Yield evaluation of shallow hand-dug wells for irrigation in Upper Gana and Jawe kebeles of Lemo woreda, Ethiopia

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It is important to note that a research project such as this is never accomplished without the collaboration and cooperation of various departments, organizations and people.

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Acronyms

EMA	Ethiopian Mapping Agency
ILRI	International Livestock Research Institute
IWMI	International Water Management Institute
MoWIE	Ministry of Water, Irrigation and Energy
RWH	Rainwater harvesting

Abstract
An appropriate approach of utilizing water resource is based on assessment of its quantity. Hence making assessment of the water resource quantity and its development potential is prior task that should be undertaken before making any sustainable action. Absence of assessment on yearly reserved quantity of groundwater and yield of shallow wells leads to excessive withdrawal that quickly exhausts the groundwater reserve and the well yield. Furthermore installing pumps lower than the yield of the well can cause inefficient utilization and higher than the yield will also lead to damage of the aquifer system.

This study was undertaken in Lemo woreda of Hadiya zone; Jawe and Upper Gana kebeles by Africa RISING. The study will avoid the anticipated problems by estimating volume of the groundwater that can be withdrawn annually and by evaluating the shallow well yield as well as by determining the average hectare of land that can be developed. Selection of pump and rain water harvesting (RWH) technique had also been undertaken to resolve the problems. Rainfall recharge and well recovery methods are employed to estimate the annual groundwater reserve and the well yield respectively.

The study shows the yearly recharge to groundwater systems is about 8.76077×10^5 m^3 in the Upper Gana micro watershed and 4.76502×10^5 m^3 in the Jawe micro watershed. Based on the recharged groundwater assumed accessible quantity, an average of 27.954 ha of land in Upper Gana micro watershed and 15.196 ha of land in the Jawe micro watershed can be developed by irrigation with 100% efficient method. The pump test also shows the well yield to be ranging from 0.308 to 0.38 lit/sec with an average of 0.348 lit/sec.

Based on this average yield, about 0.6055 ha of land in a household can be developed by irrigation with 100% efficient method. With the use of 65% efficient furrow method about 0.3936 ha of land can be developed in households. Animal driven rope and washer pump is the one that suits the average well yields and the local conditions. Farm pond is the RWH technology that fits the existing situation of the micro watersheds for supplementary irrigation and swing basket is found better to lift water harvested in the farm pond. Farm pond can develop 400 m^2 of land in average on the two dry seasons of the year.

With this it is understood only a limited irrigation is possible to be undertaken in the micro watersheds of Upper Gana and Jawe. Therefore an efficient irrigation method should be selected based on the local condition and design, assembly and test of sample for animal driving rope and washer pump and swing bucket must be undertaken.

Background

In developing countries, irrigated agriculture plays a vital role in contributing towards domestic food security and poverty alleviation. Intensifying productivity in smallholder farming is a high priority for Ethiopian Government because of the high occurrence of rural poverty and the large productivity gap in the smallholder subsector (GoE 2010). Therefore, irrigation is an important component of agricultural production in developing countries like Ethiopia (Turner et al. 2004).

Surface and groundwater are important sources of water for irrigation and they are integral part of the strategy to overcome food scarcity in developing countries including Ethiopia (Nata et al. 2009). Surface and groundwater potential of Ethiopia is estimated to be about 110.15 billion m^3 and 2.6 billion m^3 per annum, respectively (Yemane 1998).

The Ethiopian Government is implementing small scale irrigation schemes at the household level to address food security because large scale irrigation system operation and maintenance cost become potential problems. Household level irrigation schemes are promoted with a broader objective of minimizing the vulnerability of smallholder crop production systems to rainfall fluctuation and thereby enhancing food security. From the promoted techniques for small scale irrigation farm ponds of surface water resource utilization and shallow hand dug wells for groundwater resource utilization can be mentioned.

An appropriate approach to utilize these precious surface and groundwater sources is based on assessment of their quantity and development potential. Hence to make a realistic assessment of the surface and groundwater resources quantity and their development potential is a prior task that should be undertaken before making any sustainable action.

Therefore this study primarily focuses on estimation of groundwater quantity, the yearly recharged water in the micro watersheds system, and yield of shallow hand dug wells, the quantity of water delivered per unit of time which may be pumped continuously from the well (D'haeze et al. 2005). Secondly, this study focuses on the assessment of Rain Water Harvesting (RWH) technology to support shallow hand dug wells yield for supplementary use to meet the irrigation water requirement of high value crops and fodder during the two dry seasons of the year in Upper Gana and Jawe *kebeles* micro watersheds of Hadiya zone Lemo *woreda*.

Problem statement

Shallow hand-dug well is a pit dug to the groundwater table manually. These wells usually do not penetrate the groundwater deep enough to produce high water yield. Therefore investigation of the groundwater reserve and the shallow hand dug well yield is a primary and essential action to be performed prior to any development action. Pumping for irrigation can quickly exhaust the water supply of shallow hand dug well and installing pumps lower and higher than the yield of the well can cause inefficient utilization of the valuable resource and damage of the aquifer system, respectively. To avoid such problems and to make any irrigation based development actions sustainable the groundwater reserved quantity in micro watersheds and shallow hand dug well yield must be evaluated.

Limitations of the study

The study was undertaken on the end of the dry season of the year that is on the first two weeks of June. The time was expected to be the right time to take pumping data to evaluate the reliable yield of the seven sample wells of Upper Gana and Jawe micro watersheds but unexpected rain occurred on the time of pumping measurement. The rain was not too much to have major effect on the well yield result. Even though effect of the rain was negligible, the result of the wells yield has been corrected for the height of the groundwater increase to simulate the dry season groundwater height. This correction made can cause inaccuracy in the wells yield estimation.

Objectives

Major objective

- To evaluate yield of the shallow hand dug wells of seven farmers from Upper Gana and Jawe micro watersheds of Hadiya zone; Lemo *woreda*.

Specific objectives

- To assess the yearly recharged quantity of groundwater in Upper Gana and Jawe micro watershed.
- To approximate potential area of land that can be developed by irrigation in the Upper Gana and Jawe micro watersheds.
- To evaluate average yield of hand dug wells in Upper Gana and Jawe micro watersheds.
- To estimate the average potential area of land that can be developed in households in Upper Gana and Jawe micro watersheds.
- To increase depth for the seven wells in Upper Gana and Jawe micro watersheds.
- To assess and recommend the precise pumping equipment for the drawing of the water from the shallow hand dug wells and from the rain water harvesting technology in Upper Gana and Jawe micro watersheds.
- To assess surface water hydrology system of the micro watersheds of Upper Gana and Jawe and recommend the appropriate water harvesting technology for the studied seven farmers.
- Awareness creation on groundwater resource and potential and irrigation systems for the seven farmers in Upper Gana and Jawe micro watersheds.

Description of the study area

The Lemo Gilgel Ghibe sub-basin is one of the sub-basins of the Omo Ghibe basin, one of the twelve basins of Ethiopia, and is located completely in the southern nation’s nationalities people region. Hosaena City is found within this sub-basin and the watershed divide line of the basin passes through Jajura town. The Lemo Gilgel Ghibe sub-basin is found between 7°25'55" and 7°37'41" latitude and 37°37'55" and 37°52'48" longitude.

The Upper Gana and Jawe micro watersheds are the two micro watersheds from the 26 micro watersheds found in Lemo Gilgel Ghibe sub-basin. These two micro watersheds are specific areas where the study has been undertaken.

The Upper Gana micro watershed, named after the *kebele*, has an area of about 1946.54 ha and is located between 7°31'55" and 7°33'54" latitude and 37°40'48" and 37°45'58" longitude. This micro watershed is drain by two major rivers called Ajacho and Dageramo.

The Jawe micro watershed, also named after the *kebele*, has an area of about 1024.73 ha of land. It is located between 7°30'54" and 7°25'55" latitude and 37°45'29" and 37°49'12" longitudes. The major river that drains this Jawe micro watershed is Ajo. Morsito town is found to the north, Fonko town is found northeast, Jajura and Gimbichu town are located to the southwest, Angacha and Durame towns are situated to the southeast of these two micro watersheds.

The Lemo Omo Ghibe sub-basin covers about 40,909 ha comprising 24 micro watersheds. Upper Gana and Jawe micro watersheds are two of these 24 micro watersheds where interventions have been undertaking on irrigated fodder, high value crops and watershed rehabilitation, conservation and development activities by the Africa RISING project.

The Upper Gana and the Jawe micro watersheds approximately cover together about an area of 2971.27 ha of land and are about 7.2% of the total area of the sub Lemo Gilgel Ghibe sub-basin as can be seen in Figure 1. The focal area of the study where groundwater potential, shallow hand dug wells yield had been undertaken, that is wells location map is shown in Figure 2.

Figure 1. Locations of the Upper Gana and Jawe micro watersheds

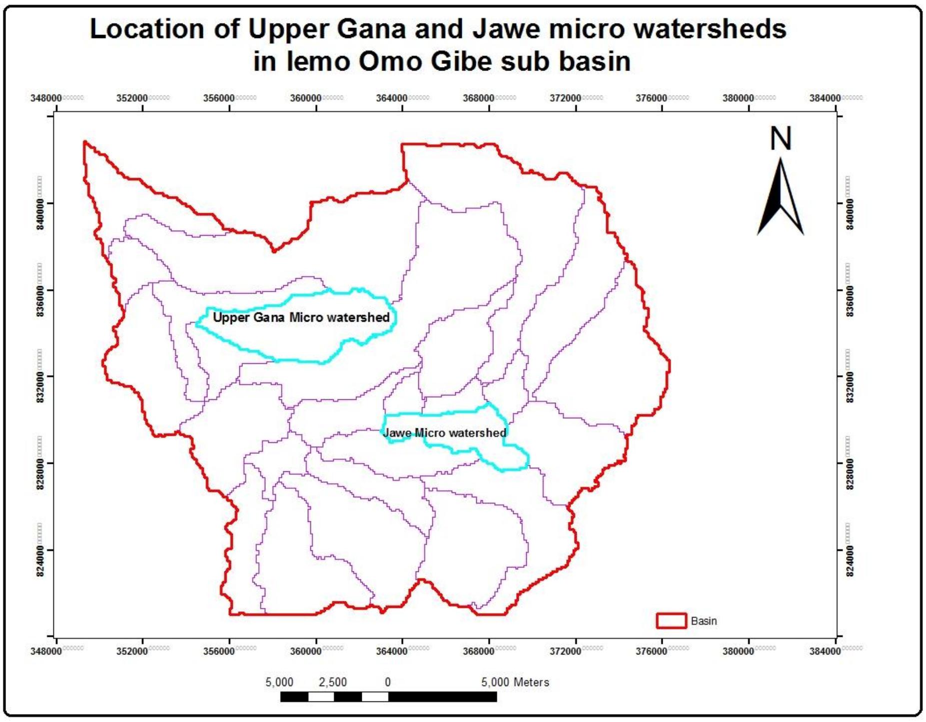

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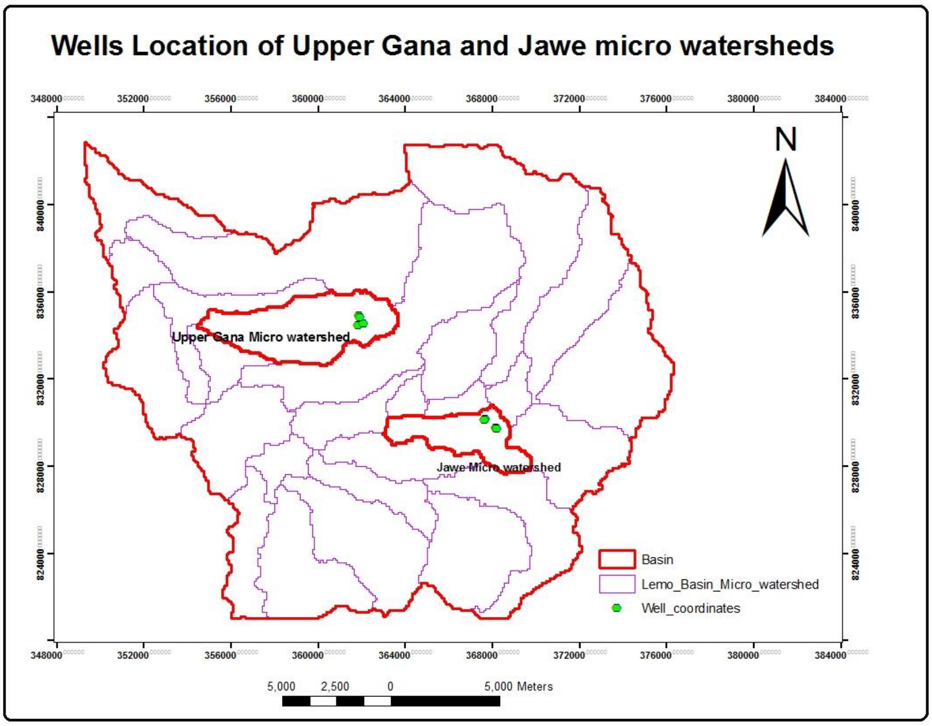
Figure 2. Studied wells location map in the Upper Gana and Jawe micro watersheds



Climate and hydrology

The annual rainfall of the area is from 1300 mm in Upper Gana micro watershed area and about 1350 mm in Jawe micro watershed based on the Isohyets that pass through the micro watersheds shown in Figure 4 and as can be inferred from the Durame station data that is the nearest station possible to these micro watersheds. Both the Upper Gana and Jawe micro watersheds have two maximum rainfall seasons from June to August (Kiremt) and from January to February (Bulge). The annual temperature of both micro watersheds ranges from 9–26ºC according to the Lemo *woreda* administration Agricultural bureau natural resource conservation and utilization core work process information.

The rivers in the Upper Gana Micro watershed are commonly called Ajacho and Dageramo and the major river that drains Jawe micro watershed is Ajo River. These major rivers of the micro watersheds are perennials that flow all year around but their discharge decreases significantly during the dry months of the year. The river Ajo of the Jawe micro watershed flows towards and joins the Upper Gana rivers that are Ajacho and Dageramo and these micro watersheds are interconnected in their surface hydrology. These rivers Ajo, Ajaco and Dageramo drain all the Upper Gana and Jawe micro watersheds towards the Gilgel Ghibe River as shown in Figure 3.

Figure 3. Drainage network of Upper Gana and Jawe micro watersheds

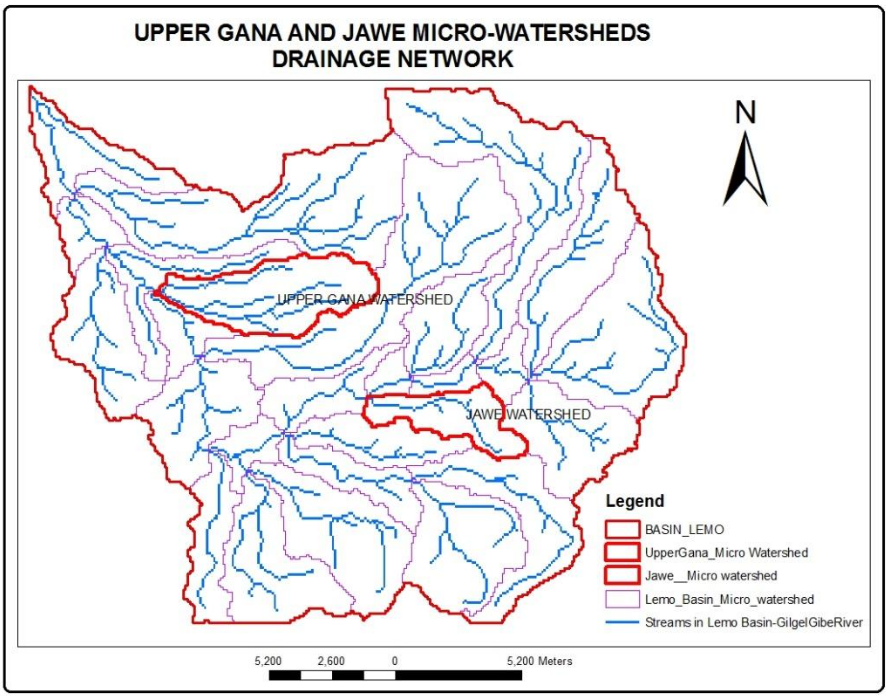
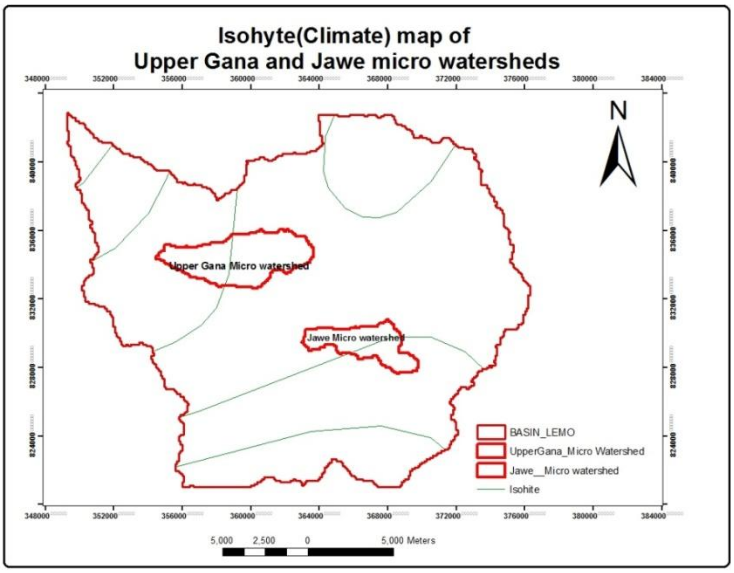


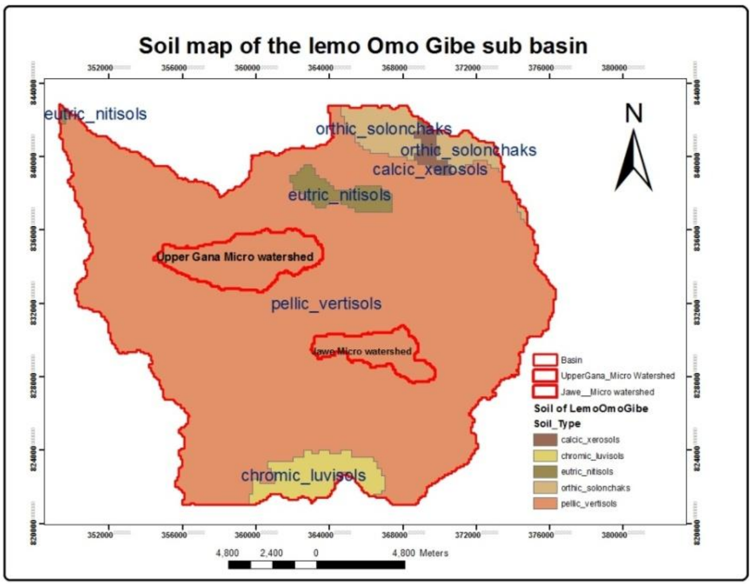
Figure 4. Isohyets map of Upper Gana and Jawe micro watersheds



Soils

The soils of both the Upper Gana and Jawe micro watersheds is Pellic Vertisol as is extracted from the Omo Ghibe master plan study and is shown in Figure 7. The scale this map is 1:250,000 scale therefore it can be used only in comparative sense. This soil is black in colour and has a relatively high water storage capacity in the root zone because of its depth and high clay content.

Figure 5. Soil map of the Lemo Omo Ghibe sub-basin



Geomorphology

The altitude of the Lemo Gilgel Ghibe sub-basin is situated between 1722 and 2829 metre above sea level as extracted from the 30 m resolution DEM map of the sub-basin so it is grouped under Woyina Dega and Dega traditional agro ecological zone. The sub-basin is located just on the watershed divide of the rift valley lakes basin drains to the Omo Ghibe basin. The sub-basin lied along one of the major tributaries of Omo Ghibe River called Ajo from about four upper catchments that are from the north, east and south parts of the sub-basin many little streams flow down from south to northwest to Gilgel Ghibe River as shown in Figure 4 below, and it is slope areas with the maximum of about 15% that is almost flat the micro watersheds lies as shown in Arc GIS.

As observed on from Upper Gana and Jawe micro watersheds separate slope maps the maximum slope in Upper Gana micro watershed is 14.7068% and maximum slope in Jawe micro watershed is 17.59% their mean slope is about 5.36969 and 5.14649respectively as it can be clearly depicted in Figures 6 and 7. An average of about 99% of both the micro watershed area is level (<3%), gently sloping (3–8%) and moderately slopping (8–15%) land with the anticipated drainage characteristics of more infiltration; minimum runoff; flood and erosivity.

Figure 6. Slope map of the Lemo Omo Ghibe sub-basin

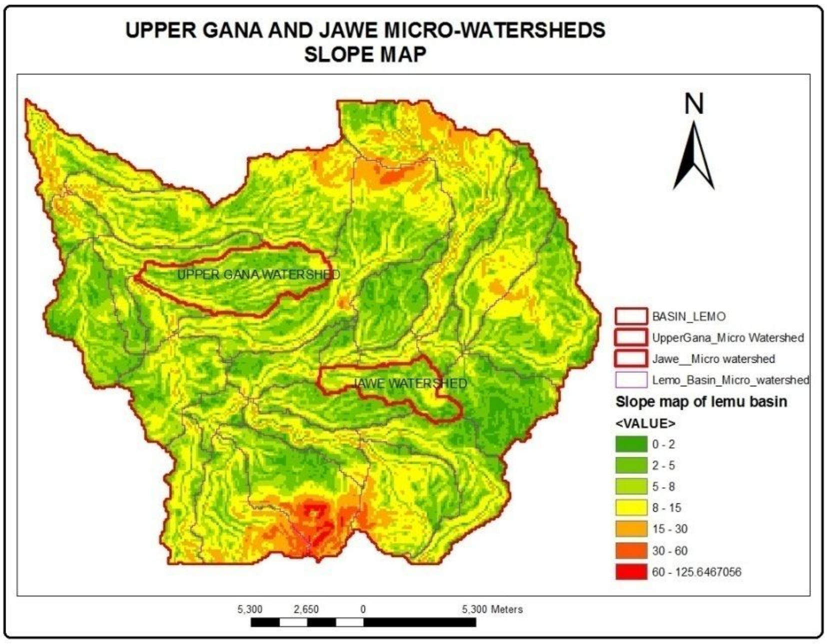


Figure 7. Slope map of Upper Gana Micro watershed

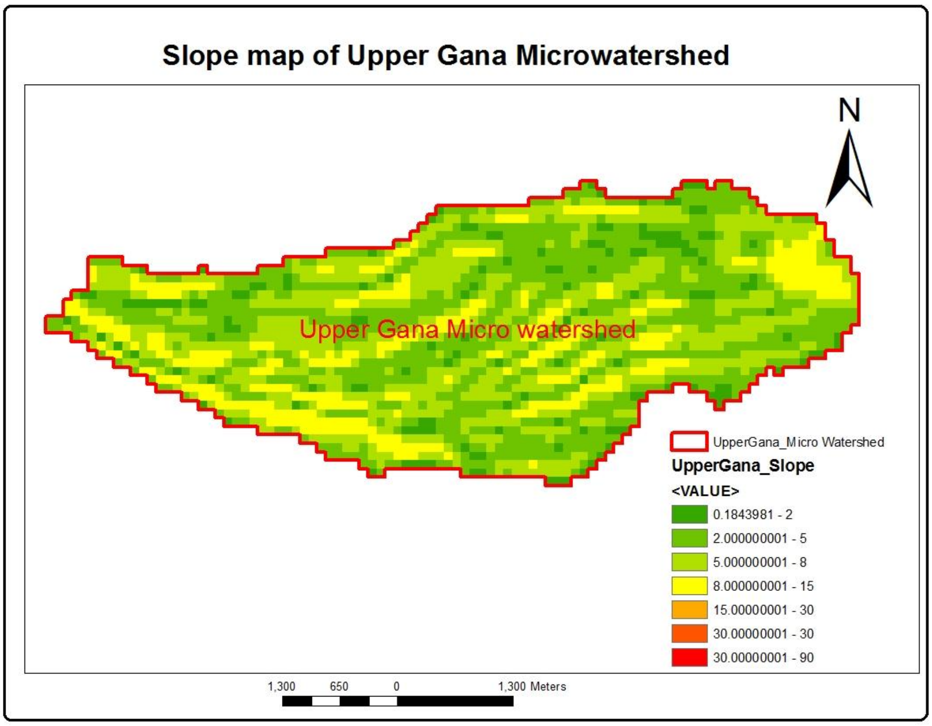
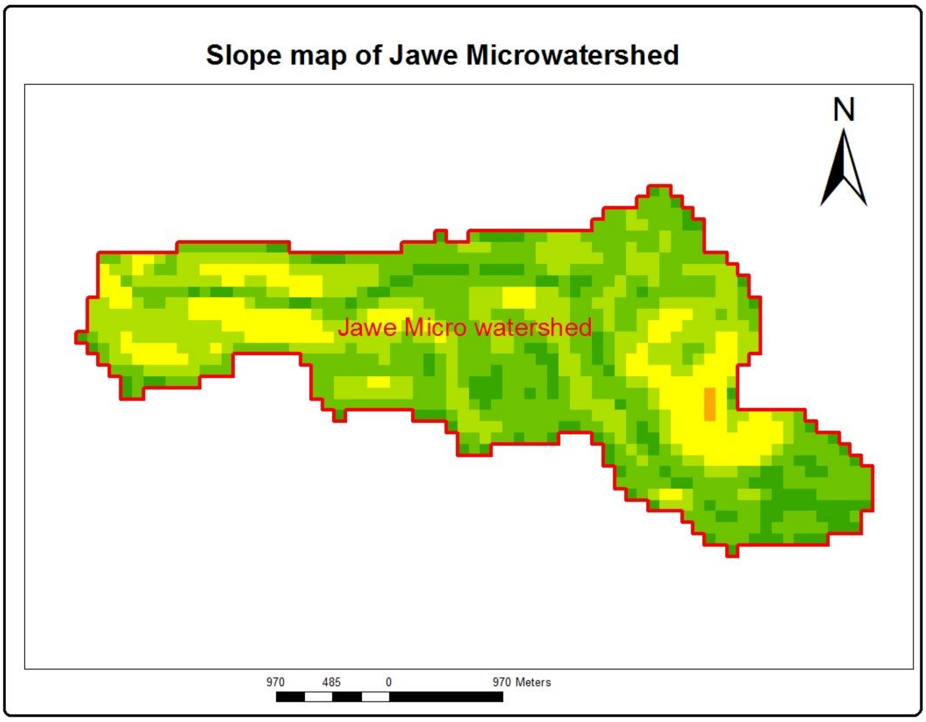


Figure 8. Slope map of Jawe micro watershed



Methodology

Data

Primary data

a. GPS point location data was collected for the studied seven wells and the suitable area for the micro ponds to be constructed.
b. Measured and recorded removed water volume in litre and time elapsed for the extraction of each studied seven wells of Upper Gana and Jawe micro watersheds with submersible pump.
c. Upper Gana and Jawe micro watersheds surveyed Biophysical data.

Secondary data

a. Mean annual rainfall data of the Micro watersheds as extracted from the Ethiopian Isohyets' map that passes through the micro watersheds.
b. 30 metre DEM map of the Lemu Gilgel Ghibe sub-basin from the http://www.jspacesystems.org.ja/ersdac/GDEM/E/4.html.
c. FAO soil classification based soil map of the micro watershed from Ethiopian soil map.
d. 2011 land sat Satellite Image of the study area with resolution 30 m from Earth Explorer(http://earthexplorer.usgs.gov)

Materials

- Pump: Submersible
- Flow metering and control devices: Calibrated bucket or barrel
- Water level measuring devices: Tape measure
- GPS
- Microsoft Excel

Methods

Groundwater resource assessment method

To study of potential groundwater resource lack of usable data was faced. To quantify the total available groundwater resource of Upper Gana and Jawe micro watersheds a simple method has been employed based on a Rainfall – Recharge coefficient. This method is described below.

Rainfall recharge method

Reference to work in the Omo Giba basin, generally suggests that the annual recharge to groundwater comprises a given 5% of the annual rainfall. Based on this figure and the areal extent of the Upper Gana and Jawe micro watersheds catchment groundwater recharged is estimated so this data well help the development planning of the water resource serving as a sign post of a yearly limit of maximum utilization.

Well yield testing method

Currently there are number of techniques for testing domestic water wells to determine the potential yield. Three of the most common techniques are the **well recovery, specific capacity** and the **peak demand** tests. Specific capacity and well recovery are science-based tests and peak demand test is more subjective. While there is likely no consensus as to which method is the best for determining yield, ground-water scientists generally prefer well recovery or specific capacity methods. Therefore this study uses well recovery method to study the well yield of the Upper Gana and Jawe micro watersheds as specific capacity test needs a highly calibrated pumping system.

Well recovery test: A recovery test is fairly simple to conduct. A well is pumped down a substantial distance from the initial static water level and then water level recovery is monitored and timed. The procedure for this test is generally as follows:

1. Pump the well down fairly rapidly.
2. Shut the pump off and record the time.
3. Immediately measure the water level.
4. Continue to measure the water level at frequent intervals recording the time for each measurement. At first, the water levels should be measured at intervals as often as can be physically done. Water levels should be recorded at no less than one minute intervals initially.
5. It is recommended that the recovery test be continued until the well has recovered at least 90% of the original water level.
6. Determine the volume in litre per metre of well bore based on the well diameter. Multiply the litre per metre of well bore times the recording of water level jump back during the recovery. Then divide the result by the time of this recovery to a yield estimated rate of Litres per second.

Water lifting pump selection method

Human and animal powered water lifting devices have been traditionally used in irrigation in a number of places around the world. Many of the technologies applied today have been used for thousands of years. Recent developments have concentrated on increasing the efficiency of water lifting by combining ease of use with higher water delivery. The selection of pump is based on the yield of the studied wells and considers:

Technical aspects like:

- **Lift height** and **yield:** for example how much water is required for irrigation purposes? How high does the lifter have to raise the water?
- **Operators:** like is the lifter suitable and acceptable to the people who will operate it? Is the operation comfortable to use and realistic for the group responsible for irrigation? Are there health and safety considerations?

Financial and economic aspects:

- **Capital cost:** like what is the initial cost of the water lifter? Does the village have sufficient funds or is a loan required? How soon will the community be able to pay back the loan/ recover this investment?
- **Material and manufacturing costs:** can the lifter be manufactured using local skills and materials?
- **Operating costs:** what is the operating cost of the lifter? Does the village have sufficient manpower/animal power to operate the lifter for all the time it is needed?
- **Maintenance costs:** what is the cost of maintaining/ repairing the lifter? Are the skills to maintain/ repair the water lifter available locally? Are spare parts available and affordable? How often is the lifter likely to need maintenance and/or repair? How long will repairs take and what will the villagers do in the meantime?

Life expectancy: how long is the lifter expected to last before it has to be replaced?

Household/community: is there a community organization capable of overseeing operation, maintenance and management of the device and the water? Will the users be instructed how to use and look after the device? These data have been collected from the micro watersheds of Upper

Gana and Jawe *kebeles* selected farmers households in specific and the community in general in order to select the most efficient and sustainable as well as economically reasonable type of pump that lifts water up to the ground surface for any conveyance system of to be selected.

Types of human- and animal-powered water lifters

Human and Animal Powered Water Lifters can be split into two categories: those designed to lift surface water and those designed to raise groundwater. **Surface water** is present in depressions, lakes, rivers, reservoirs and ponds. **Groundwater** flows or seeps downward through the earth filling up the spaces between soil, sand and rock to form a saturated zone. The Upper surface of this saturated zone is called the 'water table.' The water table may be just below the surface like a spring or oasis or it may be over 100 metres down. The only way to get access to this water is by digging and/or drilling.

Surface water lifters

Surface water lifters are generally the simplest form of human and animal water lifters because the water is readily accessible and does not need to be raised more than a few metres. Common examples of these Surface Water Lifters are *Swing basket; Shadouf, Dhone, Persian Wheel and Archimedean screw* were considered to lift water from the selected surface water harvesting techniques

Groundwater lifters

The following section presents the main types of human and animal powered devices used for lifting water from shallow and deep wells for irrigation purposes. *Rope and Bucket, Shallow-Well Piston Pump, Treadle pump, Rower and Rope and Washer Pump* have been considered for selection to lift water from the studied seven shallow hand dug wells .

Water harvesting technology assessment methods

Rainwater harvesting is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions.

Major categories of RWH

RWH systems for crop production are divided into three major categories as In-situ rain water harvesting, Internal (Micro) catchment RWH and External (Macro) catchment RWH.

In-situ rain water harvesting is water conservation and is basically a prevention of net runoff from a given cropped area by holding rain water and prolonging the time for infiltration. The in-situ RWH is achieved mainly by the means of deep tillage, contour farming and ridging and Agronomic practices. Internal (Micro) catchment RWH is mainly used for growing medium water demanding crops such as maize, sorghum, groundnuts and millet. The major characteristics of the system include: *Pitting, Strip catchment tillage, Contour bunds, Semi-circular bunds.*

External (Macro) catchment RWH involves the collection of runoff from large areas which are at an appreciable distance from where it is being used. This is sometimes used with intermediate storage of water outside the farm for later use as supplementary irrigation. Hillside sheet/rill runoff utilization, Floodwater harvesting within the stream bed, Ephemeral Stream Diversion and RWH with storage can be mentioned as an example for this type of RWH. As External (Macro) catchment RWH system specially RWH with storage is basically functioning as supplementary irrigation sources of water therefore this study focuses and limited itself on this type of RWH system .

Types of RWH with storage considered and evaluated in this study are Hand-dug Wells, Low cost Water Lifting, Low Cost Micro-ponds, Percolation pit, Percolation Pond, Farm Pond Construction.

For selecting a suitable size and construction of the type of RWH with storage site investigation have been made and drainage network generated from DEM with 30 m and as well a 3D model and slope analysis, soil type of the micro watersheds of Upper Gana and Jawe for selection of the suitable areas to implement farm level ponds to supplement the selected seven shallow hands dug wells of the seven farmer households various water uses.

Well protection materials selection method

Most hand dug wells are highly exposed to erosion, soil creep, flooding and contamination. Making protection of the groundwater source is vital. Protection involves the protection from runoff water, and the protection from objects, animals or particles falling inside the well (GROENWALL 2010). Open dug wells (i.e. without a sealing or apron), particularly those with very large diameters (>1 metres), are very likely to get contaminated and hence should not be constructed.

The wells physical conditions and the risk of physical damages of the wells have been surveyed on the field of the seven hand dug wells of the Upper Gana and Jawe micro watersheds and protection materials were selected based on the protection strength, durability, affordability, aesthetic value of the material.

Results and discussion

Groundwater resource assessment

The quantity of rainfall that infiltrates to groundwater clearly depends upon a range of factors including rainfall volume and intensity, evapotranspiration, surface run off, soil permeability, soil moisture deficit, and the permeability of the unsaturated zone of the underlying strata. Evaluation of this quantity from the considering all the values is difficult because of short of data but it can be estimated with rainfall recharge coefficient.

Estimation of rainfall recharge quantity of micro watersheds is one of the most important aspects of groundwater resource evaluation. A direct field measurement of recharge is beyond the scope of this study but the value for the rainfall recharge coefficient for the Lemo Omo Ghibe sub-basin is estimated from the previous master plan study of the Omo Ghibe basin.

Annual recharge quantity-for the micro watersheds of Upper Gana and Jawe was estimated based on rainfall recharge coefficient of the Lemo Omo Ghibe sub-basin. Value for the rainfall recharge coefficient of the Lemo Omo Ghibe sub-basin was calculated by subtracting surface run-off and actual evapotranspiration from rainfall to find change in storage. The calculated change in storage of the Lemo Omo Ghibe sub-basin is in turn used for the calculation of the Lemo Omo Ghibe sub-basin rainfall recharge calculation that is by dividing this change in storage to the total amount of rainfall in the area of the sub-basin. This relationship is defined by a simple empirical formula, i.e.:

This approach to estimating rainfall recharge coefficient is simple in theory, but because of the uncertainties inherent in determining appropriate values for the variables, the final output using this method is only an approximation of actual rainfall-yearly recharge in the micro watersheds. Therefore the estimated yearly recharged water for the Upper Gana and Jawe micro watersheds can be used for comparative purposes only.

The yearly recharged water in the micro watersheds of Upper Gana and Jawe, as employed indicates that there is of the order of 8.76077x105 m3 of recharge to groundwater systems throughout the Upper Gana Micro watershed and 4.76502x10x105 m3 of recharge to groundwater systems throughout the Jawe micro watersheds as can be depicted in Table 1.

Table 1. Annual rainfall recharge in Upper Gana and Jawe micro watersheds

No.	Micro watershed	Area(m^2)	Mean annualrainfall(mm)	Mean recharge at 5% (mm)	Mean recharge(m^3/year)
1	Upper Gana	19468389.647	1300	45	876077.534115
2	Jawe	10247360.470	1350	46.5	476502.261855

For various reasons the entire recharge estimated above cannot be abstracted for irrigation purposes. In particular is the need to sustain the water resource rather than deplete it steadily by abstracting more than the annual recharge. In addition there will be economic and technical constraints related to pumping lift (which in turn is related to water level drawdown) and accessibility of the most favourable abstraction points. Consequently, only a small percentage of the available recharge can be abstracted. Assuming arbitrarily that about 20% of the available recharge can be abstracted, and then the total groundwater resource that may be developed is estimated at175215.4 m^3/year in Upper Gana micro watershed and 95300.4 m^3/year in Jawe micro watershed.

Development scenario in the micro watersheds

The gross irrigation need is the continuous flow of water required for good crop production during the irrigation season. The gross irrigation need may be determined quickly, just to get a rough idea of the volume of water needed. This quick method is called the approximate method and is suitable for preliminary planning only, or when there is a lack of reliable data therefore based on this method and the total volume of groundwater resource that can be developed as well as with approximate values of seasonal crop water needs a simple example of development scenario can be formulated and potential area of land to be irrigated can be calculated for Upper Gana and Jawe *kebeles* with assumptions as stated below.

Assumptions

- 20%volume of water that is recharged in the micro watersheds is totally utilized with ideal 100% efficient irrigation techniques, pumping system, conveyance and distribution.
- Scenario 1. If 75% volume of the water is used for high value crops and if 25% volume of water is used for irrigated fodder.
- Scenario 2. If 50% volume of the water is used for high value crops and if 50% volume of water is used for irrigated fodder.
- Scenario 3. If 25% volume of the water is used for high value crops and if 75% volume of water is used for irrigated fodder.

Table 2. Potential irrigable land of the micro watersheds in hectare based on the annual recharged groundwater quantity

No.	Micro watershed	Types of plant			Scenario 1 crop75% 25% vegetable	Scenario 2 50% crop 50% vegetable	Scenario 3 25% crop 75% vegetable
1	Upper Gana	Crops		mm/ha/growth period	Potential irrigable land in ha	Potential irrigable land in ha	Potential irrigable land in ha
		1	Wheat,	650	6.738	4.492	2.246
		2	Barley,	650	6.738	4.492	2.246
		3	Maize	800	5.475	3.65	1.825
		Vegetable					
		1	Potato	700	2.0856	4.1712	6.2568
		2	Onion	550	2.6544	5.3088	7.9632
		3	Cabbage	500	2.920	5.84	8.76
Total potential irrigable land					26.611	27.954	29.297
1	Jawe	Crops					
		1	Wheat,	650	3.665	2.44	1.22
		2	Barley,	650	3.665	2.44	1.22
		3	Maize	800	2.978	1.98	0.99
		vegetable					
		1	Potato	700	1.134	2.268	3.402
		2	Onion	550	1.443	2.886	4.329
		3	Cabbage	500	1.588	3.176	4.764
Total potential irrigable land					14.473	15.19	15.925

As can be clearly depicted from the table the groundwater irrigation potential is 26.611, 27.954, 29.297 ha for scenario 1, 2 and 3 respectively in hectare in Upper Gana micro watershed and 14.473, 15.19, 15.925ha for scenario 1, 2 and 3 respectively in hectare in Jawe micro watershed with assumptions stated above.

Well yield

Safe yield of the seven hand dug wells of Upper Gana and Jawe micro watersheds were measured scientifically based on the methodology specified the study had been under taken during the end of the dry season that is on the last two weeks of June, 2014. Based on the result the yield of the wells is from 0.308 to 0.38 lit/sec, with an average of 0.348 lit/sec. The abstraction of water from the ground at a greater rate than it is being recharged leads to a lowering of the water table and upsets the equilibrium between discharge and recharge therefore every intended irrigation development activity should be based or limit itself to this safe yield so that it will be wise utilization of the precious natural resource that leads to sustainable development action. The volume of water in the wells varies depending on dimensions of the well. The average volume of water up to the position of static water level is 1308.57 litre. Based on the volume of water in the well, calculated recovery time of the wells ranges from 43 min to 83 minutes with an average time of recovery 62.388 minutes.

Table 3. Irrigation potential indicator table based on yield of wells

Yield	Irrigation potential
0.25–2.5 litre/s and 0.5–5.0 litre/s	Limited or localized
5.0–10.0 litre/s	Small scale
5.0–50.0 litre/s	Broad scale

Development scenario in households

Assumptions

- 100% efficient irrigation techniques, pumping system, conveyance and distribution.
- 24 hours of continuous withdrawal of water per day with the average yield of 0.348 lit/sec for Upper Gana and for Jawe micro watersheds.
- Average approximate duration of growth stages the crops and vegetables crops to be 120 days.
- Scenario 1. If 75%of the average well yield is used for high value crops and if 25% volume of water is used for irrigated fodder.
- Scenario 2. If 50% of the average well yield is used for high value crops and if 50% volume of water is used for irrigated fodder.
- Scenario 3. If 25% of the average well yield is used for high value crops and if 75% volume of water is used for irrigated fodder.

Table 4. Potential irrigable land of the households in hectare based on average yield of the wells

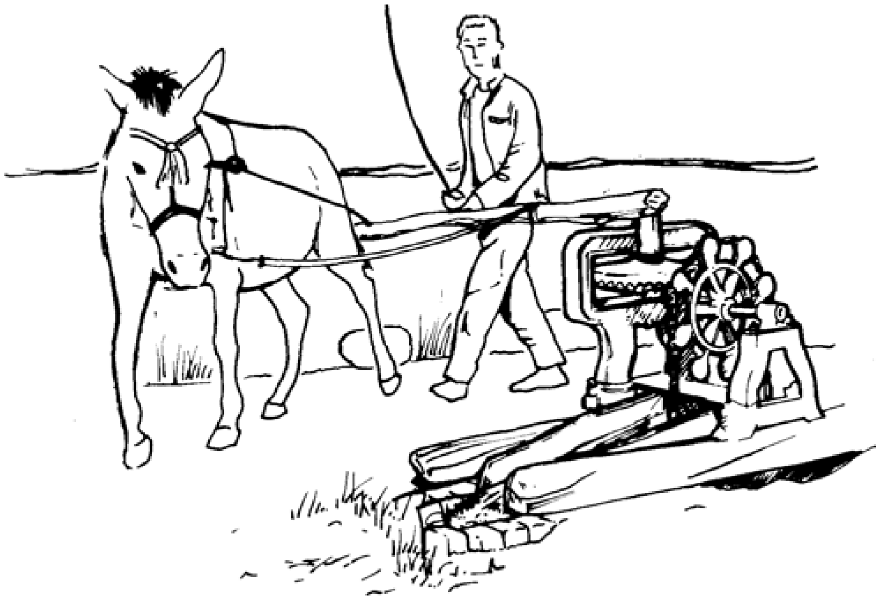
<table>
<tr><td>No.</td><td>Micro watershed</td><td colspan="3">Types of plant</td><td>Scenario 1
75% crop
25% vegetable</td><td>Scenario 2
50% crop
50% vegetable</td><td>Scenario 3
25% crop
75% vegetable</td></tr>
<tr><td rowspan="4">1</td><td rowspan="4">Upper Gana and Jawe</td><td colspan="2">Crops</td><td>mm/ha/growth period</td><td>Potential irrigable land in ha</td><td>Potential irrigable land in ha</td><td>Potential irrigable land in ha</td></tr>
<tr><td>1</td><td>Wheat or Barley</td><td>650</td><td>0.4163</td><td>0.2775</td><td>0.1387</td></tr>
<tr><td colspan="2">Vegetable</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>Onion or Cabbage</td><td>550</td><td>0.1640</td><td>0.328</td><td>0.492</td></tr>
<tr><td colspan="4">Total potential irrigable land</td><td></td><td>0.5803</td><td>0.6055</td><td>0.6307</td></tr>
</table>

As can be clearly depicted from the table an average of 0.6055 ha land for different scenario of development can be developed with 100% efficient irrigation technique per the households in Upper Gana and Jawe micro watersheds with the assumptions stated above. If the households use furrow irrigation method having a possible maximum efficiency of about 65% an average of 0.3936 ha of land can be developed by irrigation individual households.

Water lifting pump selection

The selection of water lifting technology for the Upper Gana and Jawe considers all the possible criteria as technical aspect, Financial and Economic Aspects, Life expectancy, Household/ Community. Based on the considered criteria for selection of the right type of pump that fits the average well yields and considers almost all the needs and that fulfil the gaps of the local condition Animal driven rope and washer pumps shown in Figure 9 is selected is selected as described in Table 5. Electrical or Fuel driven pumps are not considered here as this type of pumps needs Electric and fuel available in the local market and as well as they need high initial investment cost and operation and maintenance cost.

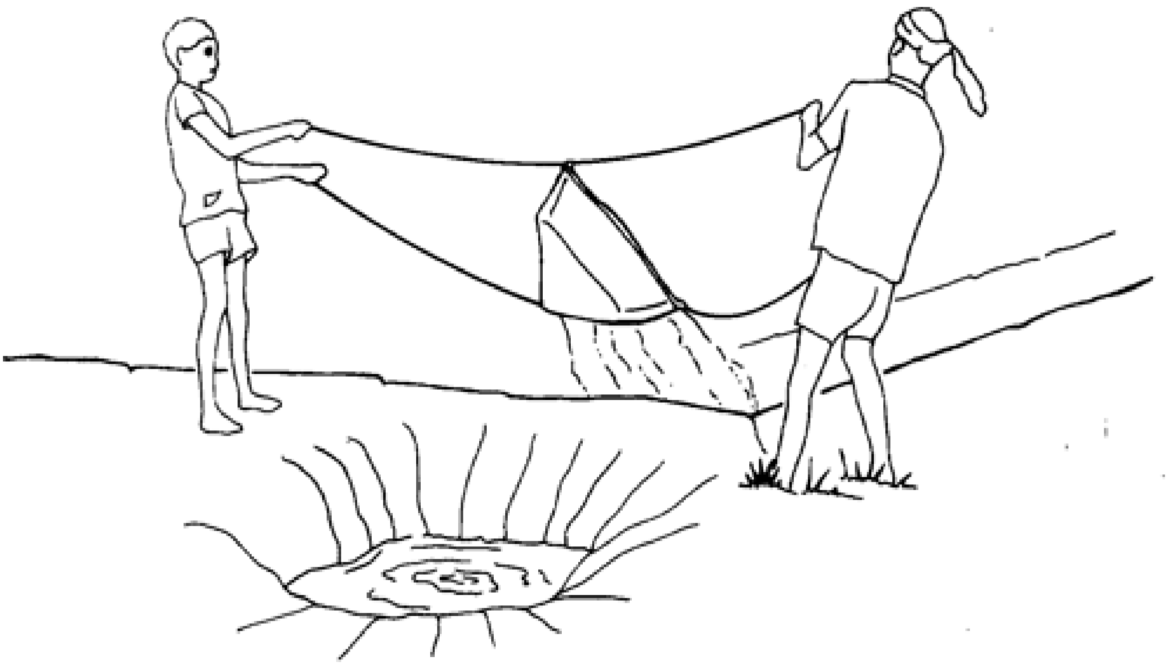
Figure 9. Animal driven rope and washer pump



Rope and washer pumps more commonly operate at depths of up to 10 m with a water yield of 0.7litre/se. The rope pump can be adapted to be operated by a horse and will raise 1 litre/se from a 20 m well. Rope and washer pumps are relatively cheap, and easy to manufacture (for wells down to 35 m rope pumps are five times cheaper than piston lift pumps.). This **rope and washer pump** requires less maintenance than other equivalent pumps and as well uses local skills and material. Their simple design helps that repairs can often be done by users and require few spare parts. Models can use parts that incorporate commonly available materials such as PVC pipe, rope, and old car parts. The main disadvantage of this type of pump for irrigation is that since this is not a pressurized system it may take time to receive water from the well with the water falling back to the level of the bottom of the well when not in use.

For the surface water harvested by Farm pond the selected lifting system is **Swing basket** shown in Figure 10 because of its many advantages as simple, inexpensive technology which can be locally made and maintained and is easy to operate by both adults and children.

Figure 10. Simple picture for Swing bucket for lifting water from farm pond to irrigation canal and animal drinking tank



The swing basket is made from cheap materials like woven bamboo strips, leather, or iron sheet to which four ropes are attached. Two people hold the basket facing each other, they dip the basket into the surface water and the basket is lifted by swinging it and emptied into an irrigation channel from which point the water flows to the fields. This lifter can be used at depths of up to 1.2 m to 2 m typical flow rates of 1 to 1.33 litre/se are obtained at depths of 0.75 m.

Table 5. Selection parameters of well water lifting pumps

Type	Manufacturer	Power source	Investment cost	Maximum lift (m)	Typical flow rate (litres/min)	Typical lift (m)	Priority level given
Surface water							
Swing basket	Basic	Human	Low	1.20	60–80	0.75	6
Shadouf/picottah	Basic/traditional	Human	Low–Medium	4.00	60	2–3	4
Dhone	Basic/traditional	Human	Low–Medium	1.50	80–60	0.30–1.00	4
Paddle wheel	Basic/traditional	Human	Low–Medium	0.50	300	0.50	3
Persian wheel	Traditional	Animal	Low–Medium	20	250–280 160–170	3 9	3
Archimedean screw	Traditional/industrial	Human	Medium–High	1.5	250–500	0.2–1.0	3
Surface water and groundwater							
Rope and bucket	Basic	Human	Low	100	15	10	3
	Basic	Animal	Low	100	150	15	3
Mohte	Basic/traditional	Animal	Low–Medium	100	130	9	3
Double bucket	Basic/traditional	Animal	Low–Medium	100	230	5	4
Suction piston	Industrial	Human	Low–Medium	7	24–36	7	3
Treadle	Basic/traditional	Human	Low–Medium	7	100	4	3
Rower	Traditional	Human	Low–Medium	7	50	4	4
Rope andwasher pump	Basic/traditional	Human	Low to Medium	35	40 10	10 35	4
	Basic/traditional	Animal	Low to Medium	35	60	20	6

Water harvesting technology assessment

From different surface water harvesting techniques being promoted for crop production ponds are one of the most reliable and economical techniques. They are now serving a variety of purposes, including water for livestock and for irrigation, fish production, fire protection, energy conservation, recreation, erosion control, and landscape improvement.

From the various types of RWH technologies with storage Hand-dug Wells, Low Cost Micro-ponds, Percolation pit, Percolation Pond, Farm Pond considered for selection and Farm pond with 8 m by 8 m area at the surface of the pond and 6 m by 6 m area at the base of the pond and with the depth of 2 m is selected for the Upper Gana and Jawe micro watersheds. The maximum volume water of this recommended type of farm pond with the above dimension is about 100 m^3. The amount of water stored in this farm pond can supplement the irrigation by shallow hand dug well by developing an average area of potential irrigable land about 200 m^2 or 0.02 ha of land for one dry season and 0.04 ha for the two dry seasons of the year.

Selected sites for the farm pond for the seven household farms

Suitable sites for farm pond are collected by GPS and corrected by flow accumulation map of the micro ponds as well as with transect walk of the site. The intended sites for the construction of the farm ponds are shown in Table 6.This suitable site is where a limited amount of excavation is required to contain, or hold back a large volume of water to support irrigation with wells at least for two months in the dry season.

Criteria considered on farm pond selection

1. Ponds should be located at a point where maximum volume of water can be collected with least digging or earth fill.
2. Ponds for livestock should be well spaced as the livestock should not travel more than one km.
3. To avoid pollution, the site should be away from farm drainage and sewage lines.
4. The drainage area should be sufficient to provide adequate runoff.

Table 6. Dimensions of wells and increased depth

Owner's name	Kebele	Well depth (m)	Water height (m)	Well diameter (m)	Increased depth (m)	Farm pond coordinate A_1(8 mx8 m), A_2(6 mx6 m)&2m depth(A part)	
						x	y
Tadege Kobo	Gana	7	1	1	0.7	361948	835041
Eshetu Alaro	Gana	3.2	1.3	1	0.36	361863	834375
Workneh Sodo	Gana	4.5	0.67	0.9	0.3	362102	834462
Workneh Kobe	Gana	3.7	0.25	0.8	0.5	361975	834803
Adinewu Ayele	Jawe	6.6	1.8	0.9	0.30	368154	829648
Arega Helelo	Jawe	5.8	0.58	1	0.10	368165	829997
Birhanu Tirkaso	Jawe	5.6	5.6	1	0.6	367823	830053

As can be depicted from the table an average of about 0.408 metre depth wells have been increased by the farmers themselves. For all the assessed farers households a farm pond possible construction coordinate have been selected so construction can be undertaken with the right dimension in the farms of the seven farmers based shown in Table 6.

Well protection materials

The well protection tools that are constructed around the well to guard physical damage of the well such as soil creep, upstream erosion and flooding and that protect the wells from contamination and sanitation risks is vital for the wells assessed during the study in both Upper Gana and Jawe area. Constructing these well protection materials around the wells helps to create awareness for irrigation system owners, communities, and local governments about the principal role of groundwater resource for their economic strength. A seal of 1 metre diameter pre-cast concrete rings (mortar tube) sub inserted half in the well and half externally with circular pre-casted concrete fittings on the top is selected for the protection of the well from all the anticipated physical damages and contaminations.

Awareness creation

In person approach awareness creation have been used so that the knowledge gap about the groundwater reserve, the water cycle, surface water and groundwater hydrology, conservation and wise utilization of these precious resources, irrigation, and irrigation benefits have been raised.

Conclusions and recommendations

Conclusions

The analysis shows the yearly recharge to groundwater systems is about 8.76077×10^5 m^3 throughout the Upper Gana Micro watershed and $4.76502 \times 10 \times 10^5$ m^3 throughout the Jawe micro watersheds. From this total amount only a small percentage of the available recharge can be abstracted. Assuming arbitrarily that about 20% of the available recharge can be abstracted then the total groundwater resource that may be developed is evaluated to be 175215.4m^3/year in Upper Gana micro watershed and 95300.4m^3/year in Jawe micro watershed. Based on this available total groundwater an average of about 27.954 ha of land in Upper Gana micro watershed and 15.196ha of land in the Jawe micro watershed can be developed by 100% efficient irrigation techniques.

The analysis of the pump test in the Upper Gana and Jawe micro watersheds have shown the result of the wells yield ranging from 0.308 to 0.38 lit/sec, with an average of 0.348 lit/sec. The average volume of water up to the position of static water level is about 1308.57 litre. Based on the volume of water in the well, calculated recovery time of the wells ranges from 43 min to 83 minutes with an average time of recovery 62.388 minutes. Based on this average yield of the wells an average of about 0.6055 ha of land per households can be developed by 100% efficient irrigation method in Upper Gana and Jawe micro watersheds. With the use furrow irrigation method in the households having minimum efficiency of about 65% an average of 0.3936 ha of land can be developed by irrigation individual households.

The result also shows the right type of pump that fits the average well yields and considers almost all the needs of the community and that fulfil the gaps of the local condition is animal driven rope and washer pump. Rope and washer pumps are relatively cheap; easy to manufacture; requires less maintenance than other equivalent pumps; uses local skills and material for construction. The simple design of this rope and washer pump helps that maintenance can often be done by users; require few spare parts and it can operate with Horse, Donkeys and farming oxen that is available in each households. This rope and washer pumps more commonly operate at depths of up to 10 m with a water yield of 0.7 litre/se. The rope pump can be adapted to be operated by a horse and will raise 1 litre/se from a 20 m well.

The other thing that the result also revealed is the best surface water lifting techniques from the surface water harvesting system, the Farm pond, is Swing basket because of its many advantages as it is simple, inexpensive technology which can be locally made, maintained and is easy to be operated by both adults and children and even some times by a single person with the other end tied on a trees or planted poles they dip the basket into the surface water and the basket is lifted by swinging it and emptied into an irrigation channel from which point the water flows to the fields. This lifter can be used at depths from 1.2 m to 2 m. typical flow rates of 1 to 1.33 litre/se are obtained at depths of 0.75 m.

This research also tried to evaluate and find out the precise type of surface rain water harvesting (RWH) technology that supplement the limited scale shallow hand dug well based irrigation in the households. From the various types of RWH technologies with storage Hand-dug Wells, Low Cost Micro-ponds, Percolation pit, Percolation Pond, Farm Pond were considered for selection. Farm pond with 8m by 8m Area at the surface of the pond and 6m by 6 m Area at the base of the pond and with the Depth of 2 m is the recommended type of RWH technology to that should be implemented in Upper Gana and Jawe micro watersheds. The maximum volume water of this recommended type of farm pond with the above dimension is about 100 m^3. The amount of water stored in this farm pond can supplement the irrigation by shallow hand dug well by developing an average area of potential irrigable land about 200 m^2 or 0.02 ha of land for one dry season and 0.04 ha for the two dry seasons of the year.

Recommendations

- There must be recognition that practical groundwater management must be practiced in the micro catchment level. The first step of this action will be identification of an appropriate groundwater resource plan. Financial and human resource will need to be allocated for a functional level of management. Each micro watershed level developed plan may be used to build a composite *kebele*,*woreda*and zone level planning. This planning must include integration with other water resource planning to help develop the overall integrated water resource management processes.
- Water-balance components like surface run-off, change in storage and actual Evapotranspiration must be studied.
- An efficient type of irrigation method should be studied and selected based on the local condition.
- Proper design of a conveyance and distribution system which meets local conditions, good quality construction and proper operation and maintenance must be undertaken.
- Irrigation schedules (calendars) based on average crop/soil/climate must be formulated.
- Irrigation scheduling simulation models should be formulated based on the irrigation method and irrigation scheduling.
- Simple operational rules with guidelines on fixed intervals and constant water applications should be developed.
- Developing programs for field evaluation of on-farm systems is relevant for improving both irrigation scheduling and water application methods during the implementation phase.
- groundwater recharging simple soil and water conservation technologies suitable for the studied area must be studied and implemented.
- Design, assembly and test prototypes for animal driving rope and washer pump and swing bucket is essential.

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Annex 1: Illustrations

Picture 1. Red soil burrowed out to increase depth of well from 7 m to 7.7 m in Upper Gana kebele.

Picture 2. Brown soil excavated out to increase depth of a well from 3 m to 3.36 m in Upper Gana.

Picture 3. Soil dug shown to increase the depth of a well from 5.6 m to 6.2 m in Jawe *kebele*.

Picture 4. Soil dug shown to increase the depth of a well from 5.8 m to 5.9 m in Jawe *kebele*.

Picture 5. Existing well protection style observed which is exposed to erosion, flooding and contamination.

Picture 6. Existing well wood and earth material covering observed in Upper Gana *kebele*.

Picture 7. The observed better type of well protection structure in Jawe *kebele*.

Picture 8. Another observed better type of well protection structure in Jawe *kebele*.

Annex 2. Dimensions of wells and their conditions

Owner	Kebele	Well depth	Water height	Well diameter	Remarks
Tadege Kobo 1st well	Upper Gana	7 m	1 m	1 m	The well was tested once for production of vegetable on 200 m^2 of land and3 quintals were produced from Jan.–May and consumed home and sold in the nearer market.
Tadege Kobo 2nd well	Upper Gana	3 m	0.35 m	0.8 m	The well was dug for supplementary use. The water level dries out some times in a year.
Community well	Upper Gana	4.1 m	1.3 m	0.9 m	Community dug well on communal land for common type of use. Sanitation problem should be given attention as there is no embankment around the well and many people use without much care.
Eshetu Alaro	Upper Gana	3.2 m	1.3 m	1 m	Previous year some irrigation on small plot of land were checked and showed some hope for the future and this year as he get triddle pump he ispreparing about 300 m^2 of land for vegetable production. but he is not sure about the water source sustainability
Workneh Sodo	Upper Gana	4.5 m	0.67 m	0.9 m	No any production with groundwater but is interested in using the water if the right condition is there for him.
Workneh Kobe	Upper Gana	3.7 m	0.25 m	0.8 m	He is a well digger and took technical training how to maintain collapsed well and give some service of maintenance for neighbours. He experienced no Irrigation.
Adinewu Ayele	Jawe	6.6 m	1.8 m	0.9 m	No irrigation practice. interested in irrigation
Arega Yelelo	Jawe	5.8 m	0.58 m	1 m	Have irrigation practice on 400 m^2
Birhanu Tirkaso	Jawe	3.70	0.23 m	1 m	Some trial on irrigation practice, interested in irrigation, face silt in the well.
2nd well	Jawe	5.6 m	2,2 m	1 m	He is planning to use this well for forage production.

Annex 3. Shallow hand-dug well groundwater sources and traditional irrigation systems

Owner	Water use	Farm land (ha)	Portion of land for irrigation	Major problem for not using irrigation
Tadege Kobo	Irrigation, sanitation, cooking, drinking, livestock	2 ha	1%	
	Sanitation, cooking, drinking, livestock			
Community	Sanitation, cooking, drinking, livestock	-	-	Communal
Eshetu Alaro	Irrigation, sanitation, cooking, drinking, livestock	2 ha	-	
Workneh Sodo	Sanitation, cooking, drinking, livestock	2 ha	-	
Workneh Kobe	Sanitation, cooking, drinking, livestock	1.4	-	Failure of constructed well and not sure about the source sustainability
Adinewu Ayele	Sanitation, cooking, drinking, livestock	2 ha	-	
Arega Yelelo	Irrigation, sanitation, cooking, drinking, livestock	2ha	4%	
Birhanu Tirkaso	Sanitation, cooking, drinking, livestock	2 ha	2%	