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Evaluation of Traditional Water Lifting and Modern Water Lifting Technology: A Case of Tula Sallan of Borana, Southern Ethiopia

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Abstract

In a developing country, the technology of lifting water from deep wells installed as groundwater sources to a useful water point of access for domestic and non-domestic consumption is still on a low scale and on a threatening scale for the pastoralist community. In Ethiopia, the pastoralist communities shield above half of the land area, constituting and making the country first in the livestock population in Africa. Regardless of this fact, the study stated that pastoralists, mainly Borana, where the study took place, are very far from the central government capital of the country and were listed among the most marginalized groups in terms of availability and access to public services plus water supply service. Thus, the study took place in an area where water-lifting technology is very rare. The Borana communities traditionally evaluate water lifting to manage their permanent water source in Tula. Traditionally, in the Borana community, the selection of traditional water lifting devices for lifting potable water from Tula comprises inquiry of the Tula end sources, 'Qawa ela' depth, nature and types of 'Okole Towa' appearances, daily labor forces on the watering day called 'Obatu', and sustainability of traditionally water-well ladder called 'Irri' with regularly operation and maintenance due to its nature. In this study based on Tula-wells, discharge capacity, and accessibility to livestock demand consumption, the available technologies led to the multi-use system of Tula-wells in the Tula-Sallan Borana Cluster of Borana zone. The small irrigation of vegetables behind Tula-wells on the backside of the wells fence using water pumps deals with the distribution of water from 'Qawa ela' in the Dubluk district of the Borana zone at Tula Elwak. The multi-use purposes of the Tula-wells and Tula-Sallan Borana cluster with the help of some available technologies have their advantages and disadvantages. The traditional labor force service in Tula to lift potable water on the watering day of livestock and the energy or power needed during the use of solar or motorized pumps were compared to evaluate the traditional water lifting and modern water lifting technology in the study area. The energy required to deliver water from the end source of Tula-wells to the drinking trough at three Tula was considered.

Keywords**: Water Lifting, Tula Sallan, Well Dimensions, Waterpower**

1. INTRODUCTION

Water is an absolutely necessary element for life. The availability of water has played a key role in the development of all civilized nations. Indeed, especially in ancient times, water scarcity prevented the development of settlements (Oleson, 1984). Sustained safe drinking water supply and sanitation facilities are essential to improve the living conditions of the rural population. The provision of safe water helps to combat waterborne diseases and improves community health in general. Thus, it is an essential component of poverty alleviation. In sub-Saharan Africa, information is scarcely available concerning suitable water lifting and management technologies given a particular geographical location, and socio-economic conditions (market access, input availability and access, etc.) (Petra Schmitter el at,, 2016). During the long dry seasons of 2016, some nongovernment organizations piloted some water lifting (Irri, solar pump, and generator) and management technologies (i.e., wetting front detector) or sustainable intensification in different Horn of African Countries, including Ethiopia (ATA, 2016). This was to facilitate livestock's demand for the suitability of the adopted technologies, assess the effect of water lifting on the productivity of livestock in areas like Borana, and Afar Regional State, and to save life and assess potential increases in productivity through traditional modern livestock watering guidance.

In this study, a researcher was focused on evaluating livestock's demand suitability of the adopted technologies, assessing the effect of water lifting on the productivity of livestock in Tula Sallan Borana. It is distinguished that water demand and supply in the Borana zone are below both international and national standards. Thus, the community uses difficult traditional water lifting methods to lift water from very deep traditional deep-wells, Tula Sallan Borana (Moti Mosisa el at, 2018). Depending on the water source and availability, the technologies have led to a multi-use (agricultural, domestic, and livestock) system in the water-scarce area or lowland area of Borana, Southern Ethiopia. The watering day for livestock uses solar pumps or service delivery of water and, in combination with making generators on some Tula Sallan, produces great potential in Wachille and Dhas Tula.

2. MATERIALS AND METHODOLOGY

2.1 Description of the Study Area

The study took place in the Borana zone of the Oromia Regional state of Ethiopia. It is located in the southern part of the state (between 3°36 – 6°38'North latitude and 3°43'- 39°30' East longitude) and borders Kenya. Yabello is the capital town of the Borana zone and lies 570 km south of Addis Ababa. The zone covers 48,360 km2, of which 75% consists of lowland, frequently exposed to droughts. The zone is inhabited by almost 1 million people. (CSA, 2008). The Borana rangelands cover about 1.9 million ha. The area of Tula Sallan has a semi-arid savannah landscape, marked by gently sloping lowlands and flood plains vegetated predominantly with grass and bushland. The geology is composed of a crystalline basement with overlying sedimentary and volcanic deposits. People are predominantly involved in small-scale subsistence agriculture, agricultural production, and mainly in livestock husbandry.

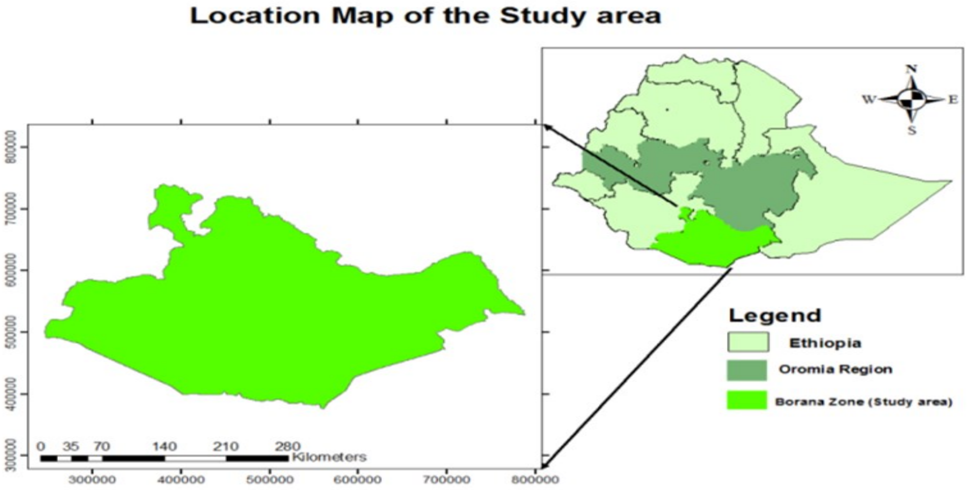

Figure 1 Location Map of the study area, the Borana zone administration low land of southern Ethiopia

The Borana zone is mainly characterized by a semi-arid climate. Drought is a common phenomenon in many parts of Borana. The lowland parts have been severely affected by recurrent droughts. The rainfall pattern is highly erratic and often does not occur at the expected time. Thus, the area is characterized by a general scarcity of surface water. The main source of water is the Tula. The annual mean temperatures vary from 19 to 240C with little seasonal variation. The average annual rainfall varies from 440 to 1100mm.

Geologically, the area comprises two major lithium-stratigraphic units ranging in age from Precambrian to Quaternary. Precambrian strata consist of crystalline rocks and associated intrusions, and Tertiary to Quaternary strata consist of volcano-sedimentary rocks; the superficial deposits are all quaternary. Hydrologically, the ephemeral drainage system of the Borana zone is located within the Genale-Dawa River basin. The main source of water is groundwater. To extract groundwater, the population of Borana are using traditional deep wells whose water retention potential varies with rainfall, the so-called' singing wells or Tula wells.

The Borana zone pastoralists survive on livestock producers. Plenty of livestock is the paramount resource of the areas that makes Ethiopia the first in Africa and the ninth in the world by cattle population. They mainly live on milk but are increasingly supplemented by cereal grain. The annual livestock off-take is very low and directed to basic household requirements. Dry land cultivation has substantially increased in the area over the last two decades. The gross income of a pastoral household is the sum of subsistence plus marketed production and currently their income is decreasing dramatically due to continuous dry climate conditions.

2.2 Data Collection

The study to produce this notion collected both primary and secondary data. Primary data was gathered through interviews with key informants, focus group discussions, administered questionnaires, and study area observation (SAO) at Tula and 'Adaadii' wells and pond sites. The collection of data was systematic in such a way as to fulfill the requirement under each specific objective. In addition, a survey was conducted at six of the nine Tula well sites (i.e., Wachile, Gorile, Gayo, Dhas, Dubuluk, and Melbana) which were selected based on reconnaissance and ease of access. The sample wells were physically measured with GPS (and tape in some cases) to determine the coordinates and depth of the groundwater points, well shaft width, and their surroundings, along with 32 aquifer points (Madda Eelaa). The sample size of the selected six-Tula represents nearly 67% coverage out of the total nine. Evaluation of the traditional water lifting methods, livestock demand and suitability of some of the adopted technologies, and the effects of water lifting on yield were considered.

Two of the nine Tula, called Gofa and Laye, are currently under de facto control of the Somali Region subsequent to the state-orchestrated occupation of the area by the Somali Region in 1991, thus inaccessible for a safe visit for physical characterization such as elevation, soil type classification, and vegetation cover. Therefore, information was taken by GPS from Google Earth while data on names, history, and ownership of the wells were gathered through in-depth interviews held in January 2020 at different places with key informants (e.g. Hon. Dr.Borbor Bule, 2020)

Under this research objective, survey data was collected on soil types, variation in water table depth, the structure of Tula, and dimensions of Tula using a water level meter. Discharge of well, energy, and waterpower during watering days of herds are measured using well depth, and volume of water lifted by water-up lifters (Tootuu). Interview data covered the traditional instruments used in the excavation of the wells, maintenance and operation, traditional water lifting devices, and techniques as bases for modern engineering standards. There have been oral historians, questions have been raised regarding ‘how’, ‘when’, and ‘by whom’ the Tula were excavated. Furthermore, to answer the research question and fulfill the research objective, issues such as the community’s indigenous technical knowledge as to the indicators used in determining areas where groundwater may be available within the customary groundwater exploration methods have been raised.

Field observation has been used to understand the present status of the Tula, whether it is properly functional, partially functional, or fully dysfunctional. Generally, SAO was applied to determine the number of wells in one cluster, and the types of soil, rock, and plants appearing in the environs of the selected Tula cluster. For secondary data, various sources relevant to the production of this thesis were consulted. These include a report by the National Meteorology Agency, reports from the Borana Zone Water, Energy and Minerals Office, books, journals, magazines, the internet, and so forth.

2.3 Data Analysis

The collected data was presented and analyzed in various forms using different techniques. The field survey data was compared with reports from the zonal administration. The water uses a calendar, which may vary according to the types of water sources and principal users, and seasonal variation (period of utilization) was determined in a chart form. The approaches to designing this study rely on both descriptive and explanatory approaches when assessing groundwater exploration, evaluating the traditional water lifting and indigenous water management system based on basic principles of the herd watering calendar. Thus, the analysis method detailed the obtained data with respect to research objectives in the following points.

2.3.1 Evaluation of Traditional Groundwater Supply (Tula Sallan)

The application of traditional groundwater supply in the case of Tula Sallan Borana focused on the traditional water-lifting method and its evaluation in terms of discharge, energy, and waterpower. Their evaluation centered on the depth of Tula and water lifting processes, Tula geometry, detention time between lifted water level, storage, and the aquifer physiognomies. Therefore, in this study, Tula's traditional structures and dimensions were taken into consideration.

2.3.1.1 Tula (Traditional Deep wells) Dimensioning

The dimensioning and designing of Tula are based on groundwater flow at the end source, discharge potential aquifer, and natural hydrological characteristics. The Borana community started dimensioning Tula from the initial point of ready-made water point to the entrance of the well structure, whether it is soft soil or hard rock. In the dimensioning process, each structure of Tula was taken into consideration. Each of the wells of Tula Sallan Borana is divided into eight structures. These were Ittisa, Gulanta, Baqassa, Dargula, Nanniga, Koloco, Faccana and Madda. The Tula structures were measured using water meters.

Figure 2 Tula structures measured at Eela Gayo and Eela Gorile

The physical structure of Tula from the top layer to the bottom layer according to its ascending depth.

Table 1 Physical structures of Tula from top to the bottom layer according to their ascending depth

S/N	Physical structures of Tula	Location & Function	Depth
1	Ittisa	The surface layer to control the livestock from getting the well	Flat surface
2	Gulanta	The Entrance of the Tula. Traditionally used as door to Tula and used as first ritual structure of Tula	No depth
3	Baqassa	The way seems canal that take both animals and people to the Daargula site.	Slightly slope
4	Daargula	The wider structure that consists of Nanniga/Through and used as animals watering phase.	Deep and wide (No slope)
5	Nanniga	Water Drinking Through and storage	Shallow structure
6	Koloco	Pass way of water from Fcacana to Nanniga	3rd deepest structure
7	Faccana	Temporary Reservoir	2nd deepest structure of Tula
8	Qaa’a Eelaa	The end source of Tula	Deepest part of Tula

Table 2 Tula structures with measured dimensions at Gayo, Gorile, Melbana and Wachille wells.

Name of Ela at d/t Tula		Width at d/t structure (in meter)			Length(m) Gulanta to Dargula	Well Depth(m)
		Dargula	Baqassa	Baqassa to Gulanta		
Gorile	Galanticha	12	7	4	132	32
	Odicha Balla	16	6	4	130	30
	Allo	10	5	4	131	33
Gayo	Ababa	12	5	3	117	25
	Dhibayu	10	6	3.5	129	26
	Gadulticha	13	6.5	4	131	30
Wachile	Kallu	13	7	5	146	28
	Siba	11	5	4	138	27
Melbana	Dubana	10	5	3	86	22
	Arusicha	9	6	4	80	20

The traditional Tula structures and sizes are not homogenous. The structures are different from entrance to end structures. They are affected by types of soil, rock, and land cover. According to dimensions, the Irri (traditional ladder) has been made both in a temporary reservoir (Faccana) and aquifer (Qaa'a Eelaa) structures.

2.3.1.2 Wells Discharge

The well discharge calculation is based on the type of flow (steady and unsteady) and the well aquifer, whether confined or unconfined. The Borana traditional deep wells are connected with the unconfined aquifer. In the case of Tula Sallan, the well discharge was calculated by Darcy's constant equation of area and velocity. Hence, discharge is the product of area and velocity.

$$Q = AV, A = LW = \pi r2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where: Q = discharge of the wells
A = Area
V = velocity of the up lifted water
r = radius of the 'Qaa'aa Eelaa' (aquifer)
L = length/height of the aquifer (h)
W = width of the aquifer

$$V = \frac{S}{t} = \frac{h}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Q = \frac{\pi r2h}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$Q = \frac{\pi r2dh}{dt}$$

To calculate the Tula discharge, a researcher measured the static level of water at 'Qaa'aa Eelaa' before 'Tootuu' started to lift water to a temporary reservoir, the water level after the first circle of water up lifters and dentation time of water to reach the indicated level. The 'Qaa'aa Eelaa' (aquifer) depth and the water level were measured by a water level meter.

With the help of a stopwatch, the speed at 'Tootuu' lifted water from the end source (aquifer) at Eela Odicha was 1m/s with a statistical depth of water of 12m out of a 14m depth aquifer and seven pair chains of 'tootuu'. The radius of the well aquifer was 1m. As 'Tootuu' started to lift water in a bucket of ten liters for ten minutes, the water level decreased to 11.838. Then, based on the above formula, the well discharge was calculated as follows.

$$Q = \frac{\pi r2dh}{dt}$$

$$Q = 3.14(1m)2 * \frac{12m - 11.838m}{30min * \frac{60s}{min}} 0002826m3/s = 17L/min$$

Similarly, the discharge of Galanticha of Gorile and Dhibayu of Gayo was calculated. The Galanticha and Dhibayu discharges after the first twenty minutes of filling the temporary reservoir were 15L/min and 17L/min respectively.

2.3.1.3 Livestock demand calculation

To calculate the livestock water demand, the researcher has used the below-mentioned procedures. These were by determining the standard livestock daily consumption in terms of weight equivalent called Tropical Livestock Unit (TLU) and adding the numbers of herds served on selected wells. The average body weight of one TLU is 250 kg and an animal consumes one liter of water per day for each 10 kg of body weight on average. Therefore, about 25 liters of water is required daily for each livestock unit. Hence, the daily water demand is estimated by calculating the equivalent TLU of the animal multiplied by 25 liters (CLARK, 1997).

Table 3 Standard livestock's daily consumptions

Livestock	Consumption (Liter per animal per day)
Cattle	60
Mule, Horse, Donkeys	40
Goat, Sheep	5
Camel	2
Chickens	0.2

In Borana, the livestock's water demand unit per watering day in Tula has expanded to the three normal watering days. Thus, the number of livestock that could serve from a single well in a day, supported by the survey taken and interview data collected at Gorile, Wachille, and Irdar is detailed in the following table.

Table 4 Livestock feeds per watering day for eela Odicha and Galanticha of Gorile Tula

Name of Ela	Livestock feeds	1st day	2nday	3rd
Galanticha	Cattle	350	400	513
	Goats	400	100	87
	Camel	20	-	-
	Horse, donkey and mule	30	10	15
	TOTAL	800	510	615
Odicha Balla	Cattle	500	300	800
	Goats	400-500	200	450
	Camel	30	-	1.
	Horse, donkey and mule	15	30	24
	TOTAL	900	530	1274

Thus, the TLU was calculated by considering the number of herds to be watered and average daily consumption. Thus, from the tables (3 and 4) for Eela Galaanticha, on the first watering day, the number of watered animals was 800 heads. The average LTU was 25. Then the daily water demand for livestock has been calculated as follows:

$$TLU\ discharge\ (Qtlu) = Number\ of\ animalss\ multiple\ by\ average\ LTU\ daily\ consumption \ldots. \ (4)$$

$$Q\ TLU = 800 * 25\ lpd\ = \frac{20{,}000L}{d} = \frac{20m3}{day}.$$

During the watering days ('Obaa') of herds, the ‘Tootuu’ (water lifters) invest a large amount of energy to lift the drop of water from the Tula aquifer (Madda). Hence, energy invested by Tootuu on a watering day was calculated based on the amount of water in the up lifters, the depth of the 'Madda Eelaa' from the Faccana or 'Afaan Naqaa' (the first step ladder to enter the madda), the weights of water up lifters and the acceleration due to gravity.

2.3.1.4 Energy Calculation

Energy is the ability or capacity to do work. Work is the product of force and distance travelled. In physics, work defined as the amount of energy required to perform a physical task. If force is constant, work can simply calculate using the equation:

$$Work(W) = Force(F) * Distance(S) \ldots\ldots\ldots\ldots \ (5)$$

In water Engineering, lifting water out of the top of a tank or from the deep well requires work because the liquid is moving against gravity. During the calculation of the energy needed to lift up groundwater from *Tula*, researcher was visualized the work required to lift drop of water from aquifer (qaa’aa eelaa) to fill the temporary reservoir (faccana). Thus, lifting a series of masses against gravity and allowing the water to trip out from end source.

$$Force(F) = mass(m) * acceleration\ due\ to\ gravity(g)$$

$$W = F * S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (6)$$

In calculation of the work done due to applied force of Obaatuu (labors group to sustain Tula) on specific herds watering day, their total weights and net travelled distances between home and Tula should have known. In this study, to calculate the capacity of work of ‘Tootuu’ during herds watering day, mass of labors, average height (depth) of Tula aquifer (qaa’aa eelaa) and acceleration due to gravity have been considered. Thus, the mass of water up lifters on some wells had identified. Noted that’ the weight of ‘Tootuu’ was taken in default from informants at selected well/Eela on specific watering day. Instead of name the coding, and the mode of the median value has selected for calculation.

Table 5 Summary of Ela Odicha Balla of Gorile ‘*Obaatuu’* on guyyaa Olaa to calculate energy

Name of Eelaa	Name of Totu in (Code)	No of Totu in set W(Kg) interval	Weight of Totu (in Kg)	Average weight of Totu (in Kg)	Depth of qaa’aa eelaa (in m)
Odicha Balla	1	0	<50		12
	2	3	50-60	55	
	3	**8**	60-70	65	
	4	4	70-80	75	
	5	2	80-90	85	
	6	0	90-100		
	7	0	>100		
Total Number of Totu		**17**			

Table 6 Summary of Ela Galanticha of Gorile 'Obaatuu' on guyyaa konfii to calculate energy

Name of Eelaa	Name of Totu in (Code)	No of Totu in set W (in Kg) interval	Weight of Totu (in Kg)	Average weight of Totu (in Kg)	Depth of qaa'aa eelaa (in m)
Galanticha	1	1	<50		14
	2	3	50-60	55	
	3	**6**	60-70	65	
	4	4	70-80	75	
	5	1	80-90	85	
	6	0	90-100		
	7	0	>100		
Total numbers of Totu		**15**			

Based on the above tables (6 and 7) by selecting the average weight of median value of 'Obatu' the energy possessed by 'Tootuu' during herds watering days was calculated. Thus, by considering the weight and quantity of water up lifters, the depth of the aquifer (qaa'aa eelaa/madda) and acceleration due to gravity the input energy possessed was calculated as follows.

$$Energy\ input = mass\ of\ water\ up\ lifters * numbers\ of\ water\ uplifters * average\ height\ of\ tulaa * acceleartion\ due\ to\ gravity$$

$Ein\ =\ nMgh$……………………. (7)

Where: E_{in} = Energy input by water up lifters

n = Quantity of water up lifters required on the watering day

M = weight water up lifters

g = acceleration due to gravity

h = average depth of *Tula* aquifer.

From the table (6); the 15 waters up lifters were with average weight of 65kg and 14m average depth of Tula aquifer was taken for Energy calculation on first day of herds watering on Ela Galanticha of Gorile Tula.

$$Ein\ = nMgh$$

$$Ein = \ 15 * 65 * 14 * 9.81\ = \frac{133{,}906.5kgm}{s2m} = 133.91KW.$$

From this calculation, 133.91KW was the energy possessed by '*Tootuu'* (water up lifters) once a time to fill the faccana (temporary reservoir) at Ela Galanticha of *Tula* Gorile.

Now, the rate at which energy flow has used per time or the amount of energy used to do work was known. Based on the effort performed by possessed energy during watering day waterpower can be calculated.

2.3.1.5 Waterpower calculation

Energy is the ability or capacity to do work. Power is the rate at which energy flow has used per time or the rate at which work has performed or the amount of energy used to do work or shows how quickly work done. In engineering, the definition of a force has drawn from the second law of Newton and known as a newton unit of measurement. In practice, unit newton is equal to the force generated by the gravity acting on the mass of unit kilogram of matter. In short, it has represented as N. The force on unit kg of mass is ten newtons of load due to the gravitational force 9.81m/s2 approximately 10m/s2. Moreover, power has given in watt, which is the product of force applied to lift water from the *Tula* and distance of the end source to the watering trough, which is the water-access point for people and their livestock.

Mathematically:

1N =unit kg* ten m/s2 of gravitational force = 1Kg*10m/s2*10=10N

$$Force(F) = mass(m) * acceleration(g)$$

$F = ma \text{ or } F = mg$ ……… (8)

$$Mass = \frac{Volume}{density}, m = \frac{V}{p}$$

$$\text{Then;}\quad F = \frac{V}{p} * g = \frac{\frac{1m3}{1kg}}{ms2} * \frac{10m}{s2} = 10N$$

Therefore, the power of water is the product of force invested to lift water from the end source of Tula and distance occupied by the chain of ‘tootuu’.

$$P = F * S \ = \ 1N * 1m \ = \ 1NM \ = 1Watt$$

The yield of waterpower of Tula overcome by ‘Tootuu’ was calculated using the following procedure.

At the first, the depth (height) of the ‘qaa’aa eelaa’ (aquifer) and volume of lifting device has known. Then, the Power needed to lift water from Tula is the product of the force needed to lift water and height or depth of Tula aquifer below ‘faccana’. Therefore, the waterpower given as:

$$\text{Power needed to lift water from Tula} \ = \text{force needed to lift water} * \text{height of Tula aquifer}$$

According the above formula the procedure cared out at following Ela.

Table 7 Depth of aquifer (qaa'aa eelaa) and Volume of Okolee too'aa

Name of Well/Ela	Depth of aquifer (qaa’aa eelaa)	Volume of Each Bucket (L)
Galanticha	14	10
Odicha	12	10
Qallu	16	10

At a Gorile Tula researcher, select ela Galanticha and Odicha Balla for the data sample. The given height of ‘Ela/well’ for ‘qawa-ela’ or end source was 14m, Q=10L/s, time to reach ‘faccana’ 1min of six chain of persons with all have bucket/okole of 10L, means totally 60L

Then, $1L = 1Kg,\ Q = \frac{V}{t}, V = Qt = \frac{60L}{1min} = \frac{60L}{60s} = 1m3\ = F * S * 1 = 10N * 14m = 140Watts$

The 140 watts means “140 water watts" in a minute at Ela Galanticha of Gorile. ‘*Tootuu*’ were on continuous water lifting task for more than six hours. Similarly, on each watering day based on the worked hours the waterpower was calculated.

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of Borana traditional water lifting and application of available technologies

In order to evaluate traditional water lifting method, the excavation of *Tula* and water lifting process certain primary procedures in the design were considered *Tula* geometry, storage and the aquifer. With regard to geometry, the traditional evaluation of water lifting was taken into account the depth of the well (*qaa'aa eelaa*) in the geological environment of *Tula* cluster and the aquifer's recharge region of the well structures responsible for water rise at end source. Moreover, dimensioning and designing of *Tula* according to their groundwater flow at end source, discharge potential of the aquifer and wells utilization for maximum productivity were had considered.

The easiest and safest method of dimensioning and designing of a *Tula* by the Borana community has been excavating it from the initial point of ready-made water point to the entrance of the well structure, starting with loose soil and cutting into the hard rock of the end source in the traditional hand-drilling (auguring). The structure of a *Tula* from entrance to end structures is/are not straight cut-ways and has affected by the soil type and rock formation.

Figure 3 Dimensioning of a of Tula at eela Gorile

The Borana Oromo community starts dimensioning and designing Tula excavation from the initial point of water point to the exit point (i.e., the entrance to the well). Traditional hand-drilling (auguring) considered the nature of the earth materials ranging from a very loose and easily sliding soil known among the indigenous well engineers as ‘biyyee yaatoo’, to the hard rock of end aquifers.

In a consolidated ground, including rock formations, the Tula stand unlined and unable to resist external loads and thus render structural susceptibility to collapse. However, the indigenous water engineers always reinforce the upper section with bush fences and other local materials. In case of naturally soft soils, a more reinforced stone structure has put in place to avoid or lessen the risk. With development intervention made, nowadays, some structures have

improved at several Tula with significant reduction in the depth as well as durability of such structures as 'faccana, naanniga' and the steps for instance, plastered with cement concretes.
Another key challenge was in the lay out where runoff enters through 'Baqassaa', resulting, sometimes, in over flooding of the entire structure depending on intensity of rainfall, but most of the time in a mixture of flood water and surface materials (barbaa) transported and deposited around the watering trough. This study depicted that, the height or depth of a Tula from the ground level point to the aquifer ranges between 20m to 40m; 10-20m from faccana to aquifer; while the length or horizontal distance from 'Gulantaa to Daargulaa' varies from 60m to 140m based on the depth of the well (see Table 3). During dimensioning, excavation and water lifting process 'Irri' has used as a ladder to connect permanent and temporary storage of wells.
'Irrii', is a strong tree trunk (or a bundle of trunks). It has erected or suspended as a ladder to enter the deep 'qaa'a eelaa' down to the aquifer point. It also serves as a stepping point used by the water up-lifters (tootuu) from the aquifer into the temporary reservoir and from the reservoir into the watering trough. 'Irrii' has also used in China and some other parts of the Far East.
The safety of 'irrii' depends on the strength of the material it is made of the strength of the rope used in tying it to the available solid material (nearby-standing tree, log or rock), the art and skill in placing it. With age, loss of friction and slippery surface, irrii may break or fall, exposing the labor force to a great danger. Moreover, some deep structures of the Tula are too dark to see due to turn and twist in the Tula system and entail more risks.

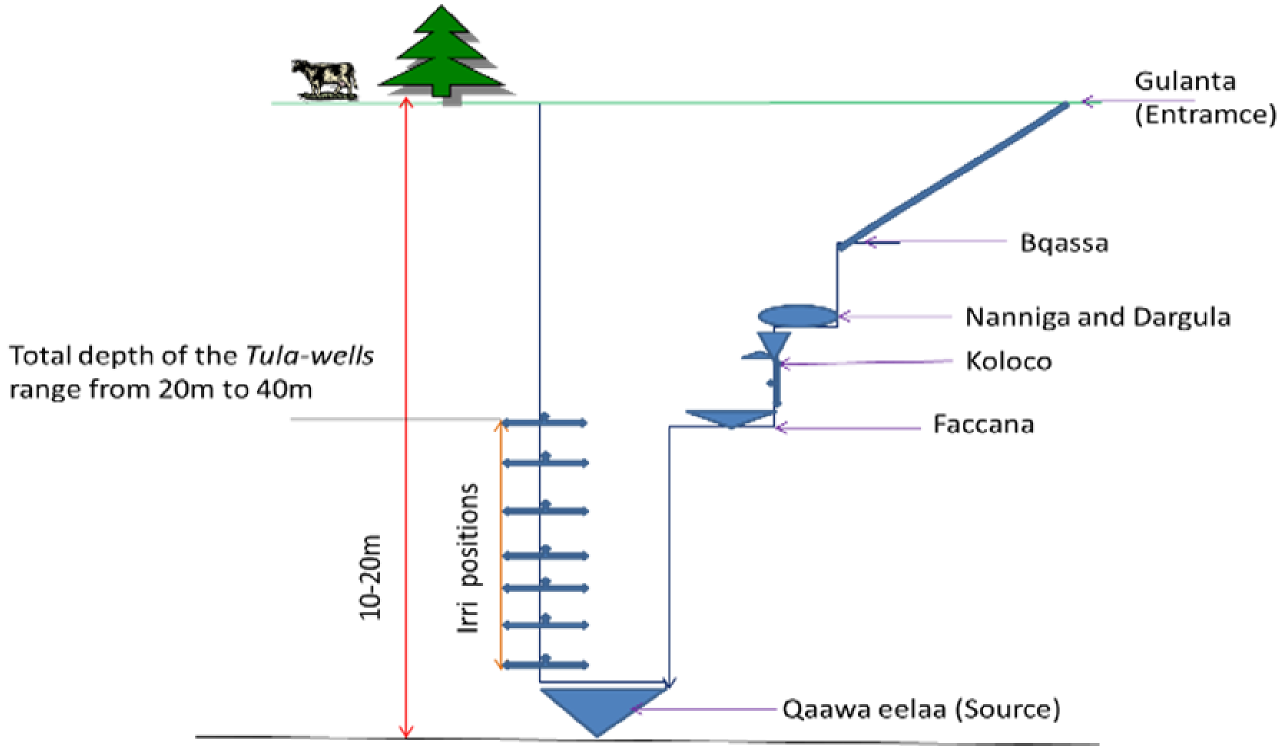

Figure 4 Borana traditional Tula profile and Irrii as core tool in traditional water lifting

In the evaluation of water lifting method, dimensioning and designing of *Tula* (any water wells) used for multipurpose according to their groundwater flow at end source, discharge potential groundwater use for max productivity had required if water-lifting devices had well planned. For details see 'Water lifting devices (Baumann, 2000)

3.1.1 Tula discharge estimate from the traditional and various water-lifting technologies
During the fieldwork, the researcher measured the yield of six wells at Gorile, Dhas and Wachille clusters. Tootuu use leather buckets (okolee too'aa) to uplift the groundwater, whereas solar radiation pumps and simple diesel motorized pump have also used at Dhas and Wachille Tula clusters respectively. The discharges estimated from the water-lifting technologies is shown in the below table.

Table 8 Comparison of the amount of water discharge in liter per minute between hand lifting versus improved technologies at Gorile, Wachille and Dhas Tula

Ela/wells	Discharge in (L/min)	Methods of water lifting			Location of *Tul*a cluster
		Okolee/Totu	Solar pump	Motorized Pump	
Odicha Balla	17	✓			Gorile
Galanticha	15	✓			
Qawa	27		✓		Dhas
Goba Alla	18			✓	Wachille
Dhibayu	17	✓			

From the above table, evaluation of traditional water lifting method and application of technologies used at selected Tula shows a small yield difference between these methods. The median yields for tootuu (using okolee too'aa), or an equivalent ten-liter jerry-can, with motorized pump and solar radiation pump at Gorile, Wachille and Dhas are 18,17, and 19 L/min respectively, showing a minor yield variation but the power, energy output and efficiency differs. Based on this, attempt was been made to calculate the energy and power invested to lift the mentioned amount of water (see section 2.3.1.4-5).

3.1.2 Livestock water demand calculation at Tula

The available applied technology (motorized pump and solar radiation pump) was not widely used in the Tula clusters, except for a few installations done at limited points. Therefore, only the traditional water lifting method was considered in livestock's water demand calculation. Livestock water demand was calculated and established on the standard livestock daily consumption in terms of weight equivalent called Tropical Livestock Unit (TLU) and adding the numbers of herds served on selected Tula. An attempt has been made here to determine the number of herds that can serve from a single well in a day. As the herd-watering day, demand unit per watering day has expanded to the three normal watering days the needed water demand based on the quantity of herds watered.

Table 9 Summary of livestock water demand value at ela Galanticha and Odicha Balla of Tula Gorile on three watering day and standard livestock daily consumptions

Name of Ela	Watering day	Total number of herds on watering day	Total Livestock Demand (in m3)	Livestock	Consumption (Liter per animal per day
Galanticha	**1**	**800**	20	Cattle	60
	2	510	12.75	Mule, Horse, Donkey	40
	3	615	15.375		
Odicha Balla	1	900	22.5	Goat, Sheep	5
	2	530	13.25	Camel	2
	3	1274	31.85	Chickens	0.2

The calculation of livestock demand based on standard LVU and herds watered at Tula has revealed that in one watering day, the eela/well called Galaanticha (means 'the well of Galaantuu clan') alone serves 800 heads of animal (see above table). Thus, centered on the daily consumption of each species, it is possible to calculate the aggregate annual herd size served by the Tula in Borana. In addition, one remarkable point is that, no matter how much the size of the herds brought for watering purposes, it is inconceivable to take the herds back home without watering them due to fatigue on the part of water up-lifters.

According to my informants, if a labor shortage has been experienced at a particular well, people from the neighboring wells are obliged to fill the gap based on Boorantittii (being Borana/Oromo) beyond the economic principle of reciprocity. Therefore, although the job was physically exhausting, the social obligation and the shame put individually or collectively on the 'Tootuu' of that particular day overcame the physical fatigue. Hence, through the blend of

homegrown technical groundwater engineering and social mechanisms, the Borana Oromo have been able to provide water for domestic and livestock consumption from deep inside the subsurface structure for centuries.
From the calculation of Ela Galanticha LVU, daily demand was 20m3/d, and according to water, trucking in arid zone BWMO' with a unit cubic meter costs twenty-five ETB birr. The financial cost estimation formula of 20*25 Birr, it costs around 500 Birr per 20m3/d. In order to lift this small drop of water, it is conceivable to imagine how much labor force has invested in Tula over a few hours' time, which recurs on every watering day. Thus, the energy they possessed during the watering day and the labor force invested in Tula over watering day herds were very huge.

3.1.3 Energy possesses by 'Totu' from Tula during herds watering day

From the field survey at the Tula cluster mentioned earlier, the amount of labor required on each watering day was ten to twenty persons of average weight of 60-70kg. Thus, 15 men of 65 average kg were taken to calculate the daily energy needed to lift water from the deep wells. On the three watering days of the selected Tula, the average weight of tootuu was 60-70kg. Formerly, based on the obtained data, the average value of certain parameters such as mass, gravity and height were determined. Hence, for eela Galanticha (m=65Kg, the average weight of tootuu, h=14m, the average height of 'Qaa'a Eelaa' the end source discharge) and acceleration due to gravity, g=9.81kgm/s2). Therefore, for the first time to fill the 'Faccana', 133.91KW energy was needed. However, based on numbers of herds on a specific watering day, the water up lifting activities could continuous about 6 hour's means at least quarter of a day. This indicates how huge an amount of labor force has been invested in a single Tula (deep well) in Borana. The field survey data also shows that in a single Tula cluster, there exist now, minimum of 5-30 individual wells. The critical energy of Borana's young people's in Borana's invested in fetching one cubic meter of water alone was very huge, and the amount of labor wastage was dismaying. As a general, with respect to the modern water engineering technology, the manual water lifting was tough and need enormous energy. For details see (Petra Schmitter, 2016).
Consequently, the amount of energy water lifters possessed on a single Tula was very huge. This shows how the people of Borana lose a lot of energy to lift the small amount of water from Tula. Therefore, considering the advantage and disadvantage of traditional water lifting and supply for livestock and consumption in terms of input and output energy and comparing it with the water lifted by available technologies in the study area, a few key analytical points have been highlighted below as the effect of water lifters on Tula.

3.1.4 Effect of traditional water lifting methods on Totu and application of technologies

In analyzing the effect of water lifting applied per event, no differences have been observed for the water applied throughout the time event of the watering day by totu (both male and female). A men's chain lifted water from the aquifer (madda) while a women's group lifted it from the temporary reservoir (faccana). The men's chain was long and, therefore, high loss of lifted water had been observed along the chain. Nevertheless, as the water reaches the faccana, the totu from the 'Faccana' into naanniga delivered water with less wastage. This indicates that, despite some variations, the two groups of water up-lifters were exposed to somewhat similar constraints and opportunities, but the effect of 'water power' has been taken into consideration.
The instant energy of the forces acting as 'Tootuu(totu)' to lift water from the Tula relative to the axis of turning 'okolee 'Too'aa' from 'Qaa'a Eelaa' to Faccana. In using the solar radiation and motorized pump, these forces or labor forces were optimized. However, they were rare in the Tula cluster and were not completely adopted. Thus, the effect of traditional water lifting methods on Totu is likely because the moments of acting forces relative to the axis of rotation are determined by the law of rotational motion in hydroelectric and water pumping machines (Dilshod Kodirov and Obid Tursunov, January 2019).

3.1.5 Waterpower during the water lifting exercise

In relation to the traditional water lifting methods and some available water lifting technologies, an attempt has been made to explain the meaning of waterpower, which in turn needs a 'drawdown' of Tula's definition of force. In engineering, the definition of a force is drawn from the second law of Newton and is known as a newton unit of measurement.
Force to lift water from the Tula aquifer is the product of the chain of persons and acceleration due to gravity that applies from the top to bottom of the borehole called 'qaa'a eelaa' (aquifer). In addition, mass is a volume of water

lifted from Tula per density of the water. The unit watt of power used to lift water from the Tula is/ is equal to the unit newton of force applied to lift unit meter within one second; or, equivalently, a unit watt is equal to a unit newton if every second's water is lifted through a unit meter of the length of 'irrii'.

Using the traditional water-lifting device, the chain of 'Tootuu' lifts the water unit meter and 10 liters of water is raised from the end source each minute with movements of water up-lifters. Then, the yield of the lifted water is unit liter/ second. In water engineering application, a unit liter is equivalent to unit kilogram weights in physics, and the general engineering tender force a unit kg is ten Newton. Therefore, the unit liter per second lifted yield of Tula is comparable to ten Newton/second.

In an economic calculation, the efficiency of water lifting is given in water watts per vested amount of money, such as watts per USD, watt per ETB etc. Note that in water engineering and water-lifting technologies, the old term "horsepower" (HP) should be avoided when computing waterpower, as water horsepower is the minimum power required to move water.

Generally, the Tula, waterpower calculation noted that the power wasted by a chain of persons on each herd-watering day is very huge and implies marginalization in terms of development planning. How energy or power wasted in manual water lifting is pointed out in the next section.

3.1.6 How water up-lifters loss energy or power

The nature of traditional and modern water-lifting devices was that water could be lifted higher than the theoretically determined water head. For example, if the vertical height of a well is 15m and the water lifted to 16 m, the excessive lift is 1m or that is parallel to only 5 percent of the lifted water. In the same way, in view of this study, from the illustration taken at eela Gorile, the water head was 4m and the water lifted 5m. In each movement of uplifting 'tootuu' exchanges 'okolee 'Too'aa' among the chain's members, then 50% of the waterpower was wasted. In the Borana traditional water lifting method, people draw water into the loss of a temporary reservoir that increases water and losses waterpower because they lift water at least half a meter.

Figure 5 Madda or qaa'a eelaa (the borhole), Faccana and Koloco structures of Tula well at Gorile (eela Odicha), showing that how water lose by traditional lifting method.

The smallest power invested in water lifting at Gorile was the yield taken from a single 'okolee Too'aa' and that was 15 water watts. Actually, there was no limit on waterpower for any watering day as the herd size and the households served are not automatically fixed, but for a watering day with a small herd size and a small number of households, the invested power was about 5000 water watts at Odicha Ballaa and Galaanticha wells at Gorile. The figure below from Dhas indicates that by a solar radiation pump, the well yields about 250 watts, but if manual labor was preferred instead, 30 chains of men were needed.

Figure 6 Solar radiation pump installed at the Gaadulticha well in Dhas

According to the findings of this study, a single motorized diesel pump can replace up to three hundred labor forces. On the other hand, solar radiation pumps installed at Tula sites often yield small amounts of water due to power fluctuations with changes in the weather and season of the year.

In order to adjust the waterpower, the devices used for water lifting from Tula should be selected in accordance with the available power source. For example, an adult person should not work with a tool intended for a child and donkeys should not draw camel-powered devices for lifting water or for any other purposes. In addition, women should not carry 25L of water on their back, but in pastoralist communities, women sometimes carry more than 25L of water, which has numerous effects on their health.

3.1.7 Emerging issues about Tula

A number of processes with both positive and negative results are unfolding around the Tula. Below is the outline.

- As it is a case in some Tula clusters, some water owner families are obtaining solar radiation pumps or a diesel motor to draw more water than required for the regular services. They are engaging in some instances in small irrigation behind the wells, using the 'surplus' water to grow food crops. Whereas food production is a positive venture, tilling the land in the vicinity of the Tula exposes the latter to siltation and overflowing risks.
- Tula has attracted the emergence of small towns with consequences for sustainability of the wells and water hygiene.
- As a Tula has a limited depth due to labor requirements, it may thus face slowdown of discharge.
- Modern techniques, solar panels and motorized schemes, for example, are replacing the traditional water lifting devices around the wells. The community seems happy about the lessened burden and improved efficiency in watering their herds. However, they often raise concerns about the schemes affecting the aquifer and the imminent risk to service sustainability related to technical failures in these schemes and shortages of diesel/petrol.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The Borana Oromo community has been able to pursue successful pastoral production in the semi-arid environment through application of indigenous groundwater engineering skills developed over centuries, and sophisticated institutional arrangements in managing water scarcity. The Tula is a great manifestation of ancient human civilization, which demonstrated pastoralist innovation in overcoming environmental and technological constraints. Specialized knowledge in water exploration, profound engineering skill in designing and executing structural works has been applied to enable supply of water for human, livestock and wildlife consumption from deep aquifers accessed via amazingly difficult cuttings into soft and hard rocks.

The job of lifting water from the sub-surface structure was risky, arduous, monotonous, time-consuming, and involves the use of locally available instruments and materials which are 'backward' in the light of present technological advancement, but has been the back bone to the subsistence economy of pastoralists for a long time. This means that the practice was successful when considered in social, economic, technological and demographic contexts of the time. With technological improvements in the water uplifting method, however, the huge amount of energy and the time invested in watering the herds could be improved and be used to address the emerging demands of the day. For example, the need for saving labor is becoming crucial day by day in the present economic context of Borana, where participation in other non-pastoral activities is becoming crucial to supplement household income. Moreover, with improved methods of water lifting, the aggregate number of herd units served by the Tula could increase while herd-watering frequency could reduce depending on the yield at individual wells.

Technical solutions are required to resolve the existing human burden inherent in manual uplifting of water from the deep aquifers (both in shallow and Tula) and the materials used to fetch water. It is equally important, however, to set any intervention endeavor (externally driven intervention in particular) in the institutional context of the society in consideration for sustainability, equity and internal societal harmony.

4.2 Recommendation

Based on the key findings of this study, the following suggestions have been forwarded:

1. The rich indigenous engineering tradition of Borana demonstrated by the Tula could be recognized as tangible heritage, which if protected and promoted well, can inform how human societies make life possible by overcoming environmental difficulties through labor and other resource mobilizations to develop and manage scarce resources. Similar practices may exist in different parts of Ethiopia that should be assessed, documented, recognized and applied in integration with scientific knowledge to develop water lifting techniques in rural parts of Ethiopia, in particular.
2. This study dealt with the technical engineering and social aspects of Borana Tula. The researcher’s initial intention to run laboratory tests to determine the quality and hygiene of Tula water lifted through human chains could not have materialized due to security and time constraints in the field. It is hereby recommended that future research endeavors should pay attention to this matter and bridge the information gap created in the present study.

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