irrigation Agronomy Studies. Addis Ababa, Ethiopia.

[122] WWDSWE (Water Works Design and supervision Enterprise), 1998. Feasibility study report for the Raya valley Agricultural development project Volume III: Agriculture Annex K. Livestock

The Raya pressurized irrigation project is located between 12°16' and 12°55' N latitudes and 39°22' and 39°53'E longitudes. It is found at about 600 kms north of Addis Ababa and at 180 kms south of Mekelle, the capital of the National Regional State of Tigray. It is bordered by the Afar National Regional State to the east, the Amhara National Regional State to the south, part of Ofla and Enda Mehoni Woeredas to the west and Alaje and Hintalo Woredas of Tigray National Regional State. The surface watershed of the valley approximately covers a total land area of 2369 km^2.

The Raya valley pressurized irrigation project is located in the lower flat plain of Raya Valley in Raya Azebo and Alamata Woreda and the general objective of pressurized irrigation project is to utilize the immense natural resources of the valley and produce high value commercial and food crops which are suitable to the area and ensure food security at local, regional and national levels, to produce raw materials for agro-industries and export crops for foreign exchange earnings. According to the study report, taking the estimated ground water and land potential of the valley in one hand and method of irrigation to be used on the other hand in to account, the project is planned to develop 6,000ha and 12,000ha cultivated land in Alamata and Raya sub basins respectively at large scale using different ground water sources. Accordingly, the total area to be developed is 18,000ha[123].

Annex 10: Detailed GIS Map of Borena zone and Kobo Girana (separate document)

Annex 11: Technical Drawings SWPs and Irrigation Systems (separate document)

[123] Water Works Design and Supervision Enterprise in Association with Intercontinental Consultants and Technocrats Pvt. Ltd (2011)

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