POLITECNICO DI TORINO

MASTER'S DEGREE IN CIVIL ENGINEERING

Master's Degree Thesis

Small community water supplies in the Isiolo County, Kenya

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Abstract

Issues of access to drinking water for human use affect the whole world. The most difficult challenges to face are in the sub-Saharan Africa countries, with consequences that in recent years have been amplified by climate change and population growth.

The Italian NGO LVIA – Lay Volunteers International Association – has been working in Kenya for more than 50 years to improve living conditions of the beneficiary populations, also with interventions in the water sector that contribute to the achievement of the *No.6 Sustainable Development Goals* (SDGs) which aims to ensure the availability and sustainable management of water and sanitation.

Since 2012, projects have, as main beneficiaries, the pastoral communities in the rural areas of Isiolo County. Isiolo County, like Northern Kenya in general, has been plagued for years by severe droughts and floods that put a strain on water sources and the already precarious water infrastructure, generating stress among the populations.

The research that is presented is the result of an internship carried out in Isiolo County between March and May 2020, with the aim of collaborating in the international cooperation development projects implemented by LVIA in the water sector.

The collaborative activities results will be presented, concerning the emergency project for the rehabilitation of water supply systems in the villages of Duse, Bulesa/Godha, Sericho, Gafarsa, Oldonyiro, Kipsing, Kinna affected by floods at the end of 2019 which caused severe damage in various areas of the county.

In addition, rehabilitation of Boji village water supply system will be analysed in detail. The project involved the construction of water kiosks as common points for the inhabitants water collection, the construction of troughs for livestock which is the main source of income for households, the installation of solar pumping system associated with diesel generator backup system which draws water from borehole, the establishment of a water service pricing system, and the technical and management training of a water management committee. All these activities have enabled the inhabitants of the Boji village to solve the main issues concerning access to safe water and its model can be proposed as one of the best solutions for sustainable water supply in rural areas of Kenya.

Acknowledgment

First, I would like to thank all the LVIA staff – Lay Volunteers International Association – Italian NGO that has been active in international cooperation for over 50 years and works in 10 African countries to improve the community's life quality. Among these countries there is also Kenya, where my internship took place at their headquarters in Isiolo County.

Especially, I would like to thank Andrea Bessone, LVIA Desk Officer Burundi, Ethiopia and Kenya, for supporting this project from day one and doing everything possible to make it happen.

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Chapter 1

Access to Drinking Water in Africa and Kenya

The WASH – Water, Sanitation and Hygiene – situation in sub-Saharan Africa is becoming increasingly uncertain over the years. The water demand increases more and more strongly due to an exponential population growth and consequent urbanization. On the other hand, climate change also affects the drinking water availability. 42% of sub-Saharan African populations do not have adequate basic water supply and 72% do not have basic sanitation [1].

Africa is facing unprecedented urbanization: data show that its urban population could increase from 345 million people in 2014 to 1.5 billion people by 2050 [2]. This increase implies that only a part of city dwellers will have access to water supply systems. Today, only 56% of the cities' inhabitants have easier access to water. This value has decreased compared to previous years, when it was 67% in 2003. In addition, only 11% of city dwellers have a sewer connection [3].

Unlike other countries, strong urbanization is not balanced by adequate economic growth. This also affects infrastructure quality and quantity related to water and hygiene. Therefore, action is needed on investments, which must be increased compared to the amounts already allocated in order to achieve the objectives set by the *Sustainable Development Goals* (SDGs)[1], especially for poverty reduction (No. 1) and water and sanitation (No. 6) [4].

The inability to achieve the objectives and to overcome the challenges is due to this rapid urbanization, unstable social fabric and economic development, further increasing migratory flows within and outside Africa. Surely these challenges are great, but water sector reforms across Africa over the past two decades have also shown that it is possible to slow down water

[1] The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for people and planet peace and prosperity, now and into the future. At its heart there are the 17 Sustainable Development Goals (SDGs). (source *SDGs Knowledge Platform*)

cover reduction, and that it is possible to achieve a water access level in urban areas close to human rights standards, even in very poor countries [3].

Kenya too, to achieve SDGs No. 6, is committed to reaching by 2030 "*universal and equitable access to safe and affordable water for all; access to adequate and equitable sanitation and hygiene for all and an end to open defecation, paying special attention to the needs of women and girls and those in vulnerable situations*" [5].

Kenya is a chronic water scarcity country with total renewable water resources per capita of just over 600 m^3/inhab/year (source: *AQUASTAT Database, FAO, 2017*). This value is lower than the UN agencies and World Bank standard of 1,000 m^3/inhab/year, below which a country is under severe water stress (1,700 m^3/inhab/year is the international standard for drinking water) [6].

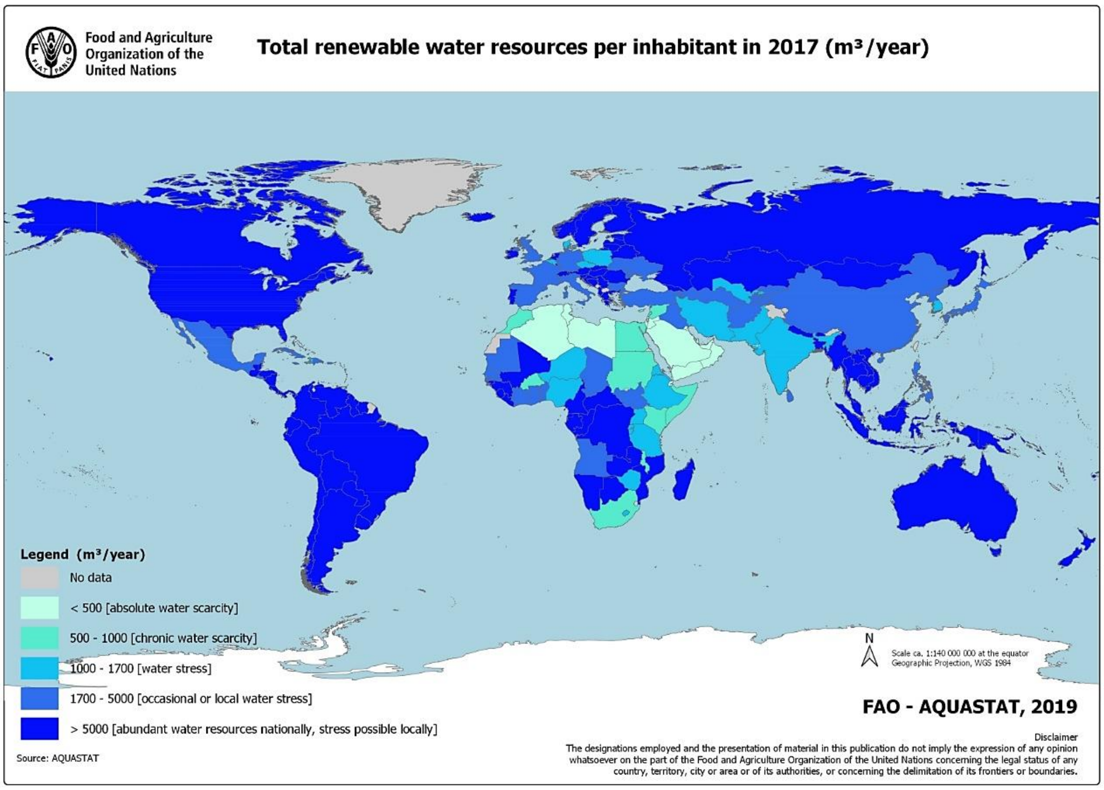


Figure 1: Total annual actual renewable water resources per inhabitant.

source: AQUASTAT Database, FAO

Over the past 20 years, there has been a slow improvement in the water supply in Kenya. According to 2016 UNICEF/WHO Joint Monitoring Programme (JMP), the Kenyan population basic water supply level increased by only 12 % in 15 years, between 2000 and 2015. In particular, 46% of the population of Kenya (specifically 88% in urban areas and 36% in rural areas) had adequate access to water in 2000, which slightly increased to 58% in 2015 (specifically 83% in urban areas and 50% in rural areas) [7]. Extrapolating this trend, it can be assumed that this value is not greater than 62 % in 2020, with an annual growth rate of 0.8%. This makes us understand that a big portion of the Kenyan population (about 40 %) continues to have no improved access to drinking water, that is, uses unsafe and not continuous water supply sources such as rivers, dams, pans and ponds, with great risk to their health [8]. These issues mostly affect rural populations in arid and semi-arid areas (ASAL), where the humanitarian organizations investments are concentrated for this reason. Like many sub-Saharan countries, Kenya has not achieved the Millennium Development Goals (MDGs)[2] targets set for 2015 [9].

In Kenya there are five main river basins that are the country's water resource basis. However, water availability is irregular throughout the country and rainfall variability implies frequent droughts and severe floods. The solution to this problem is to invest in the large and medium-sized dams' construction for surface water storage associated with controlled exploitation of groundwater, the only continuous and safe water source available [10].

The Government of Kenya (GoK) issued the *Kenya Vision 2030* in 2007, which is the country's new development plan for the period from 2008 to 2030. The Kenya Vision 2030 aims to transform and improve Kenya into a "*middle-income country that provides a high quality of life to all its citizens by 2030*" [11]. The objectives in the water sector are as follows:

- Water and sanitation - to ensure that improved water and sanitation are available and accessible to all by 2030;
- Agriculture - to increase the area under irrigation to 1.2 million ha by 2030 for increase of agricultural production;
- Environment - to be a nation that has a clean, secure and sustainable environment by 2030;
- Energy - to generate more energy and increase efficiency in energy sector.

A synergistic effort by government and local and international bodies, NGOs and donors is necessary in order to achieve these goals.

In recent years, the whole world has been suffering from the climate change effects. But across Africa, water resource is heavily affected by the increasingly harmful effects of ongoing climate change. If it does not slow down, climate change will further worsen the risks associated with changes in the distribution and availability of water resources [12]. The alternation of great droughts and heavy rainfall with increasing variability is putting a strain on the hydrology of many African countries, implying changes in the outflow, aquifers and water

[2] The eight Millennium Development Goals (MDGs) – which range from halving extreme poverty rates to halting the spread of HIV/AIDS and providing universal primary education, all by the target date of 2015 – form a blueprint agreed to by all the world's countries and all the world's leading development institutions (source *Unite Nations*)

quality of each source. In addition, a whole other set of impacts not strictly related to the water resource have negative repercussions on the water systems reliability and their operating costs.

In the case of Kenya, water availability is strongly affected by this alternation of floods and droughts because several water infrastructures are damaged or destroyed during floods and are overused during droughts, reducing lifetime and increasing maintenance costs. Unfortunately, efficient solutions in order to mitigate the impact of climate change on environment and water availability have not been found yet. Local institutions and stakeholders try to promote awareness and provide support to local communities to reduce environment exploitation and introduce renewable energies to increase water infrastructures economic sustainability.

Chapter 2

Water Resources in the Isiolo County

2.1 Overview

Isiolo County is a county of the former eastern province of Kenya. Isiolo County borders Marsabit County to the North, Samburu and Laikipia Counties to the West, Garissa County to the South-East, Wajir County to the North-East, Tana River and Kitui Counties to the South and Meru and Tharaka Nithi Counties to the South-West [13]. Its capital and largest town is Isiolo, which is 285 km from Nairobi, the capital city of Kenya. The total area covered by Isiolo County is 25,336.7 km^2 [14], which corresponds at 4.26% of the total area of Kenya (580,367 km^2 [15]).

Figure 2: Location of Isiolo County in Kenya.

Isiolo County is located in a central part of Kenya where the land it is mostly flat (Figure 2). The altitude varies gradually within its area, from about 200 m above sea level at Lorian swamp (Habaswein) to 300 m above sea level at Merti Plateau and finally to approximately 1100 m above the sea level at Isiolo town [16].

According to the 2019 Kenya Population and Housing Census, the population counts about 268,002 inhabitants (139,516 males and 128,486 females), with a population density of only 11 people per km^2. The population is made up of 58,072 households with an average size of 4.6 people per household. In view of the demographic development from 1979 to 2019, the annual growth rate is about 4.45%.

Table 1: Historical population of Isiolo County.

Years	**Pop.**	**± %**
1979	43,478	-
1989	70,078	+61.2%
1999	100,861	+43.9%
2009	143,294	+42.1%
2019	268,002	+87.0%

source: [17]

The population is divided evenly between urban areas and rural areas. It mainly consists of the Borana ethnic group, but there are minorities of Turkana, Samburu, Meru and Somalis. Most of rural population lives in semi-nomadic pastoral communities, where cattle is the main source of income and also social prestige [18]. Livestock continues to be the dominant economic sector in Isiolo County: over 80 % of the inhabitants rely on livestock for their livelihoods.[16]

The County has two constituencies, three sub-counties and ten wards. [16]

Table 2: Administrative subdivision.

Constituency	*Sub-County*	*Area [Km^2]*	*Ward*
Isiolo North	Isiolo	3,269	Wabera
			Bulla Pesa
			Burat
			Ngaremara
			Oldonyiro
	Merti	12,612	Chari
			Cherab
Isiolo South	Garbatulla	9,819	Kinna
			Garbatulla
			Sericho
Total: 2	**3**	**25,700**	**10**

source: Kenya National Bureau of Statistics, 2009.

The county is crisscrossed with six perennial rivers: Ewaso Ng'iro, Isiolo, Bisan-gurach, Bisanadhi, Likiundu and Liliaba rivers. The most important among them is Ewaso Ng'iro that has its source from the Aberdare ranges and the glaciers on the west side of Mount Kenya, the highest peak of Kenya with its 5,199 m above the sea. The river marks the border between Isiolo North and Isiolo South Constituency. Also Isiolo River begins at Mount Kenya and with Likiundu and Liliaba (that originate from Nyambene hills) flows into the North Ewaso Ngiro river. Bisan-gurach and Bisanadi Rivers are found in the southern part of the county and drains into the Tana River. There are also a large number of seasonal rivers, in particular in the area of Garbatulla, Kinna and in part of Merti and Sericho (see Figure 3). Unlike perennial rivers, seasonal rivers are rivers that flow only during the rainy season and the rest of the year are usually completely dry.

The climate of Isiolo County can be classified into three agro-climatic zones (Figure 4) that are [19]:

- *semi-arid zone* (Zone 3) that covers part of Wabera ward, Bulla Pesa, Burat and Ngare Mara wards and some portion of Oldonyiro ward in Isiolo North constituency and Kinna ward in Isiolo South constituency, where annual rain is about 500 mm;
- *arid zone* (Zone 2) that covers a portion of Chari and Garbatulla wards, where annual rain is between 250 and 500 mm;
- *very arid zone* (Zone 1) that covers Cherab and Sericho wards, where annual rain is between 150 and 250 mm.

Semi-arid zones occupy 5% of the area, 30% arid and 65% very arid [20].

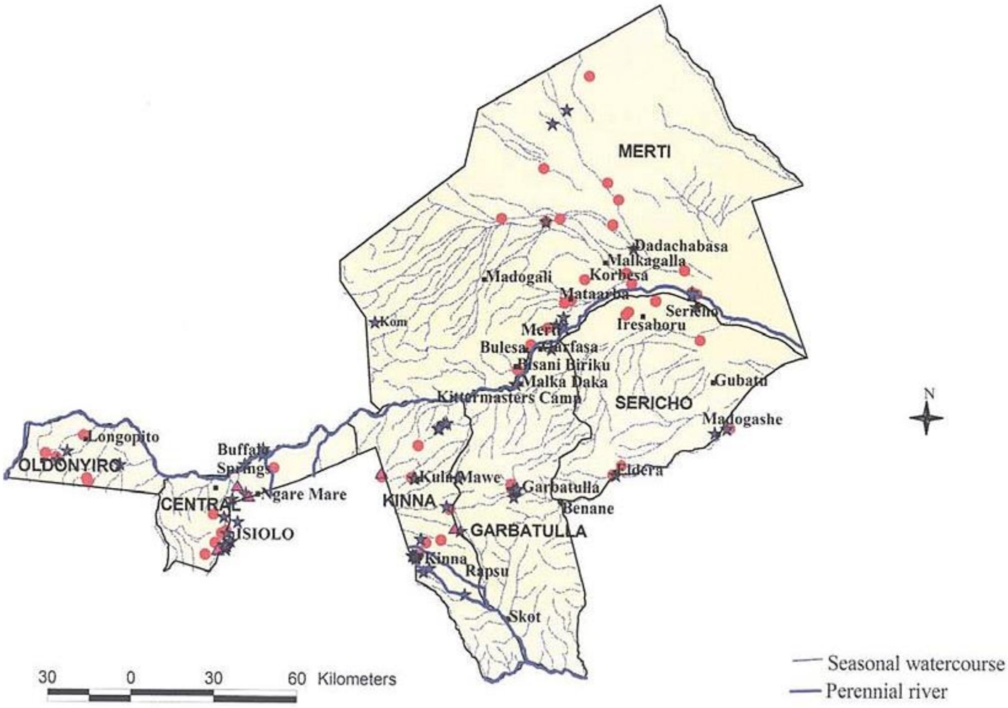


Figure 3: Spatial distribution of rivers in Isiolo County.

source:[20]

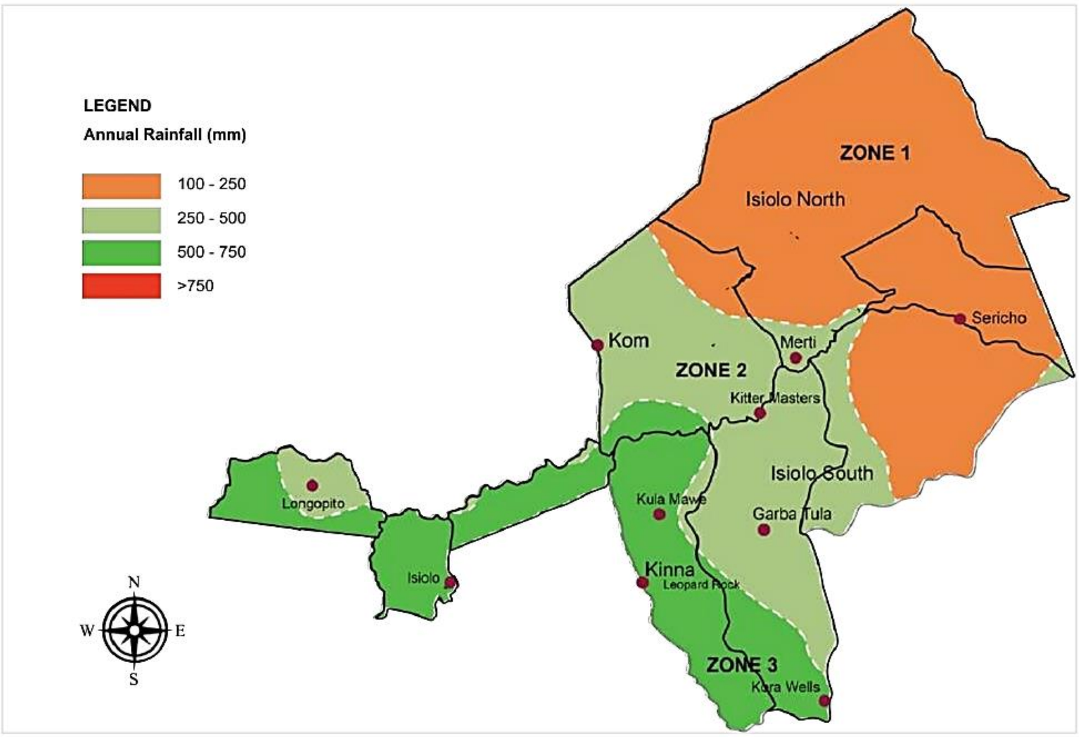
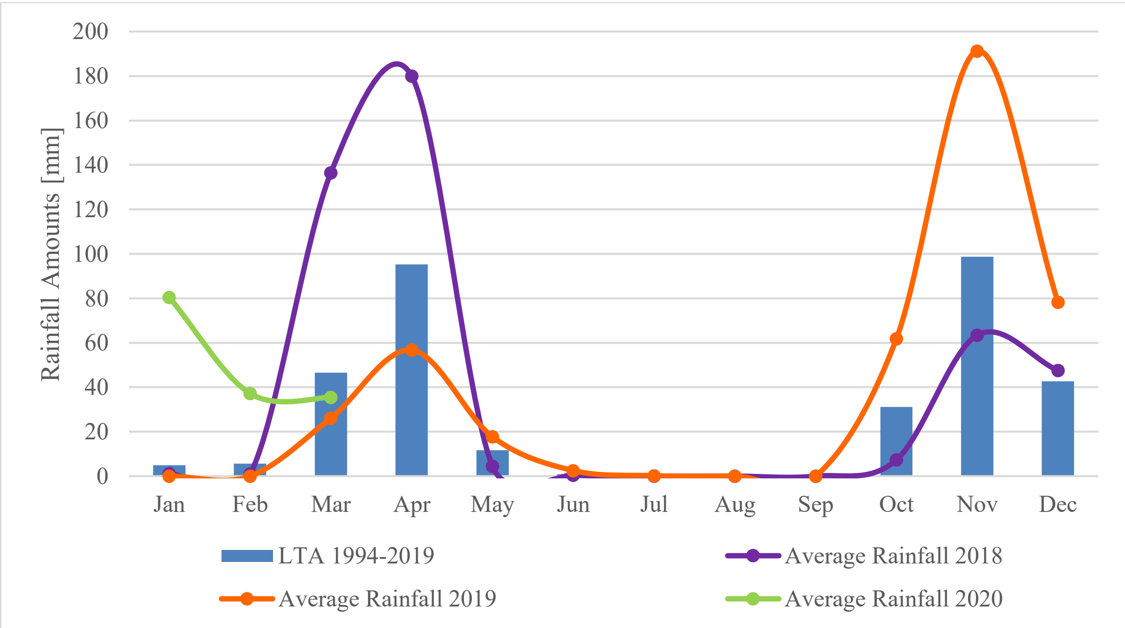


Figure 4 : Map of agro-climatic zones in Isiolo County.

source: [19]

The county climatic condition is hot and dry most of the year. The county receives annual rainfall ranging between 400-650 mm [16] and records mean annual temperatures ranging from 24ºC and 30ºC [20].

Generally the warmest period is between February-March, while the coolest is July-August, although seasonal variations in temperature are contained. The temperature and rainfall vary according to the prevailing winds that affect the Country, which determine two seasons: from October to March prevail hot and dry winds from Arabia, while from April to September the coolest and wettest winds from the Indian Ocean prevail. At the beginning of the two periods the two rainy periods are determined: the *long rain season* from March to May with the peak in April, and the less intense *short rain season* from October to December with the peak in November. The rains are mainly showers or thunderstorms in the afternoon or in the evening.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LTA 1994-2019	4.9	5.6	46.5	95.2	11.6	0.8	1	0.8	0.5	31.1	98.7	42.7
Average Rainfall 2018	1.1	1	136.5	180	4.4	0.5	0	0	0	7.3	63.4	47.5
Average Rainfall 2019	0	0	26.1	56.7	17.7	2.5	0.2	0	0	61.8	191.2	78.2
Average Rainfall 2020	80.4	37.2	35.5									

Figure 5: Average rainfall in the last 3 years vs long-term average 1994-2019.

source: [21]

The hours of sunshine per day are more than nine and for that reason, there is high potential for harvesting and utilization of solar energy, for instance using a *solar pumping system* for drinking water supplies. Winds blow across the county throughout the year and peak between July to August. This leads to a reduction in moisture. Strong winds offer a huge potential for wind-generated energy.

As it has been shown by the studies conducted by the Kenya State of the Environment and Outlook 2010 (NEMA 2011), Kenya also records climate change. Weather stations in all counties have recorded temperature and rainfall trends that are indicative of climate change.[9] Data show that the rains are becoming increasingly irregular and temperatures are rising in recent years. In particular, climate variability is implying a different distribution of seasonal rainfall during the year and extreme weather events interspersed with severe drought periods. This particularly affects rural population of the county which are increasingly affected by the lack of water during dry periods, along with damages to water infrastructures due to floods.

2.2 Water Resources

Four major drainage basins can be identified in the county area: the Ewaso Ng'iro Basin, which occupies 78% of the area and accounts for most of the drainage system in Isiolo County (Figure 6), Tana River basin to the south which occupies 10%, Galana Gof and Lagh Bogal which occupy 7% and 5% respectively [20].

Ewaso Ng'iro River rises from the Aberdare ranges and north-western slopes of Mount Kenya, where the water of its perennial glacier is collected. The Ewaso Ng'iro is a transboundary river basin [20]; this is because it originates at 200 km in the west from the Nyandarua Mountains (Aberdare ranges) but its flow increases due to contribution of Mount Kenya. The stretch upstream of the river flows for about 157 km along the border between Isiolo and Samburu Counties and then it runs through the county for 174 km, defining the boundary between Isiolo North and Isiolo South constituency. The mean flow recorded at Archers Post[3] gauge station is 20.29 m^3/s with the minimum mean monthly flow being 5.2 m^3/s and the maximum mean monthly flow at 88.1 m^3/s [20]. As it can be seen, the Ewaso Ng'Ro River has a variable flow that is affected by seasonal rainfall.

The availability of surface water sources such as rivers, streams and springs is subject to major annual variation as they follow the seasonal rain occurrence. Surface water extraction points are mainly located along rivers and streams. For instance, in some areas along the banks of Ewaso Ng'Ro it is possible to observe pumping points to fetch water for human use and

[3] Archers Post is a small settlement in Kenya's Samburu County, on the border with Isiolo County, near the stretch of Ewaso Ng'iro River that flows along the border between two counties.

small channels made to funnel off water for nearby fields irrigation, the latter especially in Kinna ward. Rivers and streams arise from sources or from the surface runoff during rainy seasons.

The main aquifers for Isiolo County water supply are [16]: the Isiolo-Nyambeni-Mount Kenya, which has a high underground water potential; Merti aquifer and Garbatulla-Modagashe aquifer, which have a low water potential; Kachuru-Kulamawe-Boji aquifer whose water surface is at high depths due to high uptake at the upstream surface water source that feeds it. Analyses carried out on these alluvial aquifers have shown good water quality, even if it is easily pollutable as they are shallow and not confined aquifers and therefore do not have an impermeable layer controlling groundwater chemistry. However, it has been observed that the basement[4] and volcanic formations may have poor quality water locally, which presents with slight salinity at high depths.

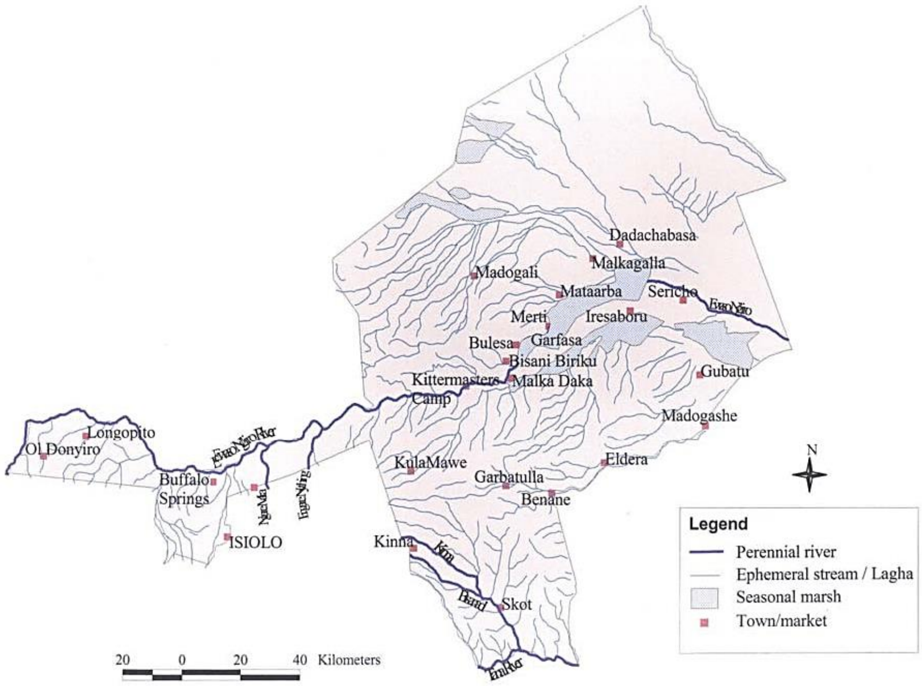


Figure 6: Drainage system of Isiolo County.

source:[20]

In Isiolo Sub-County there are volcanic areas with soils that have a high water storage potential. The water supply technologies used are mainly boreholes, shallow wells and springs [16]. According to Isiolo County Integrated Development Plan (CIPD 2018-2022), the groundwater quality of the Isiolo town is considered stable.

4 In geology, basement and crystalline basement are the rocks below a sedimentary platform or cover.

Also in Kinna ward there are volcanic areas with soils that have a good water storage potential. Boreholes yields are between 3-8 m^3/h and maximum depth up to 250 meters [16]. The groundwater potential in Oldonyiro ward is not high. Groundwater accumulates mainly in the fractured area of basement rocks. The maximum borehole depth is about 150 meters [16]. In Garbatulla ward, groundwater accumulates between sedimentary rock (limestone) and basement rock. Boreholes yields are between 15-20 m^3/h and boreholes depth is about 70 meters [16]. Boreholes drilled along the Ewaso Ng'iro River collect water from the river basin alluvial aquifer, especially from Malkadaka to Sericho in Garbatulla Sub County and from Biliku-Marara to Merti center in Merti Sub County. Boreholes in this area have a maximum depth of about 150 meters [16]. The rest of Sericho ward has little groundwater potential and quality. Boreholes in Cherab Ward of Merti Sub-County collect water from the Merti aquifer, and their yields are between 8-10 m^3/h, with good water quality. Boreholes built outside the area affected by Merti aquifer, on the contrary, have low yields and poor water quality. Boreholes depth in this zone from 250 to 350 meters [16].

As stated by CIPD 2018-2022, it's easy to think that the technological innovation in hydrogeological/geophysical investigative could change the availability and quality of groundwater potential within the county.

2.3 Availability and Access to Water

2.3.1 Water Availability

Water supply and availability in Isiolo County are closely linked to the seasons. There are great variations between the wet and dry periods. In almost the whole County it is very common to record water shortages during the drought.

Households in the rural areas do not have piped water and only a few of them have access to safe water.

Water supply in Isiolo County is guaranteed by these three types of water source:

- surface water abstractions, such as *rivers*, *streams* and *springs*;
- water infrastructures for surface water diversion, such as *sand/subsurface dams*, *infiltration galleries*, *pans* and *ponds*;
- groundwater supply systems, such as *shallow wells* and *boreholes.*

2.3.1.1 Surface Water Sources

Rivers and Streams: Rivers and streams are among the major water sources in Isiolo County, for human and livestock use. In this context, Ewaso Ng'Ro is the most important surface water source in Isiolo County. In addition, there are many valleys and badlands across the County (locally called *lagga* in Swahili, see Figure 7) which remain without flow during the dry season, but they channel a large amount of water during the rains; these are seasonal rivers. Generally, rivers and streams are not a sustainable water sources in the county [20].

Springs: Most of the springs are located within natural reserves and parks and they are not accessible to local people. Generally, the springs are near the main rivers that cross Isiolo County. In the past there were about 24 springs in the county [20], but almost half have disappeared today due to overgrazing and mismanagement. However, in some cases the community's commitment has allowed a partial recovery of deteriorated springs. Springs are sustainable clean water sources but should be well protected and maintained [20].

Figure 7: An example of "Lagga", during dry periods. The picture was taken near Duse village, in the Isiolo County, on the 7th of March 2020.

Pans and Ponds: Pans and ponds are small reservoirs with deep range from 1 to 3 meters, which are dug into the streams with raised and compacted banks all around [23] .

Figure 8: Pan near Saleti village, Merti Sub-County in the Isiolo County, March 2020.

They are built to collect and store runoff water from various surfaces. Pans receive water entirely from surface runoff while ponds are built where aquifers contribution can feed them. Pans and ponds capacity can generally range from 500 to 5,000 m^3 [23] but pans size ranges from about 10,000 to 50,000 m^3 in Isiolo [20]. Pans and ponds are generally built near settlements and are located on grazing land because the soil is more compact e less valuable than farmlands. In this case, the problem is the water pollution by livestock.

Sand/Subsurface Dams and Infiltration Galleries: Isiolo County, like all ASAL areas of Africa, is crossed by several sand rivers. Sand rivers are ephemeral streams (*laggas*), which remain dry during the drought, with the bottom covered by sand, but they channel a large amount of water during the rains (as seen above in "*Rivers and Streams*"). If a dam is built across the river, this flood water can be stored in the voids within the sand that settles upstream.

Figure 9: Left: sand dam during the rainy season; right: sand dam during the dry season.

source: [24]

During the dry season, the water is protected from evaporation, contamination and runoff. Water is extracted by digging a shallow well on the sand deposit upstream of the dam, with a slotted collector pipe that collects water in a well (Figure 10) or including a pipe or tap on the dam wall during construction [24]. It is worth pointing out that sand dam intercepts only a small volume of the watercourse, so there is no water shortage in downstream communities. In Isiolo County, there are five sand dams in Oldonyiro Ward [20].

However, when there are unstable geological formations and flat terrain, sand dams are not feasible, for instance in the flatter lower reaches of the river Ewaso Ng'iro beyond Merti [20]. It is preferred to build infiltration galleries in these areas (Figure 11). The infiltration gallery is a horizontal drain made from open jointed or perforated pipe. In this case, it is used to collect sub-surface flow from rivers. Water collected in this way is brought to a collection well or sump.

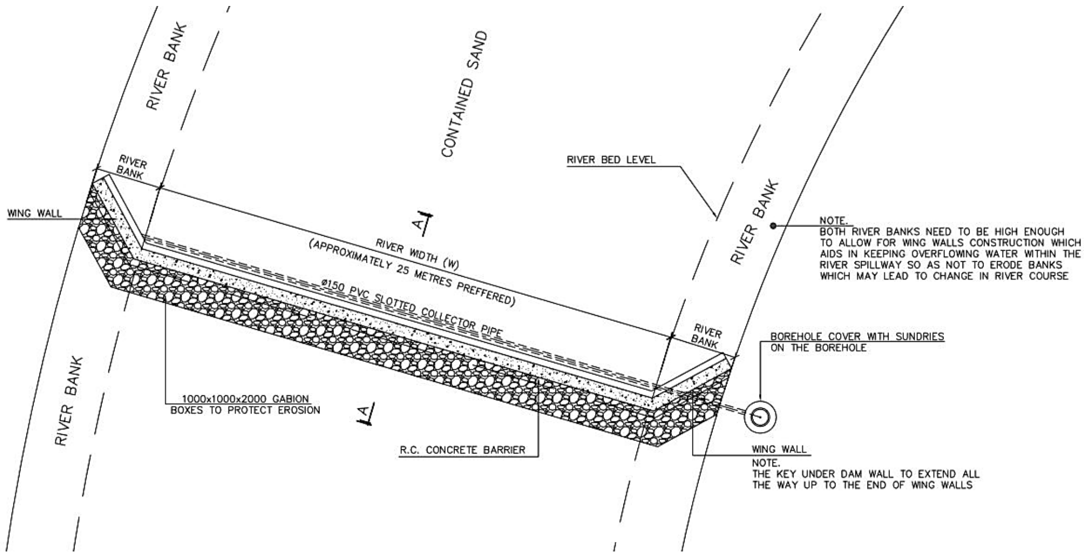


Figure 10: Plan of sand dam.

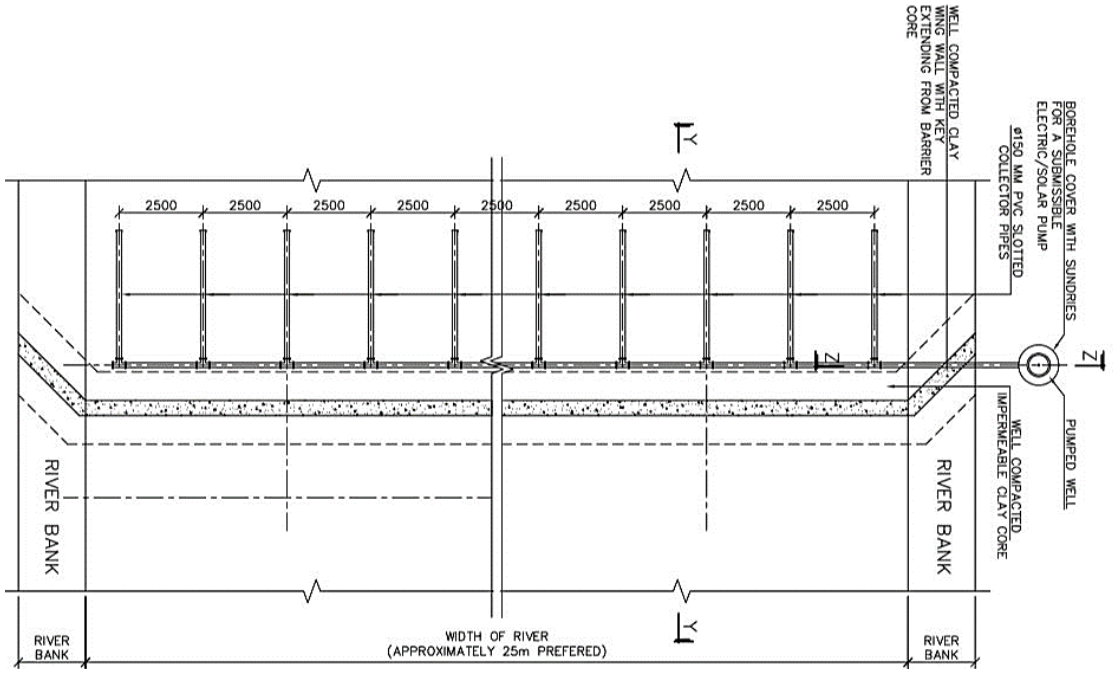


Figure 11: Plan of infiltration gallery.

source: LVIA

According to the WRAP project (MoWD 1991), rainwater harvesting and storage in dams and pans are appropriate solutions especially for livestock water supply in Isiolo County. Watering cattle is as important as water for domestic use, therefore water collection in Isiolo must take into account human and livestock water needs [20]. Precisely for this reason it is important to increase the use of facilities such as dams, pans and ponds in the county on a large-scale.

However, they are very expensive projects for local standards, although the cost of pans and ponds is much lower than dam building.

The main problems of these structures are siltation, contamination, high evaporation losses, infiltrations, ownership and community management, but they provide water supply opportunities up to the early part of the dry season and reduce the livestock water stress during this period. [20].

2.3.1.2 Groundwater Sources

Boreholes: Boreholes are the most used water source in the Isiolo County and represent 58 % of the total number of sources mapped [20]. Of these, some are operational throughout the year. Boreholes failure is generally due to poor community management, in fact a study showed that only 24% of the total number of them had an organized community management system [20]. It is important to highlight that boreholes may not work properly because local management committees do not purchase fuel for pumping or do not make ordinary maintenance.

The available data reported in [20] show that borehole depths are between about of 50-100 m, with the deepest at 250 m, and their water yields range between 3-20 m^3/h. However, their operation varies according to seasons, leaving only 15% of the boreholes operational during the dry season [20]. This is because most of them are shallow and therefore influenced by seasonal hydrological fluctuations or even by the fact that there is an over-pumping that exceeds the source's rate of aquifer natural recharge. Over-pumping lowers water table and increases pumping depth, thus increasing pumping costs. In addition, environmental problems such as reduced water quality, subsiding land and saline intrusion into aquifers can also occur [20].

Shallow Wells: A well is considered shallow if it is less than 20 m deep [20]. Generally, they are hand-scooped holes that communities usually dig during the rainy season (temporary wells). Surface water and rainfall that infiltrates the soil recharge groundwater. Groundwater penetrates through permeable soil and settles on top of waterproof layers. Shallow wells are deep enough to intercept water table at lower depths.

In the Boran systems, the water is collected by the women who line up to reach and take the water manually with containers, through a "hand-me-up" system [20]. Due to low yield of the wells, this is a slow and laborious activity and women and girls spend long hours extracting small amounts of water. In this regard, well design and management improvements are needed. Prospects should be explored to improve infiltration into sand rivers, for instance through sand/subsurface dams to increase the storage capacity of shallow wells [20].

2.3.2 Domestic Water Use

The amount of water needed for drinking, hygiene and domestic use varies according to the context. In accordance with SPHERE[5] standards, a value of 15 litres per day per person is used as a baseline value to be considered in similar contexts to those present in Kenya. It is never a maximum value and may not adapt to the contexts or interventions under consideration. During a severe drought, this value drops to 7.5 litres per person per day but only valid for a short period [25]. According to Isiolo County SMART Survey Report (January 2019), Isiolo County water consumption per capita (drinking, cooking and personal hygiene) is *14.2 l/person/day* [26]. It is slightly below than the SPHERE standards of *15 l/person/day* [25]. This value is an average that cuts maximum peaks that are reached in urban areas and the minimum peaks that are reached in rural areas. This estimated value is subject to seasonal fluctuations that, during wet periods and with normal and regular rains, can bring the average water consumption around 20-25 l/person/day [27], while during dry periods can drop average water consumption to below 10 l/person/day, reaching 5 l/person/day in some rural areas (the latter values being strongly below the SPHERE standards). Other data indicate a human water demand for Isiolo County of about 40 l/person/day rising for Isiolo Town to about 70 l/person/day and falling to 7-10 l/person/day in rural areas [28].

According to Isiolo County Drought Early Warning Bulletin for March 2020 of NDMA, the main water sources during the month under review (rainy season) included rivers, boreholes, sand dams, roof catchments, shallow wells, water pans and dams (Figure 12). Generally, households access water for domestic use from sand dams, distribution points such as water kiosks and domestic taps with water from rivers and boreholes.

[5] The SPHERE Project is an initiative to determine and promote standards by which the global community responds to the plight of people affected by disasters. This new edition updates indicators, guidance notes, and improves the overall structure and consistency of the text. It is the essential handbook for all humanitarian aid.

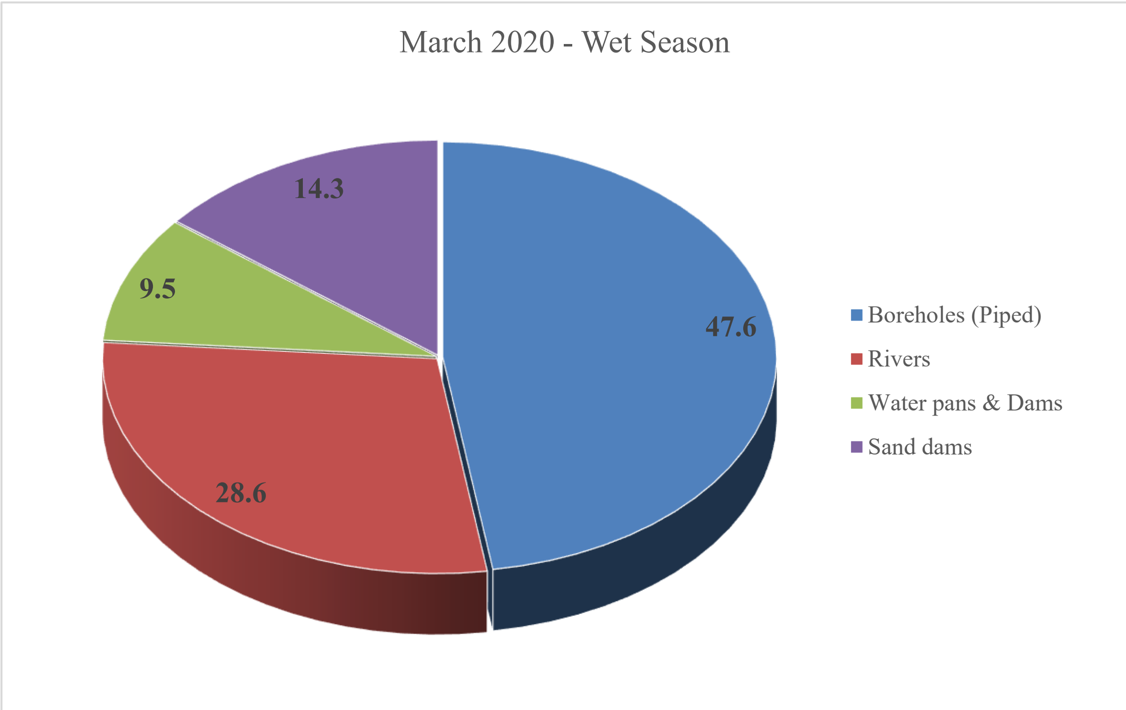


Figure 12: Main water source for Isiolo County in March 2020.

source: [21]

It can be observed that during a wet season there is a good water quantity in rivers, springs and water pans as a result of a recharge of these water sources due to rain.

Water availability in semi-permanent sources such as seasonal rivers, sand dams, traditional river wells and shallow wells generally decreases in the following months due to the end of the long rain season. There is a similar trend for the short rain season.

Compared to a dry season, according to Isiolo County Drought Early Warning Bulletin for July 2019 of NDMA, the main water sources during the month under review (dry season) included rivers boreholes, shallow wells and traditional river wells (Figure 13).

It can be observed that the main water sources in Isiolo County, both in urban areas and in arid and semi-arid areas (ASAL), are boreholes and surface water, especially rivers.

According to SPHERE standards, distance from any household to main water source should be 500 meters at most [25], which means less than 15 minutes-walk to reach the closest water point. About 80% of households in Isiolo County walk on average less than 15 minutes (less than 500 m) to collect water [26]. This estimated value is also subject to fluctuations due to rainfall pattern and seasonality. Average water access distance was 2.1 km in March 2020, which is a wet month; it increased slightly from 1.0 km in the previous month (Figure 14) [21] .

During this time, the longest distance was 4.5 km in the Cherab ward, where households traveled to the Ewaso Ng'iro River to collect water. The lowest average distance of about 0.1 km was in the casual-waged labor livelihood zone [21].

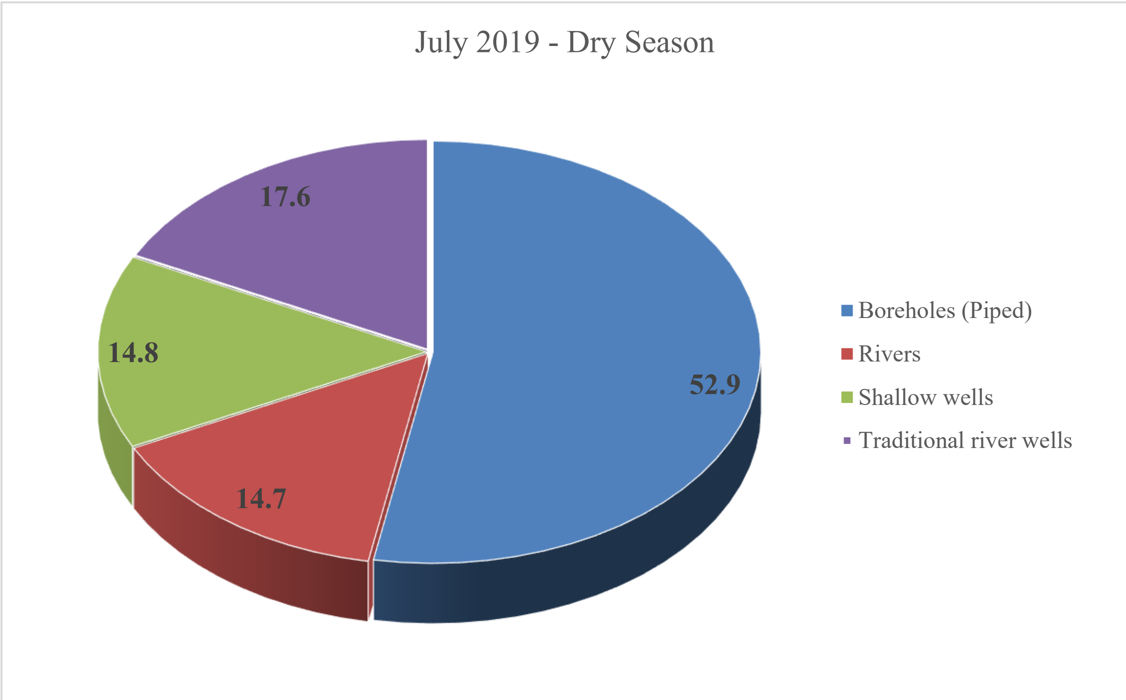


Figure 13: Main water source for Isiolo County in July 2019.

source: [29]

It can be seen from Figure 14 that average household water distance increases during dry period.

Average water cost from water kiosks is KSh 5 per 20-liter jerrican while in some settlement there is a flat rate payment about of KSh 1,000 per month per household. Generally it remains constant throughout the year.

Waiting time at main sources in a wet season is about 5-10 minutes in all livelihood zones and increases to a range of 15 to 30 minutes during a dry period.

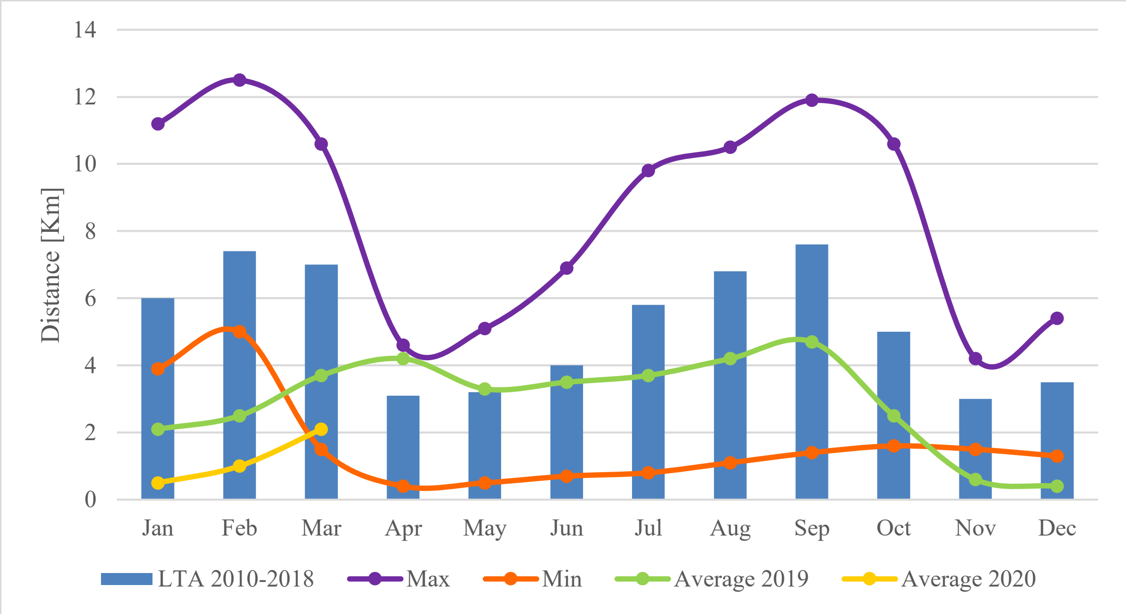


Figure 14: Average household water distance for March 2020 vs long-term average 2010-2018.

source: [21]*; NDMA, "Isiolo County Drought Early Warning Bulletin for December 2019", 2020*

Given the above, boreholes are a water source used steadily over time in Isiolo County. The comparison between dry and wet seasons shows a slight increase in the use of boreholes during the dry season as a result of the decreased availability of another sources, such as rivers whose use drops from 28.6% to 14.7% (Figure 12 and Figure 13). Dams and water pans are not reliable water sources during the dry season because they are directly fed by the rains. Perennial rivers are only suitable for nearby settlement, instead involving a large distance that other populations must travel to collect water. In addition, the populations near the rivers, even if they have a perennial water availability, have the disadvantage of flood hazard.

2.3.2.1 Water Quality and Treatment Methods

In Isiolo County, 59% of households use drinking water from improved sources, but only 12% are treating water with improved methods. 88% do not treat their water independently from the water sources [16]. Other data show that only 21.8% of the households in Isiolo County treat water before drinking [26]. Both data indicate very low values. Chemicals method is the main method of treating water in the County (Figure 15).

According to CIPD data, about 60% of water sources are saline and therefore not suitable for human consumption.

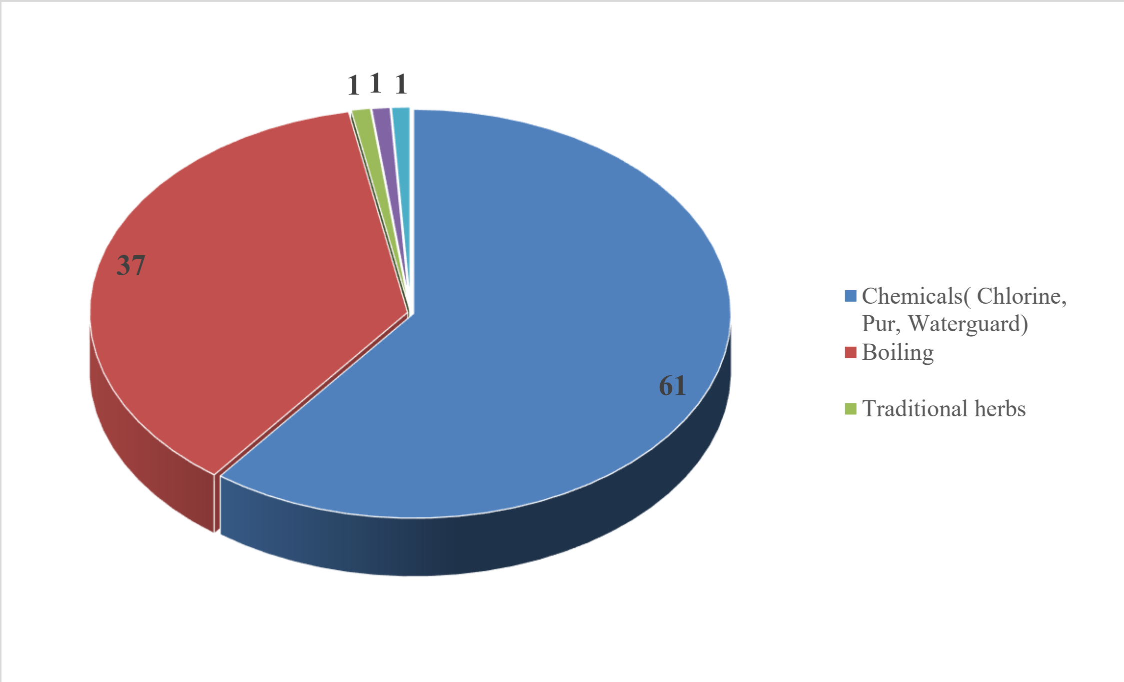


Figure 15: Water treatment methods in the Isiolo County.

source: [26]

2.4 Water Policy Framework

Kenya's water sector has undergone deep reforms through the Water Act No. 8 of 2002. Previously, National Water Conservation and Pipeline Corporation was responsible for service provision [30]. After the law was passed, the provision of services was decentralized to 91 local Water Service Providers (WSPs), coordinated by 8 regional Water Services Boards (WSBs) in charge of asset management through Service Provision Agreements (SPAs) with the WSPs. [30]. The Act also established the National Regulatory Committee, which performs performance benchmarking[6] and is responsible for the approval of SPAs and tariff adjustments. Following the introduction the Water Bill 2014, powers of the 8 WSBs were transferred to 47 Water Works Development Boards in each Kenya county [30]. This change is in line with the new Constitution of Kenya, which since 2010 has established decentralization in the counties. The Water Bill 2014 was published as the Water Act 2016 in October 2016 [31].

[6] Benchmarks are reference points that are used to compare your performance against the performance of others. These benchmarks can be comparing processes, products or operations, and the comparisons can be against other parts of the business, external companies (such as competitors) or industry best practices. Benchmarking is commonly used to compare customer satisfaction, costs and quality. (source *Bernard Marr, 2019*)

The introduction of the 2010 Kenya Constitution had important implications for the water sector. The new Constitution recognizes access to clean and safe water as a fundamental human right and assigns responsibility for water supply and sanitation to 47 new counties [32].

One of the most important regulations now in force on water resources is the Water Act 2016, which technically repeals the Water Act 2002. The Water Act 2016 is an act of Parliament that provides for the regulation, management and development of water resources, water and sewage services and for other related purposes [33]. The law brings a series of changes compared to the previous ones in the water sector with the main purpose of improving services. According to the Water Act 2016, "*Every water resource is vested in and held by the national government in trust for the people of Kenya*". The act claims that the water-related responsibilities are with the national government and the county government. And it gives top priority to domestic use of extracted water over irrigation and other purposes. Other key points of the law relating to the water sector that are in line with the Constitution's primary objectives include: action programs to guarantee water for marginalized groups; the responsibility of the national government for international waters and water resources management and the definition of national public works [32].

Consequently, the following institutions have been established:

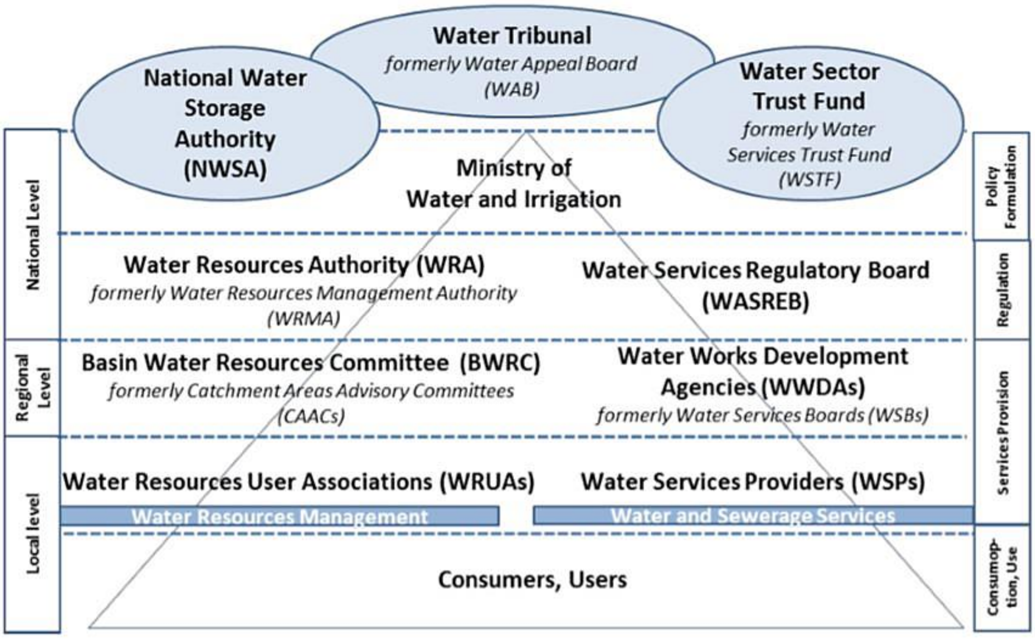


Figure 16: Redefined roles and responsibilities under Kenya's 2014 Water Bill (Water Act 2016).

source: [32]

The Water Act 2016 has an institutional framework similar to the Water Act 2002 but it replaces some institutions or renaming and redefining their membership and roles [34].

In 2018, The Ministry of Water and Sanitation was established by the Organization of the Government. Previously, the Ministry of Water Resources and Irrigation was responsible for water supply policies and the Ministry of Public Health and Sanitation was responsible for policies for sanitation [30]. The Ministry of Water and Sanitation mandate is development and management of water resources, transboundary waters, water harvesting & storage and water services & sanitation [35]. The Ministry's action is based on key legal instruments and policies such as the Constitution of Kenya, Water Act 2016, KEWI Act 2001, Legal Notice No. 252 of 2015, Agenda 2063, Sustainable Development Goals (SDGs) No. 6, the Kenya Vision 2030, the Third Medium Term Plan (MTP III) 2018-2022, Jubilee Manifesto and 'Big Four' agenda plan [35]. These legal instruments and policies help the government to improve management in the use of natural resources and to achieve its goals regarding economic growth, poverty reduction and social stability. The Ministry's commitment is focused on promoting sustainability in water resources and cross-border water management as well as on improving water and health services, while mitigating and adapting to the effects of climate change [35].

The specific functions of the Ministry are [35]:

- water resources management policy;
- water catchment area conservation, control and protection;
- water and sewerage services management policy;
- wastewater treatment and disposal policy;
- water quality and pollution control;
- sanitation management;
- management of public water schemes and community water projects;
- water harvesting and storage for domestic and industrial use;
- flood control management;
- transboundary water policy.

Chapter 3

Participation to International Cooperation Projects

3.1 Projects and Background

The research that is presented in this thesis is the result of an internship carried out in Kenya between March and May 2020, with the aim of collaborating in the international cooperation development projects implemented by the Non-Governmental Organization (NGO) LVIA – Lay Volunteers International Association. Given the area of interest of the course of study, focus was on analysis of small community water supply systems, which were implemented in rural areas of Isiolo County, where the work of LVIA staff is now consolidated. The main objective of these projects is to improve access to drinking water for rural communities in arid and semi-arid areas (ASAL) of Isiolo County, where the main problems due to severe droughts and floods are concentrated. It should be added that in this context, the LVIA's interventions general objective is to improve the living conditions for pastoral communities. Therefore, activities also focus on strengthening and diversifying the income and improving the health and hygiene conditions of the beneficiaries.

All activities that will be presented have been elaborated at LVIA office in Isiolo Town by the technical staff under the LVIA Country Representative supervision. Preliminary assessments and on-site monitoring were carried out during a few days in the villages affected by the interventions. The internship and thesis activities were supported by the LVIA technical team. The thesis was carried out in the framework of two international cooperation projects:

- ❖ *Improving access to safe water and safe hygiene practice to flood emergency affected people in Isiolo County*.
- ❖ *Rehabilitation of Boji Village water supply system.*

Below they are treated in detail.

3.1.1 Project #1

The project "*Improving access to safe water and safe hygiene practice to flood Emergency affected people in Isiolo County*" was funded by United Nations Children's Fund (UNICEF) and implemented in partnership with Lay Volunteers International Association (LVIA). This emergency project aimed to cope with the floods disastrous consequences that had affected many villages in Isiolo County at the end of 2019. As reported by LVIA technicians, after almost a year of drought, starting from the second week of October 2019 torrential rains have hit the entire Isiolo County, creating problems almost greater than those experienced during the rest of the year.

Figure 17: Damage caused by floods at the end of 2019 in Isiolo County.

source: LVIA

The 2019 Short Rains received in most parts of the country were above normal and enhanced both in terms of intensity and distribution [36]. The enhanced rains received in Isiolo County and Central Kenya caused increased water levels in major rivers, streams and drainage channels causing flooding in various parts of the County (Oldonyiro, Garbatulla, Cherab, Ngaremara, Kinna, Sericho & Bulapesa, Wabera wards). The water levels in Ewaso Ng'iro River in Isiolo County increased significantly causing flooding incidences in the lower parts of the County (Garbatulla, Merti sub-counties). Massive flooding occurred in several villages of Sericho ward (e.g Gafarsa, Eresaboru, Kombola, Badana & Sericho). The flood impacts spread across most of the livelihood zones in the County affecting a population of about 24,024 people [37]. The worst hit villages were Eresaboru and Gafarsa where 835 HHs were affected with 73 HHs displaced [38]. The borehole that serves Eresaboru was completely submerged and cut off. In Gafarsa, Duse, Bulesa Kipsing, Oldonyiro and Sericho villages, 2.8 km of pipeline were damaged disrupting access to safe water. Water pumping equipments for Oldonyiro and Kipsing water supplies were also damaged. In total this affected a population of 17,384 persons (8,969 M, 8,415 F). This programme proposed to replace the damaged pipelines, replace the damaged pumping systems, repair and desilt the intakes and install gabion, anchor blocks and other ancillary structures to ensure access to safe water for the affected population. In addition, it was proposed to install inline chlorine dozers for Kipsing, Oldonyiro which rely on sand dams and Kinna water supply which relies on a natural spring. This would ensure access to safe water to 10,174 people (5,181 M, 4,993 F) and 1,354 (730 B, 624 G) school children.

LVIA coordinated the response to flood emergencies in collaboration with county governments and other agencies and stakeholders to help make the response efficient. Especially, the action was implemented in collaboration with the Isiolo County Departments of Water Services and Public Health. Community groups and beneficiaries actively participated in the implementation of the action throughout the project cycle.

The programme was implemented in the wake of the COVID-19 pandemic. In consultation with UNICEF some of the activities were aligned to the COVID-19 response mainly to support prevention and control awareness through the hygiene promotion activities.

The expected results are listed below, defined at the beginning of the project and partially redefined following the COVID-19 emergency:

- **Result 1**: by 30th April 2020, 17,384 persons (8,969 male, 8,415 females of which 6,954 children) access permanent safe water at 7.5 to 15 litres/person/day from repaired water sources and water supply systems in the following villages: Duse, Gafarsa and Sericho in Garbatulla subcounty, Bulesa in Merti Sub-County and Oldonyiro and Kipsing in Isiolo Sub-County.

- **Result 2**: by 30th April 2020, 1,354 (730 girls and 624 boys) school children access safe water at 1-2 litres/child/day from repaired water distribution in Oldonyiro and Kipsing Primary and secondary schools.

- **Result 3**: by 30th April 23,555persons, 12,068 women and 11,487 men including 9,422 children receive critical WASH related information including hand washing with soap and infection prevention, and control awareness for COVID-19.

The first project activity was a technical inspection mission from 4 March to 7 March 2020 in the affected villages to define the conditions of the water infrastructures damaged by the flood in order to plan activities and items that were included in the tender procurement. Officers of the Isiolo County department of Public Health and department of Water services participated in the mission.

The works were divided into three different lots:

- **LOT 1:**
  - Rehabilitation of Duse Water Supply;
  - Rehabilitation of Bulesa/Godha Water Supply;
  - Rehabilitation of Sericho Water Supply;
  - Rehabilitation of Gafarsa Water Supply.
- **LOT 2:**
  - Rehabilitation of Oldonyiro Water Supply;
  - Rehabilitation of Kipsing Water Supply.
- **LOT 3:**
  - Rehabilitation of Oldonyiro Water Supply;
  - Rehabilitation of Kipsing Water Supply;
  - Installation of inline chlorine dosing for Kinna Water Supply System.

On 13th March 2020, LVIA invited a list of companies to participate in the tender. These companies are all operating in Isiolo County and were previously selected to respond in the best way and in the shortest time possible to the emergency. They then replied by sending the tender quotation and all required documents as a condition for participation in the tender.

The tenders were opened on the 19th March 2020 at 3.00 pm at LVIA Office in Isiolo, by the Evaluation Committee appointed for the purpose. The Evaluation Committee took minutes of the meeting. Tenderers participated at the tender dossier opening procedure. The evaluation consisted of the following steps:

- Examination of the administrative conformity of the Tenderers.
- Technical evaluation.
- Financial evaluation.

The Contracting Authority decided the best offer according to the following criteria:

- Compliance with administrative requirements.
- Eligibility of Tenderers.
- Assessment of the quality of proposals, considering:
    - Administrative Requirements: 30 points.
    - Technical Compliance: 50 points.
    - Price/Quality ratio: 20 points.

After the choice of three contractors (one for each lot), the contract was signed.

According to the site visit carried out by project team and contractor team from 24th to 29th March 2020 and the GoK directive to reduce VAT from 16% to 14% due to the impact of COVID19 in Kenya, LVIA decided to amend the contract signed for the works involving the water supply systems of the previously defined villages. Following the signing of the addendum to the bill of quantity, the contractors mobilised for the work that ended at the end of April 2020.

Below is a brief description of results and activities which occurred during the internship at LVIA Kenya, concerning the rehabilitation of Duse, Bulesa / Godha, Sericho, Gafarsa, Oldonyiro, Kipsing, Kinna water supply affected by the flood at the end of 2019.

- ***Rehabilitation of Duse Water Supply Pipeline***

A total of 2,151 persons (1,054 males, 1,097 females) from Duse community village benefited with access to permanent safe water at 7.5-15 l/p/day through replacement of damaged main water pipeline that supplies water to the village. The works involved replacement of damaged UPVC pipes[7] with HDPE pipes[8]. The replacement occurred along existing *laggas* (see section 2.3.1.1) where the pipeline had frequently been damaged by floods. The installation included gabions filled with gravel to act as a barrier preventing the pipeline from being carried away.

[7] Unplasticized Polyvinyl Chloride, a rigid, chemically resistant form of PVC used for piping, window frames, and other structures. (source *Lexico*)

[8] HDPE pipe is a type of flexible plastic pipe used for fluid and is often used to replace rigid pipes. Made from the thermoplastic HDPE (High-Density Polyethylene), its high level of impermeability and strong molecular bond make it suitable for high pressure pipelines. HDPE pipe is used across the globe for applications such as water mains, gas mains, sewer mains, slurry transfer lines, rural irrigation, fire system supply lines, electrical and communications conduit, and stormwater and drainage pipes.

Figure 18: Old pipeline hanging across one of the lagga (above); new pipeline installed with gabion structures across the lagga (below).

- ***Rehabilitation of Bulesa/Godha Water Supply (Rehabilitation of damaged pipeline, construction of gabions and anchor blocks, repair of Ground Masonry Tank)***

A total of 3,500 persons (1,820 males, 1,680 females) benefited with access to permanent safe water at 7.5-15 l/p/day permanent safe water through replacement of damaged rising main water pipeline thus ensuring uninterrupted water supply to the community. The work involved replacement of damaged UPVC pipes with HDPE pipes which were reinforced with gabions and anchor blocks. An existing storage tank was repaired thereby preventing water losses before distribution to communities.

Figure 19: Damaged UPVC pipes before replacement in Bulesa (left); New installed HDPE pipes in Bulesa (right).

- ***Rehabilitation of Oldonyiro Water Supply (installation of pump equipment, cleaning of intake sump, installation of inline chlorine dosing system, rehabilitation of pipeline for primary and secondary school)***

A total of 1,200 persons (624 males, 576 females) benefitted with access to permanent safe water at 7.5-15 l/p/day permanent safe water through installation of a new solar pumping system. The works involved replacement of damaged submersible pump and motor with a new solar powered 3 m^3/h submersible pump and 1.1 kW motor, cleaning of the borehole and installation of a chlorine dosing system at the main distribution tank.

A total of 941 school children (481 boys, 460 girls) would benefit with access to 1-2 litres/child/per day of permanent safe water after the re-opening of schools for rehabilitation of pipeline for Oldonyiro primary and secondary school.

Figure 20: BH site in Oldonyiro using a genset (left); new installed solar panels at Oldonyiro BH site (right).

- ***Rehabilitation of Kipsing Water Supply (installation of pumping equipment, construction of gabion structures, cleaning of intake sump, installation of inline chlorine dosing system, rehabilitation of pipeline for primary and secondary school)***

A total of 2,803 persons (1,458 males, 1,345 females) benefited with access to permanent safe water at 7.5-15 l/p/day permanent safe water through installation of a new solar pumping system. The works involved replacement of damaged submersible pump and motor with a new solar powered 7 m^3/h submersible pump and 2.2 kW motor, pipeline rehabilitation and cleaning of the borehole and installation of a chlorine dosing system at the main distribution tank.

A total of 421 school children (249 boys, 172 girls) would benefit with access to 1-2 litres/child/per day of permanent safe water after the re-opening of schools for rehabilitation of pipeline for Kipsing primary and secondary school.

Figure 21: Kipsing BH site before (left); new kipsing BH site with added solar panels (right).

Figure 22: A section of damaged water pipeline in Kipsing (left); a section of newly installed GI pipes (right).

- ***Rehabilitation of Sericho water supply (Rehabilitation of pipeline, community water point)***

A total of 4,783 persons (2,575 males, 2,208 females) benefited with access to permanent safe water at 7.5-15 l/p/day permanent safe water through pipeline rehabilitation and construction of a new community water point.

Figure 23: Women fetching water at a community water point in Sericho village.

- ***Rehabilitation of Gafarsa Water Supply (Rehabilitation of pipeline, supply, and installation of 5m3 plastic tank, construction of water kiosk)***

A total of 1,438 persons (1,509 males, 2,947 females) benefited with access to permanent safe water at 7.5-15 l/p/day permanent safe water through installations of a new pipeline and construction of new water kiosk for a settlement of persons displaced by floods.

Figure 24: Director of water services during the launch of the new water kiosk in Gafarsa.

Installation of an Inline Chlorine Dosing system for Kinna Water Supply System

A total of 6,175 persons (3,072 males, 3,099 females) benefited with access to permanent safe water at 7.5-15 l/p/day permanent safe water through installations of an inline chlorine dosing unit for Kinna water supply. The new chlorine dosing equipment will provide a solution to the persistent water contamination from the spring especially during heavy rains and flooding. Water quality analysis indicated high level of E-coli of 7 per 100ml. The system is automatic and doses chlorinated solution depending on the flow rate.

Figure 25: Inline chlorine dosing equipment installed for Kinna water supply system.

The programme activities were completed within the 3 months project lifetime. It was an emergency response to the flood consequences and therefore required immediate implementation. The programme outcomes/results were tied to the three key result areas. The project achieved 100% of the targets set at the baseline which were measured through key indicators. Below is a results summary with a comparison of the outcome indicators values between the start and end of the activity (see Table 3).

As mentioned above, the programme was implemented in the wake of the COVID-19 pandemic. Restriction on movements, closure of schools and ban on social gatherings were put in place by the government to prevent spread of the disease. The programme integrated some of hygiene promotion activities through creating awareness in line with the hygiene measures provided by the government on infection, prevention, and control of the disease.

There was a delay in movement of construction material especially from Nairobi due to restrictions on movement. County government supported the programme with a letter declaring the materials as essential services. This way the programme was completed within the scheduled timeline. Hygiene messages were conveyed through radio talk shows and vehicle mounted public address system.

Towards the end of the programme, floods were experienced in some parts of the county where some activities were ongoing. Access roads were affected which delayed transportation of materials and labour to site especially in Garbatulla sub-County.

Table 3: Comparison of the outcome indicators values between the start and end of the Project#1.

Indicator	Baseline	Targets	End of project	Cumulative progress
# of people with access to permanent safe water at 7.5 to 15 litres/person/day	0	23,555 persons 12,068 male, 11,487 females of which 9,422 children	23,555 persons	100%
# of school children with access to safe water and practicing personal hygiene including handwashing with soap	0	1,354 children 730 girls and 624 boys	1,354 children	100%
# of people recalling 3 key hygiene messages	0	23,555 persons 12,068 male, 11,487 females of which 9,422 children	35,000 persons	148%

The success of the project and the results achievement could not have been achieved without some key aspects. First, community engagement is a key pillar in ensuring the ownership and sustainability of donor-funded projects. For this reason, the active participation of the beneficiary community in the project planning and in the whole implementation has been guaranteed. Collaboration with the relevant county government departments was also very important in improving the effectiveness and efficiency of the project. It also provides an opportunity to influence government decisions in the budget allocation.

3.1.2 Project #2

The project "*Rehabilitation of Boji Village Water Supply System*" was funded by Italian Government and United Nations Children's Fund (UNICEF) and implemented by Lay Volunteers International Association (LVIA) in partnership with National Drought Management Authority (NDMA) and in collaboration with the Isiolo County Departments of Water Services and Livestock.

Figure 26: Explanatory poster at the entrance of Boji village.

This activity was part of a larger project – "*Improving access to water and the resilience of pastoral communities in Isiolo County, Kenya*", funded by Italian Government – that had the general objective of improving the living conditions of pastoral communities of Isiolo County. The specific purpose was to develop climate change resilience and mitigation mechanisms with water sources protection and rehabilitation in the most affected villages and, at the same time, to support strengthening and diversification of income, such as NTFPs (Non-timber forest products - such as resins, honey, rubber). The action was implemented in Merti and Garbatulla Sub-counties, Isiolo County (Kenya). Water sector goal was the protection and rehabilitation of water infrastructures for human and livestock use to increase water availability in the Isiolo County. The sites identification in the two Sub-counties was carried out based on "Wash Need Assessment" carried out by LVIA in 2014 and through a final comparison with the competent authorities of Isiolo County, in order to update the information collected previously. Among these sites was Boji Village.

Unlike Project #1 described above, which was an emergency response to the flood consequences and therefore required immediate implementation, the project under analysis lasted longer than 18 months. During these months, in addition to the design and implementation of rehabilitation activities of Boji village water supply system, preliminary analysis procedures and data collection necessary for the planning were implemented, as well as an ongoing and long-term monitoring; the latter with the aim of verifying the project sustainability. Precisely with the aim of ensuring long-term sustainability, an accurate infrastructure and water crisis management plan has been developed in the community.

The internship period took place in the final part of project cycle, involving the final monitoring in the village of Boji which took place in parallel to the first field visit of Project #1 held from 4th March to 7th March 2020. The visit investigated the infrastructures conditions and the Management Committee work. Video interviews and photographic documentation were collected with the aim of informing donors about the status of village's water system.

In this thesis work, it has been chosen to focus on this case. Rehabilitation of the Boji water supply system is a comprehensive project and covers all the typical aspects of an international cooperation project in the field of rural areas water resources. Through its study it is possible to analyse all technological and sometimes managerial aspects that ensure the success and sustainability of a project concerning the improvement of access to drinking water in rural areas of Kenya, in Isiolo County. About this, in the following chapters we want to talk about what are the elements that allow sustainability in the operation of infrastructure and in the perception on the beneficiary community. Although the internship period covered only a short part of the project, the information obtained from the above-mentioned field visit and the information gathered with the help of LVIA’s technical staff, made it possible to understand in detail the organization and operation of the project.

3.2 Boji Village Water Supply

Boji Village is among the rural villages located in Isiolo County, Garbatulla Sub-County in Garbatulla Ward (see Figure 27). The village is about 100 km from Isiolo town and 30 km from Garbatulla town. The village is inhabited mainly by shepherds who have put up permanent and semi-permanent houses. The village has a population of about 2,200 persons with approximately 300 Households, one primary school and one dispensary.

The intervention had the main objective to address key persistent challenges of availability and accessibility to safe water for domestic and livestock use. In addition, thanks to previous lessons learnt, LVIA focused to address these problems in a holistic approach that would have an impact to the beneficiaries through construction of climate resilient infrastructure and capacity building of the community.

Community groups and beneficiaries actively participated in the implementation of the action throughout the project cycle.

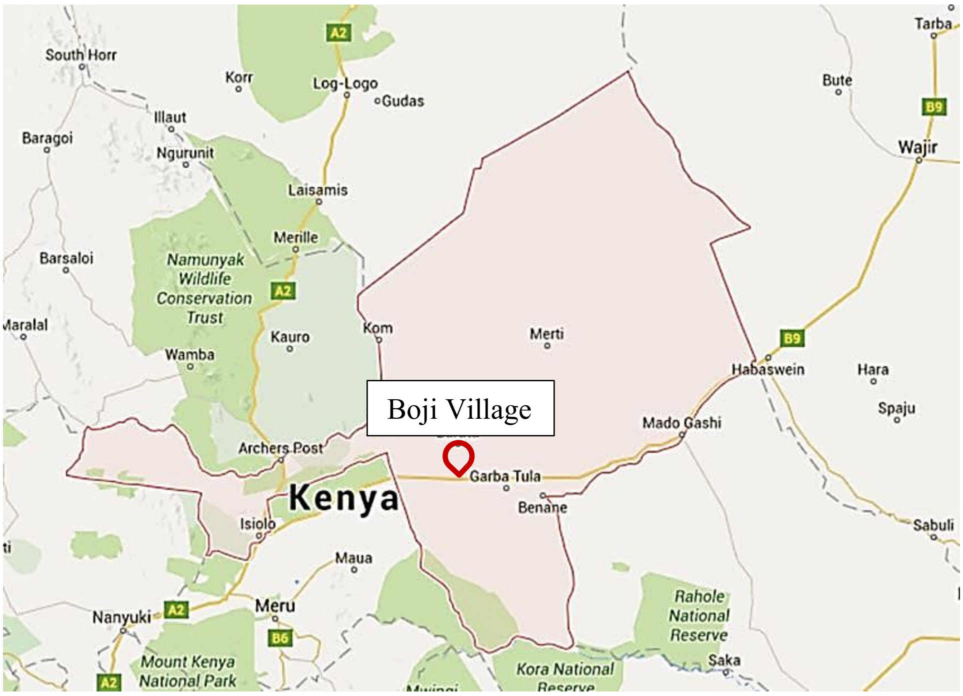


Figure 27: Location of Boji Village in Isiolo County.

The total beneficiaries reached through the project implementation are the following:

- **Direct beneficiaries**[9]:

  2,175 (Male=1,110, Female=1,065) persons, out of which 236 school children.
- **Indirect beneficiaries**[10]:

  4,544 (2,113 males, 2,431 female).
- **Livestock population benefiting**:

  Shoats=15,000, Cattle=2,600, Camels=4,500.

3.2.1 Preliminary Survey

After the Boji village was chosen as an intervention site, a preliminary survey was conducted by LVIA technicians among the beneficiary community with the aim of defining a development strategy. *Knowledge Attitude and Practice Survey* (KAP survey) was conducted to provide benchmark values for the project outcome indicators and was a useful tool for planning interventions in the village.

The survey population was made up of men, women and children residing in Boji village, where LVIA had planned to start operations within the WASH programming.

The sample unit was determined to be household. A sample size of 165 was calculated based on the target survey population of 288 households in Boji village using *Roasoft* online tool (see Figure 28). The confidence level was determined to be 95%, margin of error 5%, and a response distribution of 50%. Random sampling method was used to select households for participation in the survey.

The survey focused on quantitative and qualitative data collection using structured questionnaires developed by LVIA (see **Appendix A**). The questionnaire was based on key indicators. Data collection took a period of two days in Boji village. Data checking and validation for completeness and consistency was carried out on each day and quality control was ensured daily. Data entry was done in the office using a prepared data entry forms in Excel.

The survey achieved a total of 166 respondents, one HH more than the starting sample. Males accounted for 66% while females accounted for 34%. In terms of the level of education of the respondents, 60% have no formal education with 25%, 9% and 6% have had a formal education at primary, secondary and college level respectively. The response on the age groups of the household occupants shows that 51% are under the age of 18, while 49% of the occupants are adults. From these data obtained from the analysed sample, it is possible to

[9] Direct beneficiaries can be defined as those who will participate directly in the project and therefore benefit from its existence. (source *FAO*)

[10] Indirect beneficiaries are often, but not always, all those living within the zone of influence of the project. (source *FAO*)

conclude that the survey and the results allow to represent the conditions of Boji village quite reliably, as such data on gender, education and age are representative of the entire population. In addition, this clarified the target group of beneficiaries to whom the intervention was aimed and therefore allowed to better plan the activities.

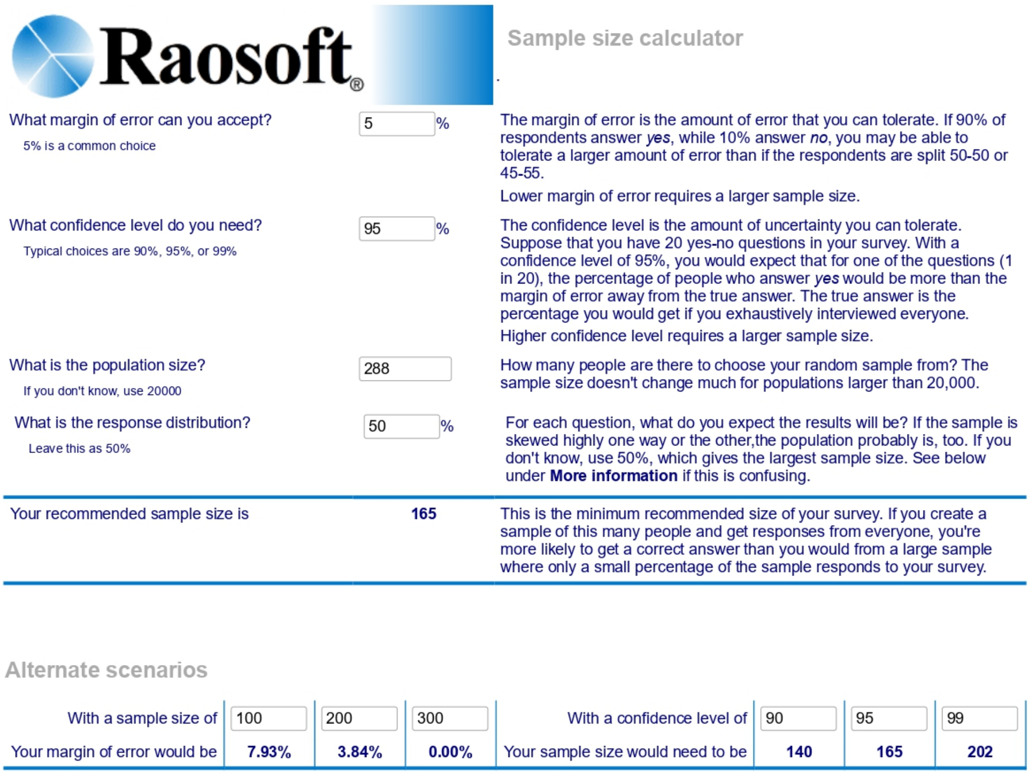


Figure 28: Raosoft report.

source: raosoft.com

3.2.2 Key Findings and Recommendations

Regarding the access to water sources the most common main water source was "unprotected well" whose water is mainly used for drinking, bathing, cooking and washing at 74% and for livestock watering 51%. The second most common water sources were the boreholes providing water for drinking, cooking, bathing and washing at 24% and livestock watering at 25%. Each of the water source and its use is shown in the Figure 29. The main concern noted for access to water sources was that 74% of the respondents used unprotected/spring (dug well). This raised a lot of concern on the quality of water for drinking and domestic use.

The calculated average of water collected per household per day for domestic use was six 20 litres jerrican equivalent to 120 litres per household per day. Based on the findings, the calculated average household size was 5 persons per household. This translated to 24 litres per person per day, which is above the minimum SPHERE standards of 15 litres per person per day for drinking, hygiene and domestic use.

Looking at the Figure 30, 72% of the households reported to cover a round trip distance range of 0-1 km to the primary water source. The key concern regarding water access was the reported maximum distance of more than 1 km (round trip) to the nearest water point by 28% of the respondents (1-2 km 25%, 2-5 km 3%) which is above the minimum SPHERE standards of 500 m. For this reason, it was important to focus on this aspect on the activities, to ensure intervention activities aiming at minimizing this number to the required standards and positioning water points at strategic locations.

In terms of the time (Figure 31), 87% of the respondents reported to take a range of 0-60 mins to and from the water source, 11% within a range of 61-120 mins and 1% within a range of 121-180 mins (round trip).

Regarding queuing time at the primary water source (see Figure 32), 37% of the respondents reported to spend between 10 to 20 minutes, 29% between 5 to 10 mins, 20% between 1 to 5 minutes, and 7% in 1 minute or less and more than 20 mins respectively. Queuing time at the water source as reported by almost 100% of the respondents, seems to be in line with the minimum SPHERE standards of not more than 30 minutes.

The survey found that animals shared water points with humans. This implies water contamination and very long waiting times for watering livestock or moving towards more distant water sources with consequent water stress.

The responsibility to collect water mainly reported to be undertaken by adult females who accounted for 96% of the overall responsibility with female children below 15 years taking 2% of the responsibility (see Figure 33). This result proved to be relevant for understanding the challenges faced by this group and in order to plan a better support for women. Some key concerns were their safety and security during water collection. The use of a Focus Group Discussion (FGD) with women and children was useful to better understand their specific needs.

In terms of water reliability (Figure 34 below), water sources were reliable with 62% of the respondents indicating that their primary water sources were available throughout. However, the result raised attention on the causes of water unavailability reported by 38% of the respondents.

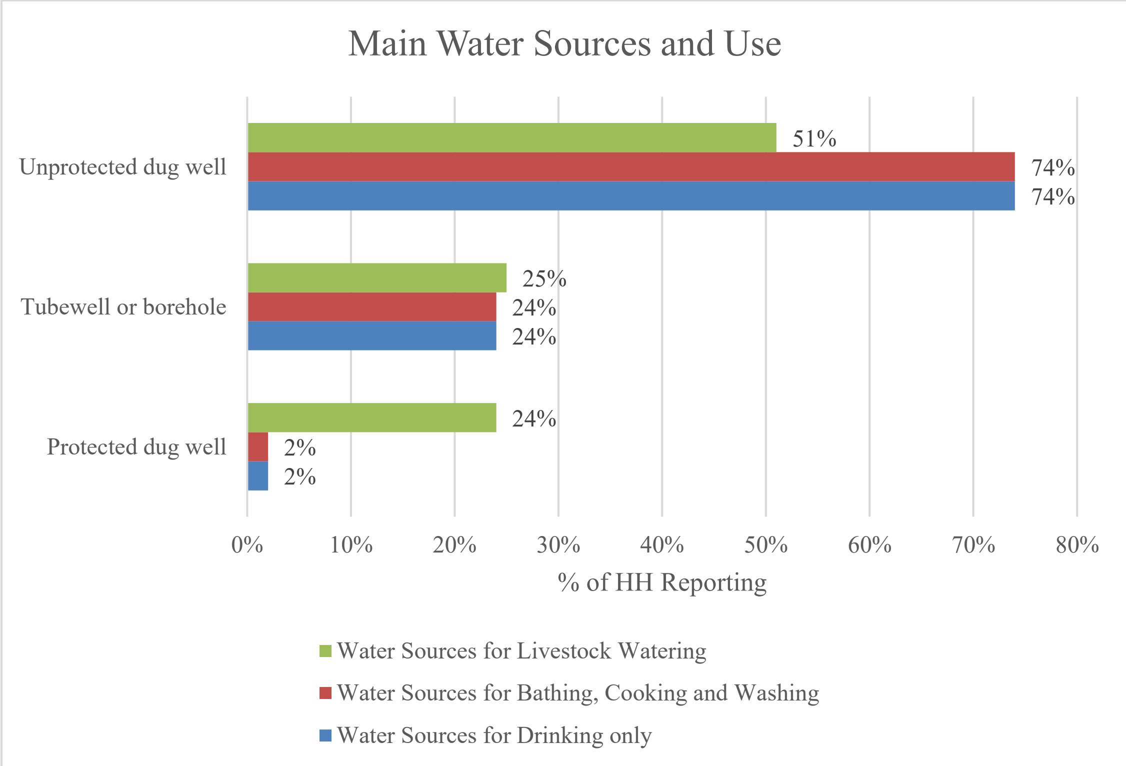


Figure 29: Main water source and use in the Boji village.

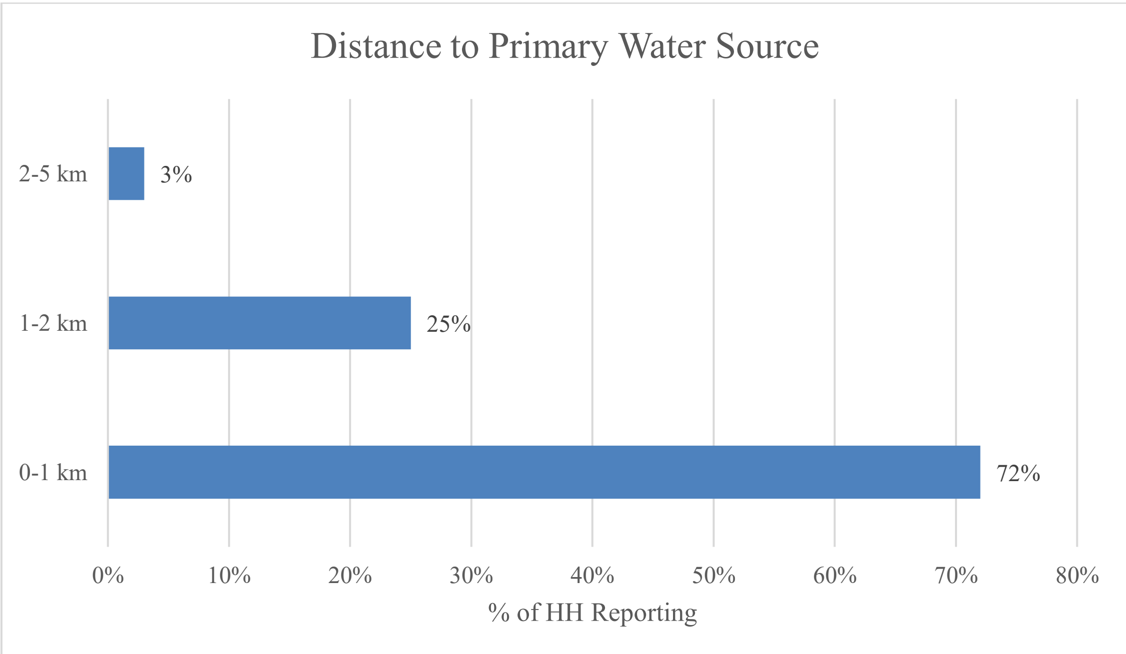


Figure 30: Distance to primary water source in the Boji village.

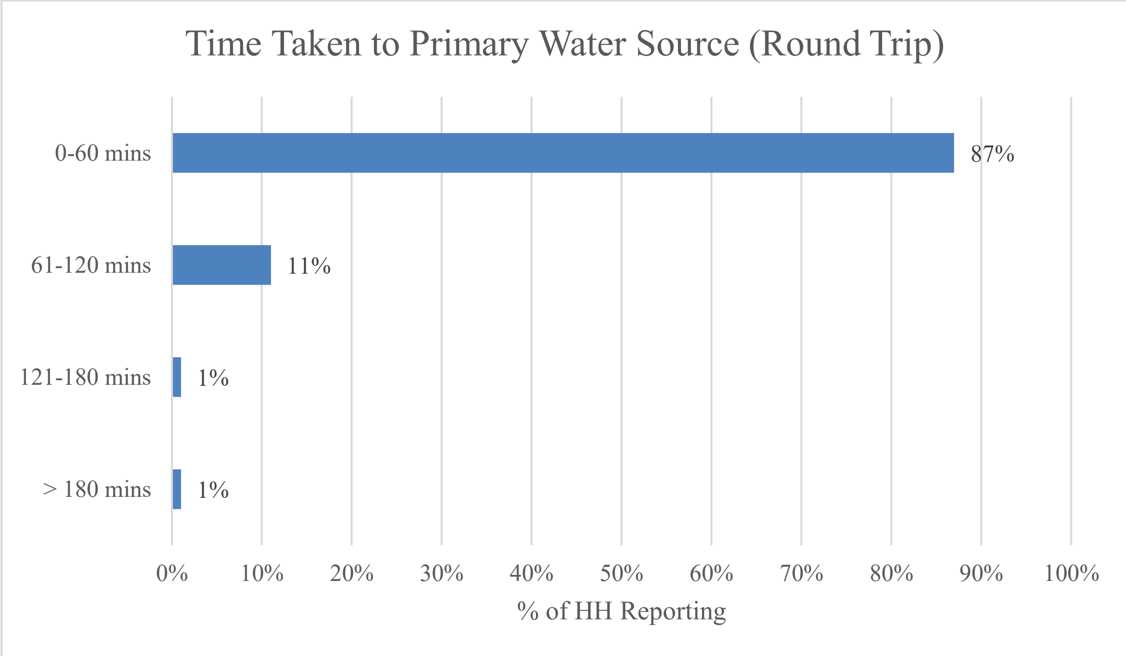


Figure 31: Time taken to primary water source in the Boji village.

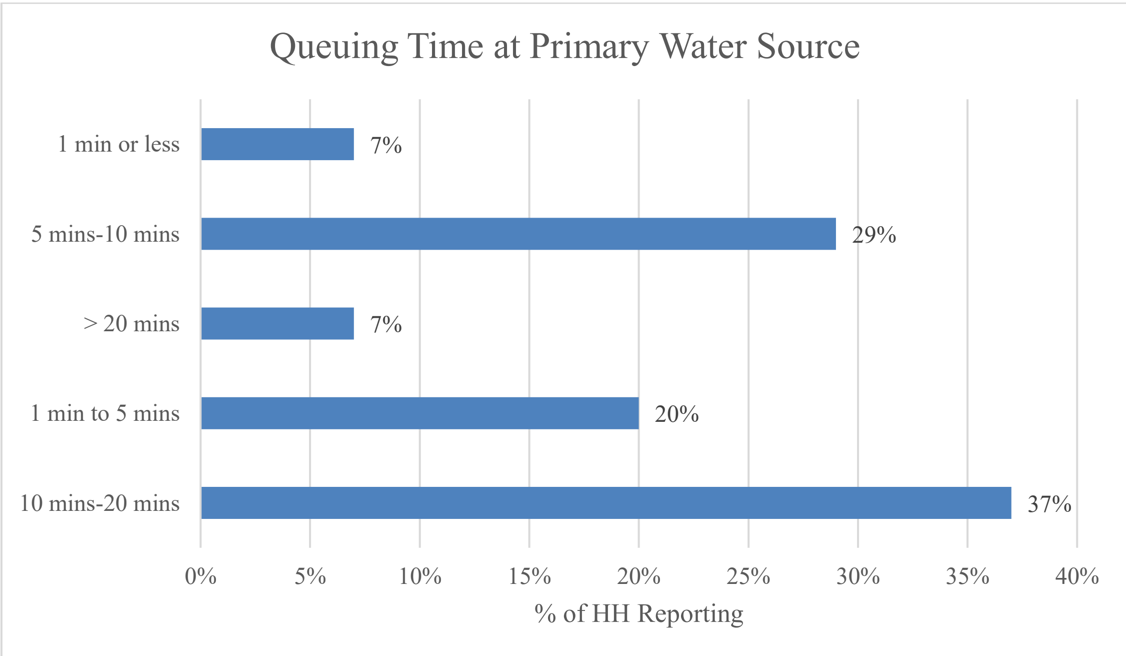


Figure 32: Queuing time at primary water source in the Boji village.

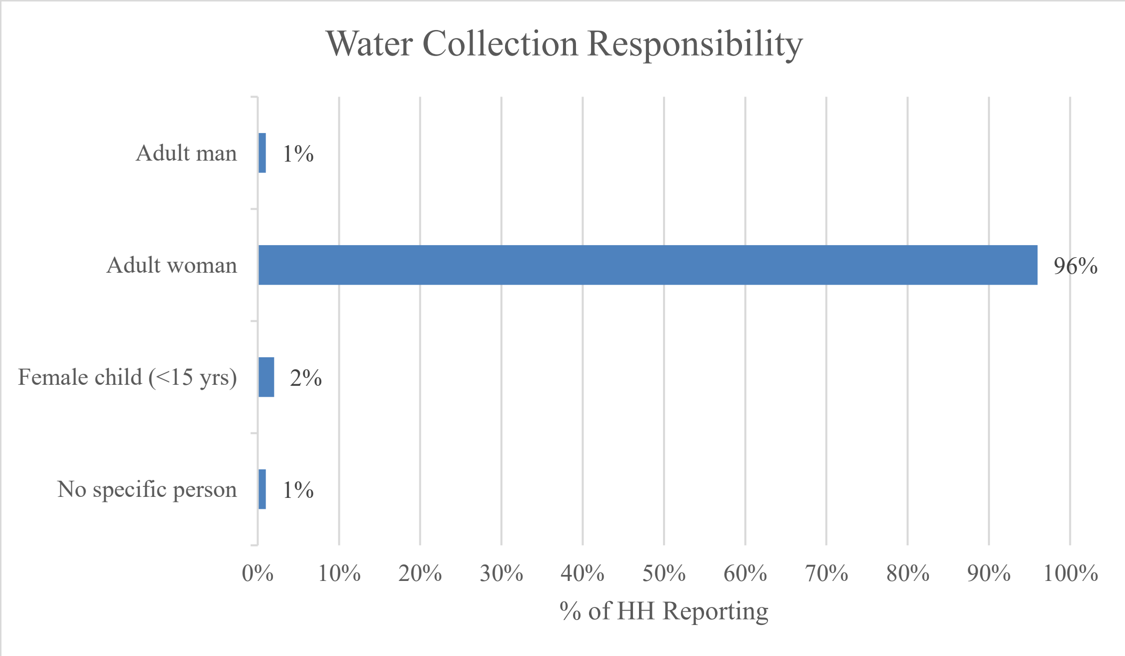


Figure 33: Water collection responsibility in the Boji village.

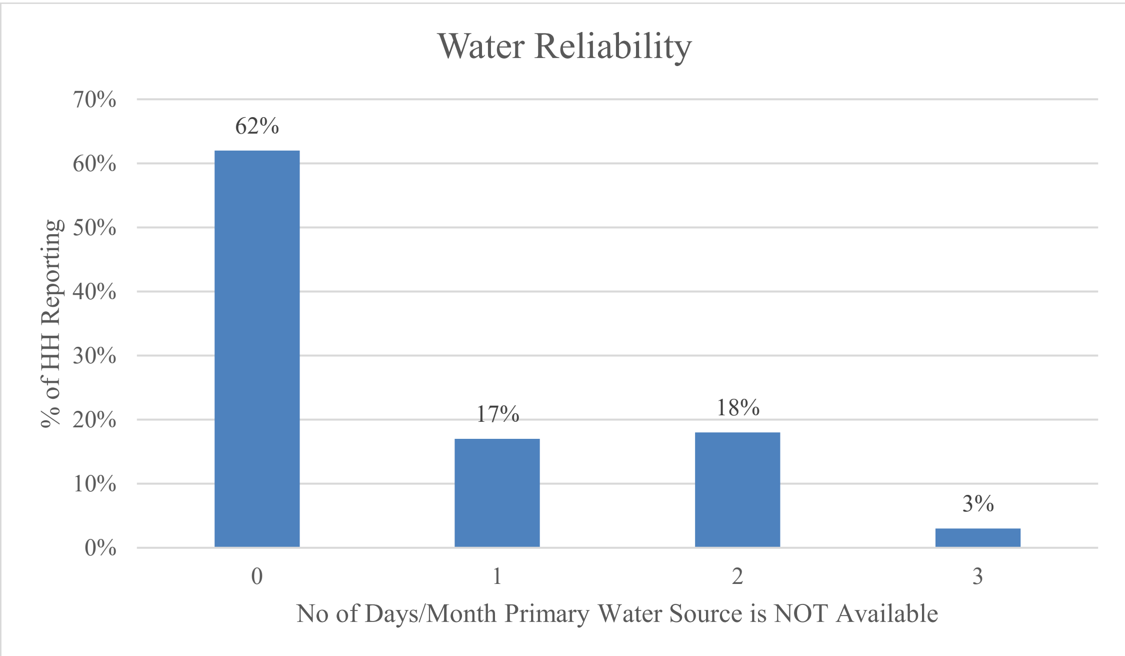


Figure 34: Water reliability in the Boji village.

100% of households reported to get water for domestic use free of charge. Water charges for livestock use ranges between KSh[11]1000 to 2000 per month.

Respondents were asked to express an opinion on different features related to drinking water, such as convenience, stability of service, healthiness, taste, smell, colour, and clarity. Regarding the features of clarity, colour, smell and taste, above 50% of respondents replied with "good". In terms of healthiness the reported rate was "fair" at 56%. In terms of convenience 43% of the households reported "poor". 65% of households define "fair" the stability of service. A summary of this analysis is provided in the Figure 35 below.

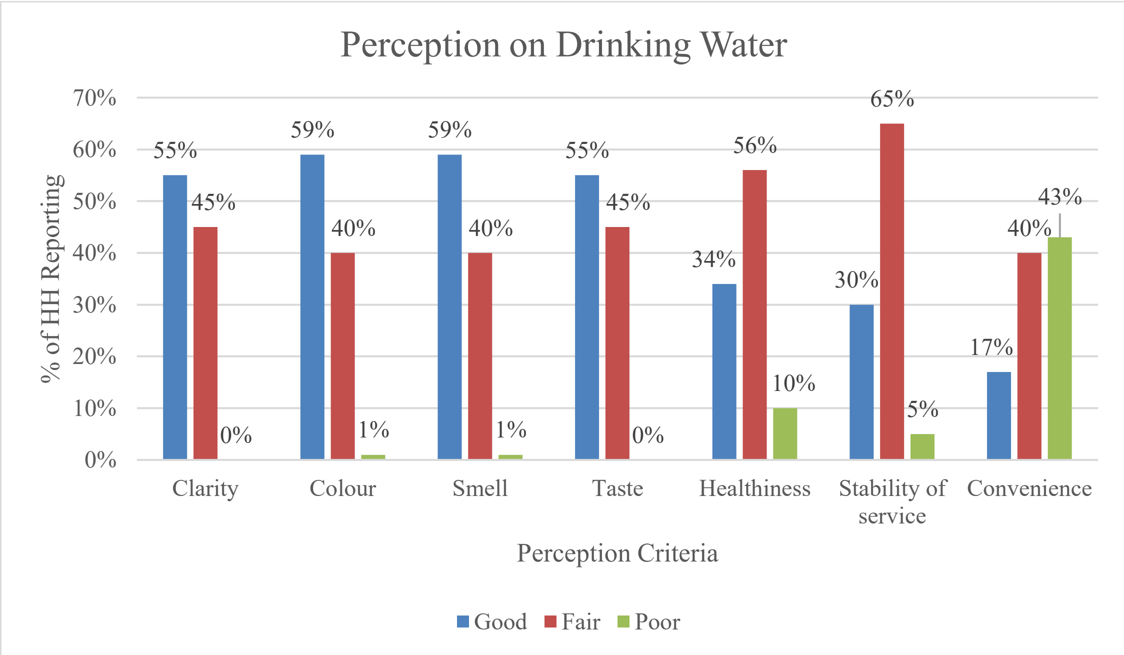


Figure 35: Perception on drinking water in the Boji village.

The key concern on water treatment was that majority of the respondents (34%, see Figure 36) reported not to know/do any form of treatment. Quality analysis of water collected by population was conducted concurrently with this survey and indicated presence of coliforms[12] in the water. The minimum SPHERE standard recommends zero coliforms in water for domestic use. It was important for WASH programmes to focus on creating more awareness and trainings towards use of household treatments, protection of water sources from pollution and possible treatment at the source. Water safety planning approach was needed.

[11] Kenyan Shilling.

[12] Coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material. Escherichia coli (E. coli) is the major species in the faecal coliform group. (source *health.ny.gov*)

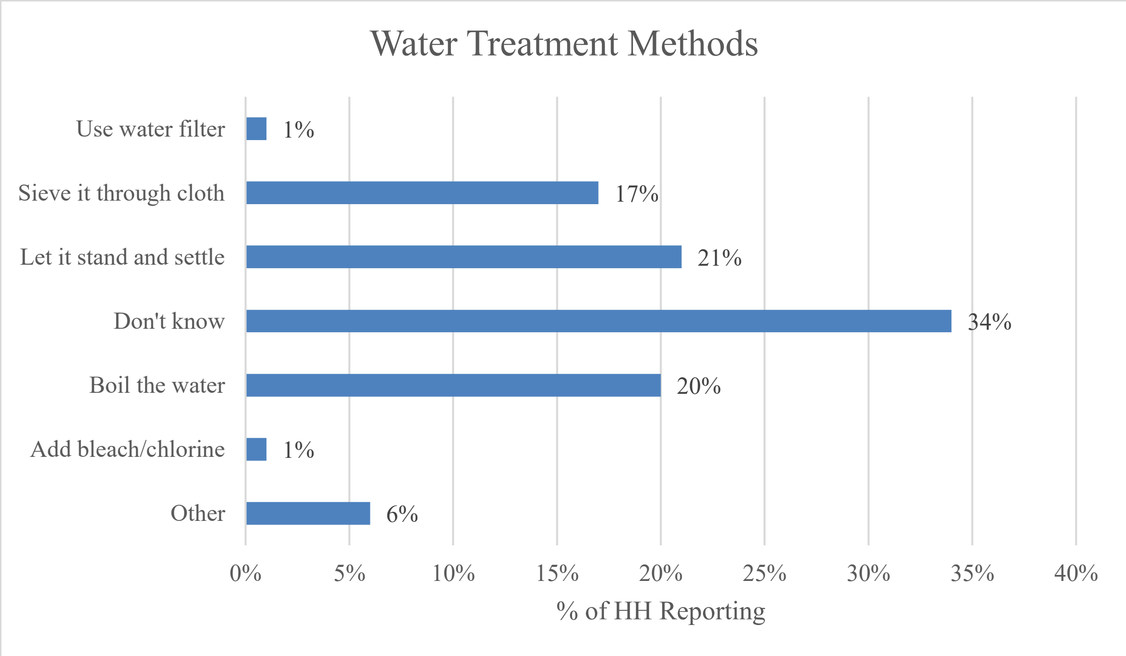


Figure 36: Water treatment methods in the Boji village.

In terms of water management and governance (see Figure 37), majority of the respondent's (99%) reported not to be aware of any existing Water Users Association bylaws. 96% reported to have no knowledge of any Annual General Meeting regarding the water group.

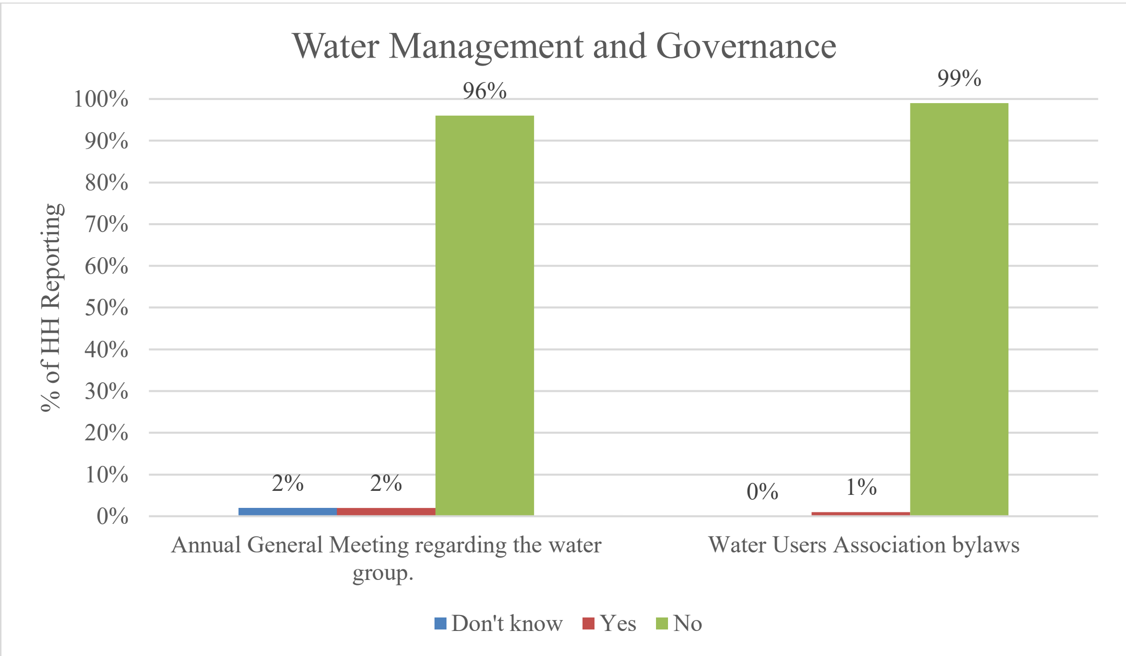


Figure 37: Water management and governance in the Boji village.

Respondents gave various recommendation on ways of improving their water supply (see Figure 38). Majority of the recommendation indicated the need for water kiosks and water by-laws at 22%, need for household connections at 19%, need for a change of the existing management committee at 15%, the need to separate human and livestock water at 14%, the need for solar water pumping and capacity building at 6% and 2% respectively.

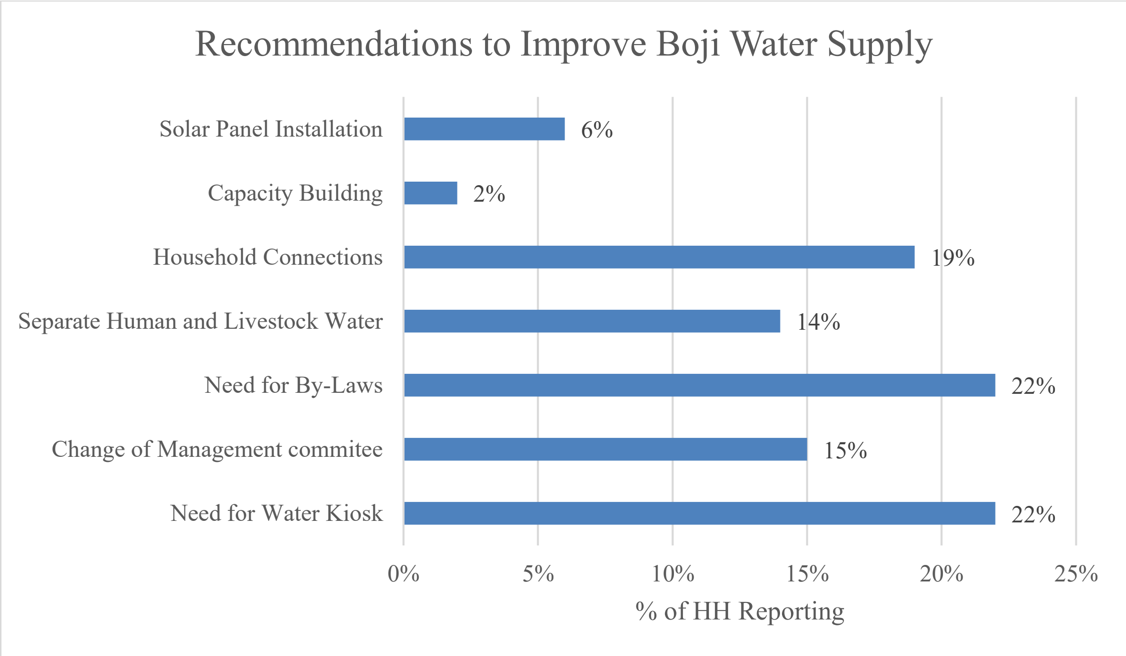


Figure 38: Recommendations to improve Boji water supply.

From results analysis obtained from KAP survey, it was possible to define key recommendations for the Boji village water supply system improvement. All following interventions planning was based on them. Key recommendations focused on the longer-term objective to be achieved through WASH programming interventions implemented by LVIA in the area. It was necessary to develop an intervention plan in collaboration with the county government and other partners to address the needs identified in the area, as summarized below.

- **Water Supply**:
  1. There was a need to establish the total yields of the various primary water sources in the village.
  2. There was a need to separate water for human and livestock use.

iii. There was a need to provide water access close to the households by use of water kiosks.

iv. There was a need to provide solar pumping systems to reduce operational costs.

- **Management and Governance**:
  i. There was a need to put in place proper water management structures for sustainability of the system.
  ii. There was a need for proper awareness creation to the community on the right to water.

3.2.3 Baseline Outcome Indicators

As seen in section 3.2.1, KAP survey aimed to define the baseline values for outcome indicators. These indicators allow you to monitor the project progress and to understand if objectives set are achieved when activities are completed. Furthermore, by defining the indicators and their values, it is possible to understand in advance what are the gaps in the water supply system and what is the degree of intervention that must be implemented. Following table lists the outcome indicators chosen for Boji project monitoring and respective baseline values obtained from survey previously discussed.

Table 4: Outcome indicators baseline values.

Indicator	Baseline
% of community using safe water sources	24%
Average distance covered to primary water source	0-1 km
Average time taken to primary water source	0-60 minutes
Average queuing time at primary water source	10-20 minutes
% water reliability	62%
Waiting time for livestock	>60 mins
# of water management committees	0

A final survey would allow to derive the values of the indicators at the end of the project and to compare them to the values at the beginning of the project to understand the degree of success and the possible reasons for failure.

3.3 Existing Water Supply System at Boji Village

During the period in which KAP survey was conducted, LVIA technicians also carried out a technical inspection to evaluate the existing water supply scheme and gather information on the village's water sources used.

The existing and still operational water sources in the village are *two boreholes* - **BH 1** and **BH 2** - and *two spring wells* close to each other. There is also a third borehole - BH3- close to BH2 but not in use for three years.

The coordinates (latitude, longitude and altitude) of the interest main points (waypoints) have been recorded through a Garmin GPS tracker, model eTrex 30.

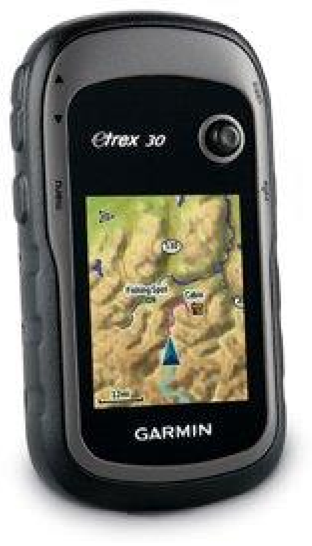


Figure 39: Garmin eTrex 30 GPS tracker.

source: garmin.com

These points, in addition to the water sources mentioned above, were also *two existing tanks*, *primary school*, *dispenser*, *mosque* and the points where the *existing above-ground pipeline* passed. The location of these waypoints has been integrated into Google Earth maps to draw a blueprint of existing status (Figure 40). An important thing to note is that the GPS tracker has a metric accuracy of at most 5 meters. However, the error margin could also be much wider, particularly with obstacles to the reception of the satellite signal. Given the survey purpose, it was not necessary to use higher precision instruments. The eTrex series can simultaneously detect both GPS and GLONASS satellites. GPS + GLONASS mode was activated and this allows shorter positioning time and greater waypoint accuracy.

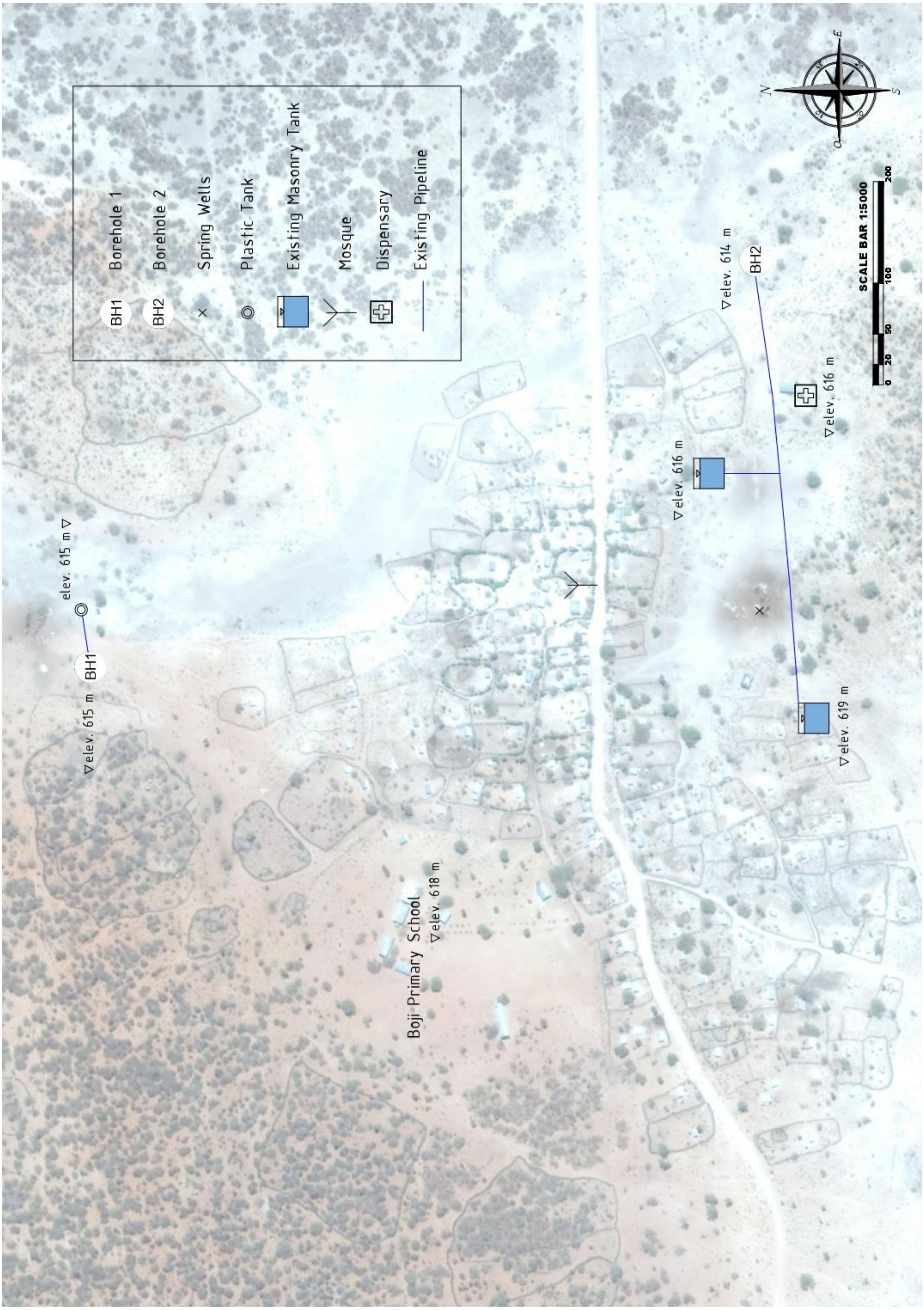


Figure 40: Existing Boji water supply system.

Pumping tests on existing water sources were conducted to determine their hydraulic characteristics. For detailed report see **Appendix B.** These pumping tests lasted 24 hours. During this period, discharge (m^3/h) and water level (m) were measured at different time intervals, which were gradually increased. Method of discharge measurement used stopwatch and 20 litres container to measure flow. The time to fill a 20 litres bucket was measured and flow rate was measured (= volume/time). Drawdown monitoring happened with the use of an electric dipper. After the end of the pumping, drawdown recovery phase was observed, during which the water level returned to the initial value (Water Rest Level - WRL).

3.3.1 Boji Boreholes

3.3.1.1 Boji Borehole 1

The borehole was installed with 4 m^3/h submersible pump. The drawdown pipes were 2” dia GI (Galvanize Iron) reduced to 1 ¼” at the outlet. Pump was driven by a generator 18.5 kVA and a stand-by one 15 kVA which was defective. Water was used for livestock watering only, pumped to a 5 m elevated 10 m^3 plastic tank. Safe yield[13] of the borehole was 18 m^3/h.

Figure 41: Existing BH 1 situation.

The following table summarizes the BH 1 pumping test.

[13] The safe yield of groundwater is the amount of water that can be withdrawn without producing an unwanted result (water resource depletion, uneconomical pumping, degradation in water quality, land subsidence).

Table 5: BH 1 pumping test.

Method of Discharge Measurement	Stopwatch and 20liter Container
Pump used	SP8A25
Water Rest Level (WRL)	26.3 m
Dynamic Level	26.55 m
Safe Yield	18 m^3/h.
Method of Monitoring Drawdown	Electric Dipper
Measured Depth of Source	56 m
Depth of Pump Intake	50 m
Size and Type of Drawdown Pipes	2” dia GI Pipes reduced at outlet to 1 ¼”
Pump Currently Operational	SP3A25 – 4 m^3/h
Current Motor size	1.5 kW

3.3.1.2 Boji Borehole 2

This borehole was drilled to replace the old one of 9 m next to it (BH 3). The existing pump was driven by solar pump 2.5 m^3/h. The existing solar panels were 6 with a wattage of 100 W per panel. There was no near storage tank and water was piped into two existing ground tanks, also used to water cattle (see Figure 40). Safe yield of the borehole was 12 m^3/h. The following table summarizes the BH 2 pumping test.

Table 6: BH 2 pumping test.

Method of Discharge Measurement	**Stopwatch and 20liter Container**
Pump used	SP3A-25
Water Rest Level (WRL)	23.60 m
Dynamic Level	24.88 m
Safe Yield	12 m^3/h.
Method of Monitoring Drawdown	Electric Dipper
Measured Depth of Source	46 m
Depth of Pump Intake	42 m
Size and Type of Drawdown Pipes	40 mm HDPE
Pump Currently Operational	SQ2-85 - 2.5 m^3/h
Current Motor size	SQ using DC

3.3.2 Boji Spring Wells

There were two spring wells close to each other. One spring well had only 0.5 m column of water and it was interconnected to another spring well at the base through a perforated GI pipe. There was a broken hand pump. The spring wells were open, and the community fetched water using a rope and an open bucket. They were also often used as a watering point for small livestock through a drinking trough that was filled with water from spring wells. This water point shared between humans and animals involved a risk of water contamination.

Figure 42: Boji springs well.

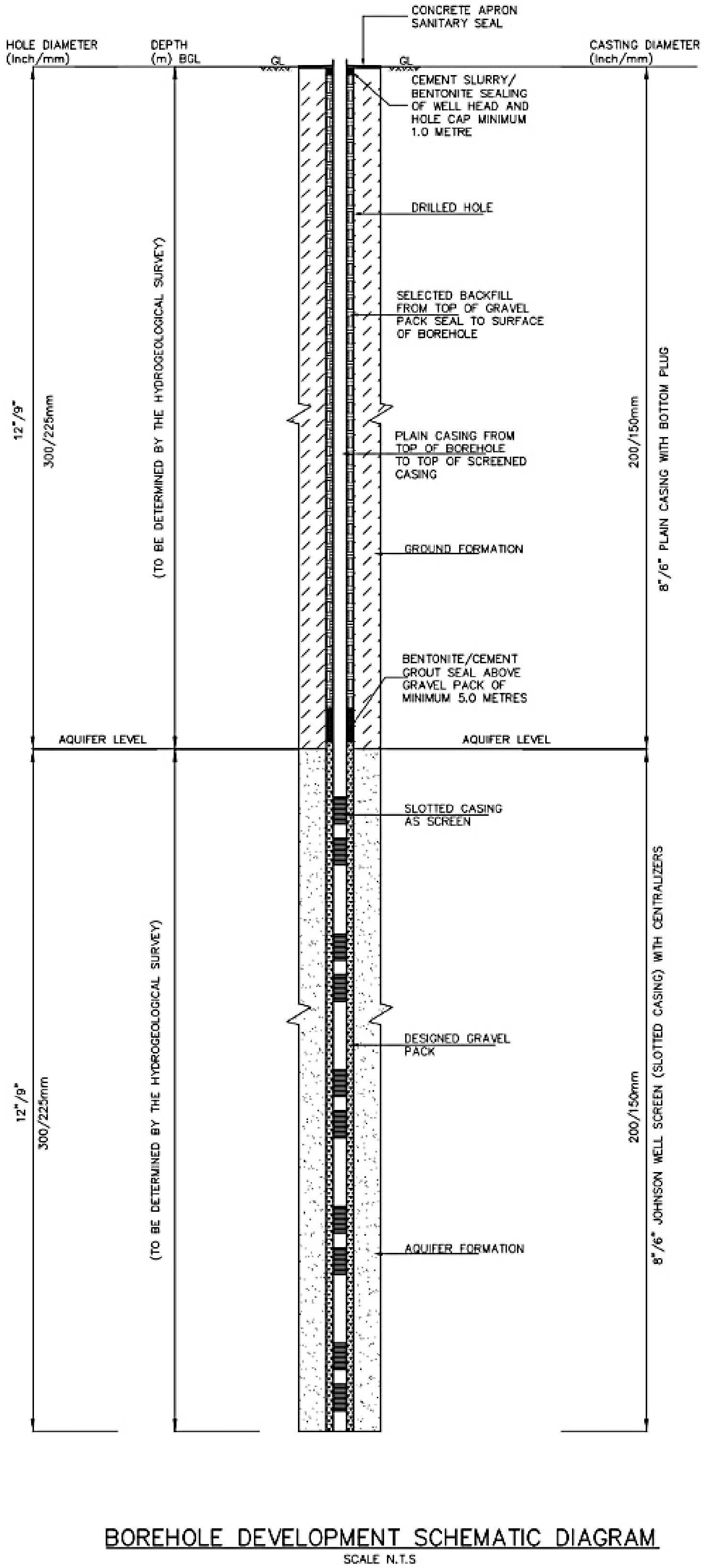


Figure 43: Borehole details #1.

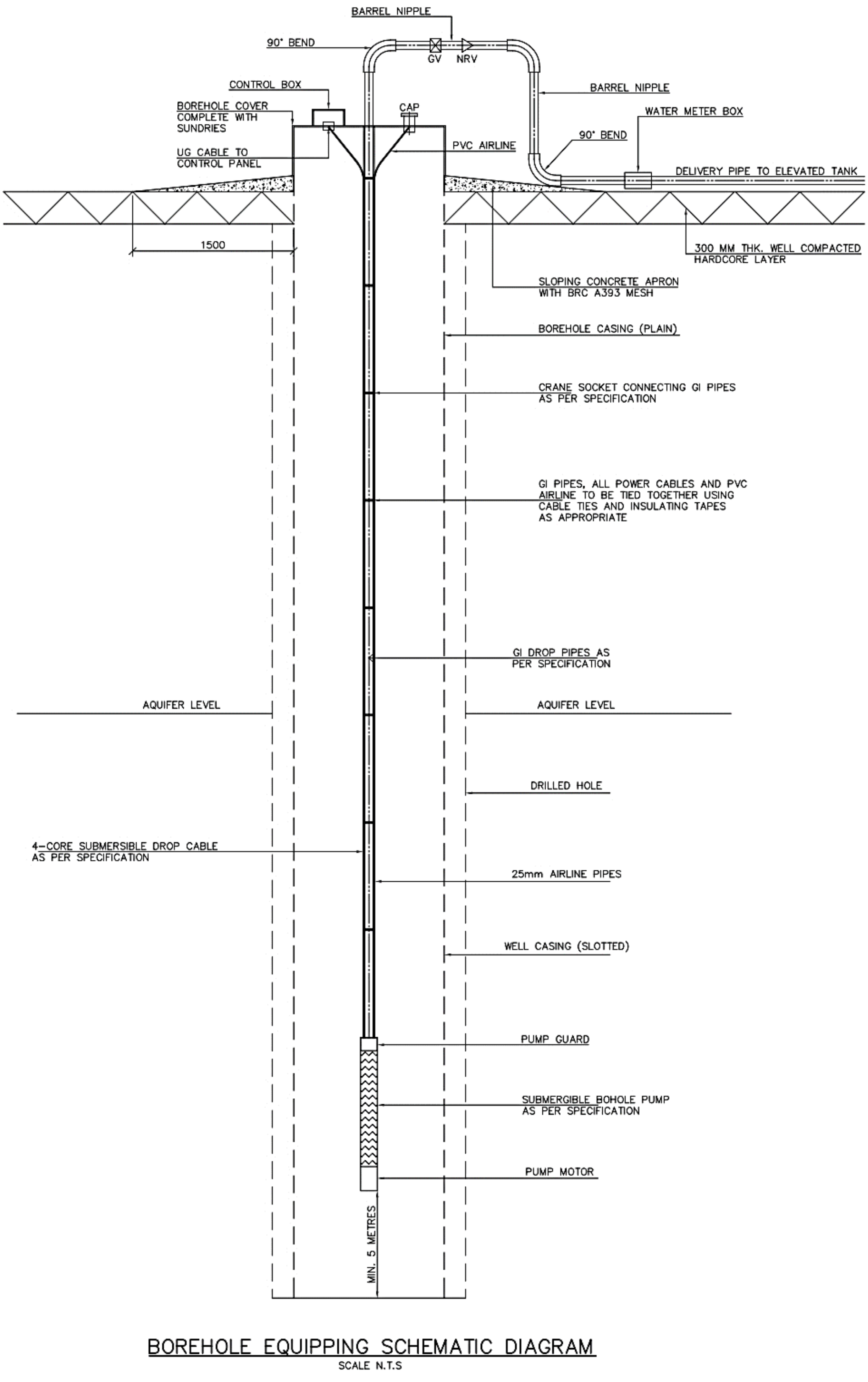


Figure 44: Borehole details #2.

source: LVIA

Chapter 4

Design of the New Boji Water Supply System

4.1 Planning the Intervention

With the information gathered and presented so far, it was possible to plan the interventions to improve the Boji village water supply system. Recalling the *key recommendations* defined in section 3.2.2, we now want to present the planned activities associating them with the issues they aimed to solve.

With the aim to improve water quality for human use, the main objective was to ensure that the population's water supply consisted of safe and reliable water sources, mainly from the two boreholes (BH 1 and BH 2). This implied the need to increase the yields of the two boreholes. As we have seen, a submersible pump was installed in the BH 1 which took 4 m^3/h of flow rate. From pumping tests, a safe yield of 18 m^3/h was recorded. It was therefore decided to increase the BH 1 flow rate to 13.5 m^3/h with the consequent installation of a new submergible pump that could guarantee that flow rate. Note that it was decided to take a flow rate lower than that which guaranteed the safe yield, to be on the safe side. Same reasoning was made for BH 2, for which it was chosen to increase the flow rate from 2.5 m^3/h to 7 m^3/h, against a safe yield of 12 m^3/h.

Another important issue to be resolved was to separate human water supply from livestock. This aimed to ensure adequate access to water for both humans and livestock and to avoid human use water points contamination. Previously, animals shared water from existing tanks and spring wells with humans. In addition, BH 1 was only used to water animals.

In this regard, water kiosks as water collection points for the community were necessary. It was chosen to build no.4 water kiosks located in different points of the village with the aim of providing access to water near households. It was decided to connect 2 water kiosks to BH 1 and 2 water kiosks to BH 2. This reduced the average distance traveled for collecting water and average queuing time at the water source. It should be pointed out that the position of these 4 water kiosks was decided in common agreement with the beneficiary community representatives. For instance, one of them was placed near a mosque, a community strategic point. In this sense, the beneficiary community involvement was also important in these decisions.

For livestock watering, it was chosen to build no.4 drinking troughs, two for cattle/camels and two for shoats[14] near BH 1. This guaranteed an exclusive water point for animals.

It was also of great importance to connect two strategic points of the village with the water sources: the primary school and the dispensary, previously not equipped with direct water. Primary school was supplied with water from BH 1, dispensary from BH 2.

All these water supplies involved the installation of new GI and UPVC[15] pipes and the possible reuse of existing ones after a condition exam.

Going into detail for boreholes, previously water was pumped from the BH1 with a submersible pump powered by a diesel generator. It was chosen to power the pumping with solar energy to reduce operating costs and ensure system sustainability. Once the pump type was chosen to guarantee the required flow rate, an adequate number of solar panels had to be installed to provide the power required for pumping. Furthermore, since the water solar pumping can only take place in the sunny hours, water storage was necessary. Therefore, it was thought to build an elevated tank to allow a water supply to the collection points by gravity. Unlike BH 1, there was already a solar pumping system for BH 2. The increased flow rate involved adding panels to existing ones to ensure the power required by the new pump. However, both systems were integrated with existing diesel generators to ensure pumping even when solar system does not generate enough power (on cloudy days) or does not work due to a fault.

As for the two spring wells, it was necessary to protect the well openings to avoid any contamination, particularly from surface water. Given the spring wells conditions, general wells cleaning was required by removing debris and sterilization. It was also necessary to sensitize population to prevalent use of water from boreholes and therefore to collect water from water kiosks, as it is safer.

Below there is a summary table of the proposed interventions associated with the results they aimed to address (Table 7). Figure 46 shows the new infrastructures plan.

[14] Sheep–goat hybrid.
[15] Unplasticized Polyvinyl Chloride. Compared to PVC, the UPVC is rigid.

Table 7: Activities summary and expected results.

		Expected results				
Activity		Safe water sources use	Distance and time reduction for water	Water reliability	Separate water for human and livestock use	System sustainability
Rehabilitation of BH1	High capacity water pump - from 4 m^3/h to 13.5 m^3/h	●		●		
	Solar pumping system with elevated tank			●		●
	No.2 water kiosks	●	●	●	●	●
	No.4 livestock troughs		●		●	
	Connection with primary school	●	●			
Rehabilitation of BH2	High capacity water pump - from 2.5 m^3/h to 7 m^3/h	●		●		
	No.2 water kiosks	●	●	●	●	●
	Connection with dispensary	●	●			
Rehabilitation of spring wells	Cleaning and protection	●			●	

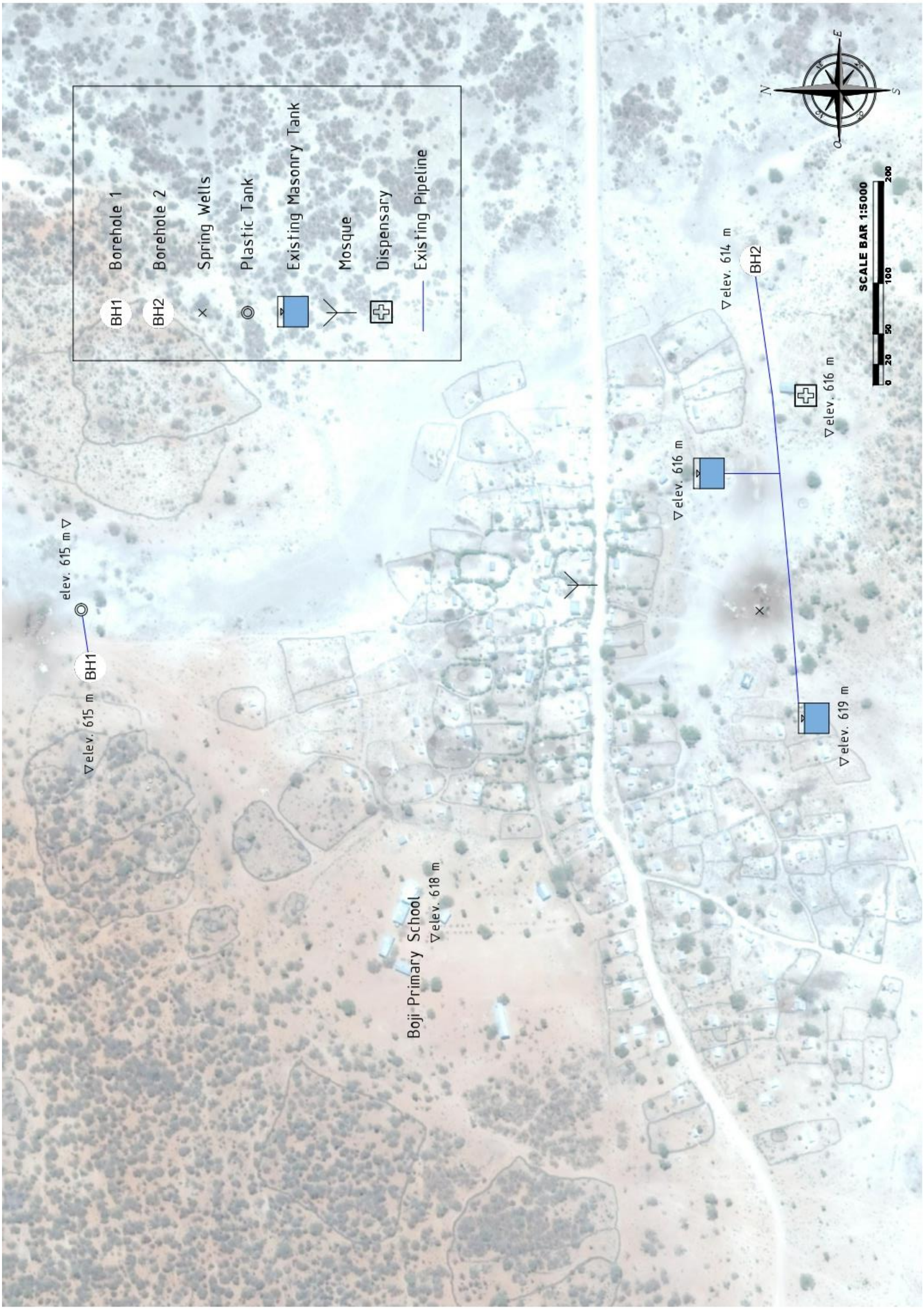


Figure 45: Existing Boji water supply system.

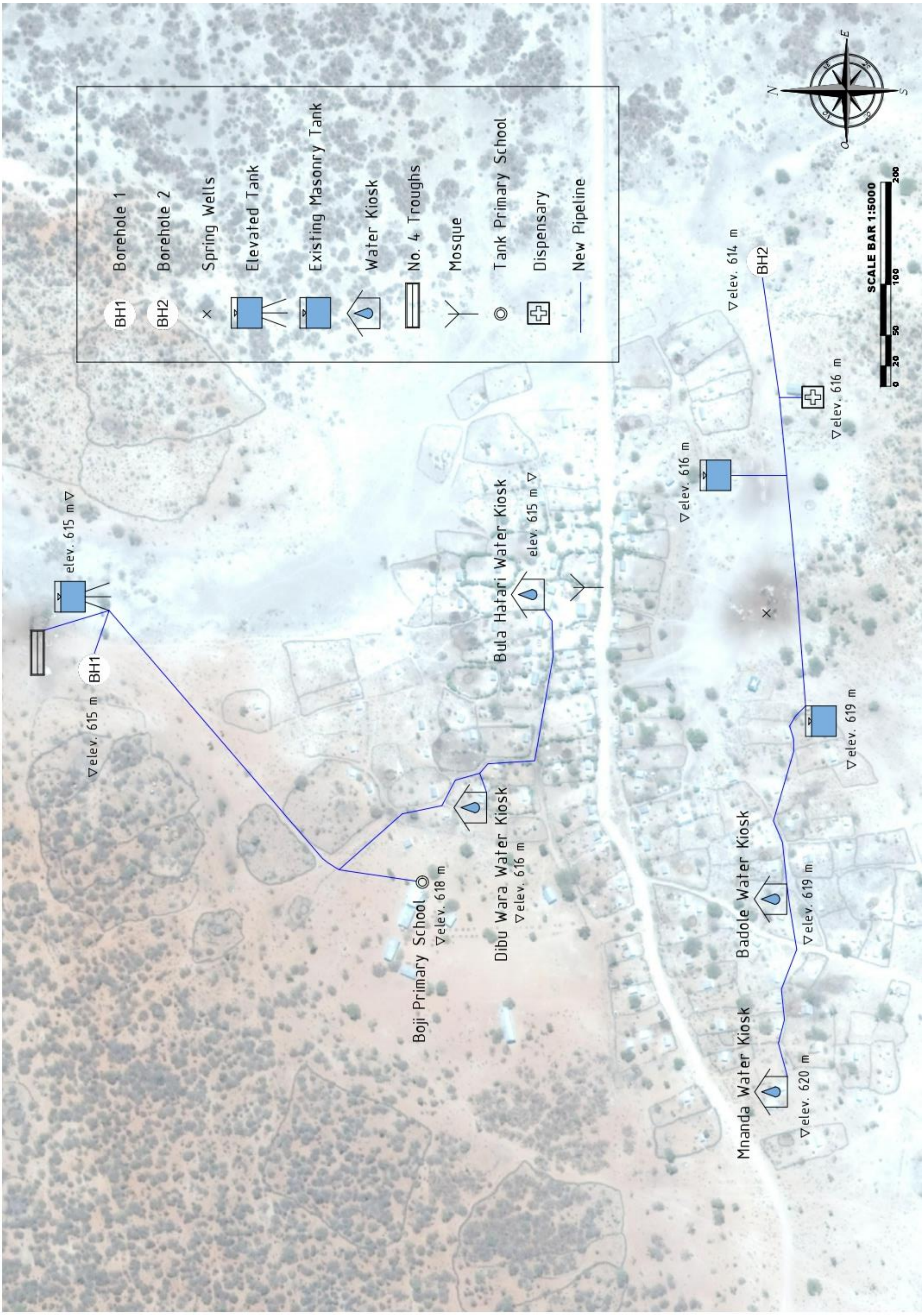


Figure 46: New Boji water supply system.

4.2 Boji Water Kiosk System

The construction of water kiosks in the Boji village was necessary to improve water supply system and access to safe water of the beneficiary community. It has been seen how water kiosks allow resolution of some important issues related to access to drinking water, which are common in almost all rural villages in the ASAL areas of Kenya.

First, they imply an exclusive community water point, separating human water supply from livestock water supply. This leads not only to improved access to water in terms of quantity but also in terms of quality.

In addition, the construction of water kiosks in the village allows a reduction of the average distance travelled for water collection. As it has been seen, their placement in the village should be chosen by common agreement with the community representatives.

It is also important to provide the village with an adequate water kiosks number to have an acceptable queuing time for the beneficiary. Generally, the number of inhabitants that a single water kiosk is able to supply during the day without excessive waiting time is 500. This is an estimate obtained from experience in other intervention projects. Therefore, being the Boji population of about 2,200 inhabitants, it was chosen to build **4 water kiosks**.

The names given to these 4 water kiosks are (see Figure 46):

- *Dibu Wara Water Kiosk,* receiving water from BH 1.
- *Bula Hatari Water Kiosk,* receiving water from BH 1.
- *Badole Water Kiosk,* receiving water from BH 2.
- *Mnanda Water Kiosk,* receiving water from BH 2.

Figure 47: Mnanda Water Kiosk.

4.2.1 Description

Boji water kiosks are made of reinforced concrete and masonry. They have a plan size of 2.6m x 2.6m and a height of about 2.8m from ground level. They are equipped with two external taps which are managed by a kiosk operator through two internal gate valves.

Boji network water supply is intermittent as it is powered by a solar pumping system that is only operational in sunny hours and days. For this reason, Boji water kiosks have a 5000 litres water storage tank. It is made of plastic and is placed on the roof of kiosk.

Dibu Wara Water Kiosk and *Bula Hatari Water Kiosk* receive water by gravity through a pipeline from an elevated tank filled by pumping the BH 1. *Badole Water Kiosk* and *Mnanda Water Kiosk* receive water through a pipeline directly from pumping the BH 2.

Inside the plastic tanks there is a float valve that stops water supply when the tank is full up to pre-set level and reopens the water flow when the level drops below a minimum (see Figure 48 and Figure 49). From the tanks comes a pipeline that brings water to the taps.

Inlet pipes and delivery pipes are in PPR[16]. Another material that can be used for these pipes is GI, although less resistant to corrosion.

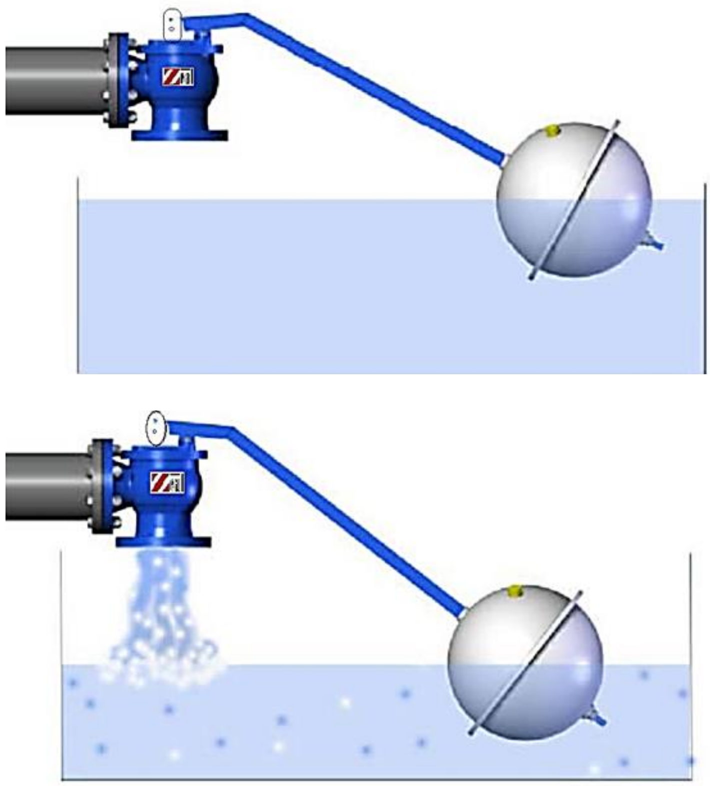


Figure 48: Float valve.

[16] PPR pipe is made of Polypropylene Random Copolymer. The PPR pipe is thicker than the PVC pipe. In addition, PPR pipe has a higher softening temperature than the PVC pipe and this is useful when the pipe is exposed to high temperatures, as in this case.

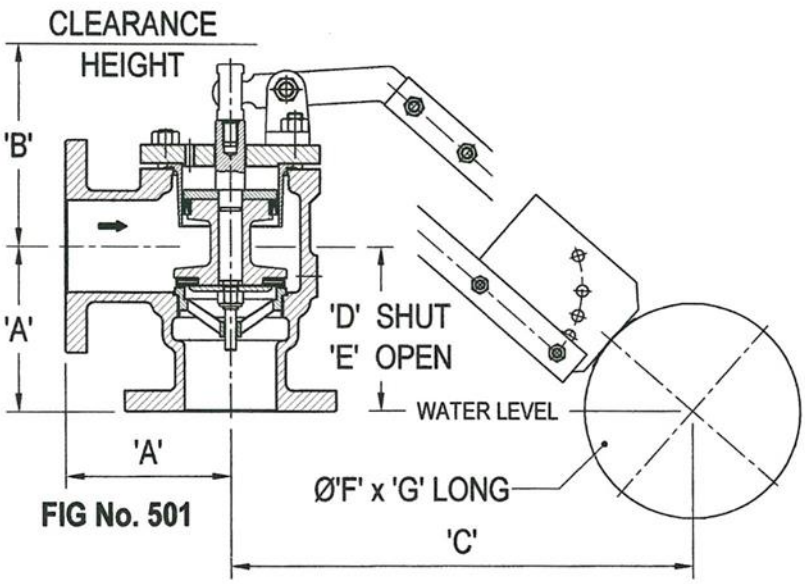


Figure 49: Float valve details.

source:Indiamart

Outside the water kiosk, at the delivery area, there is a sloping platform that conveys excess water to a catchpit where water is collected and then sent into a soakpit where it is disposed underground (Figure 50).

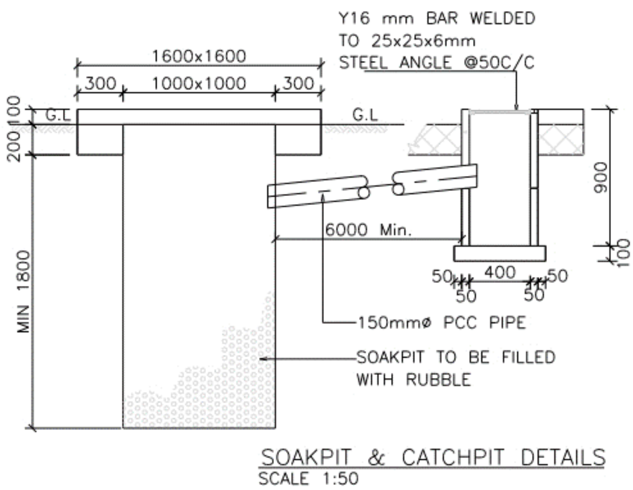
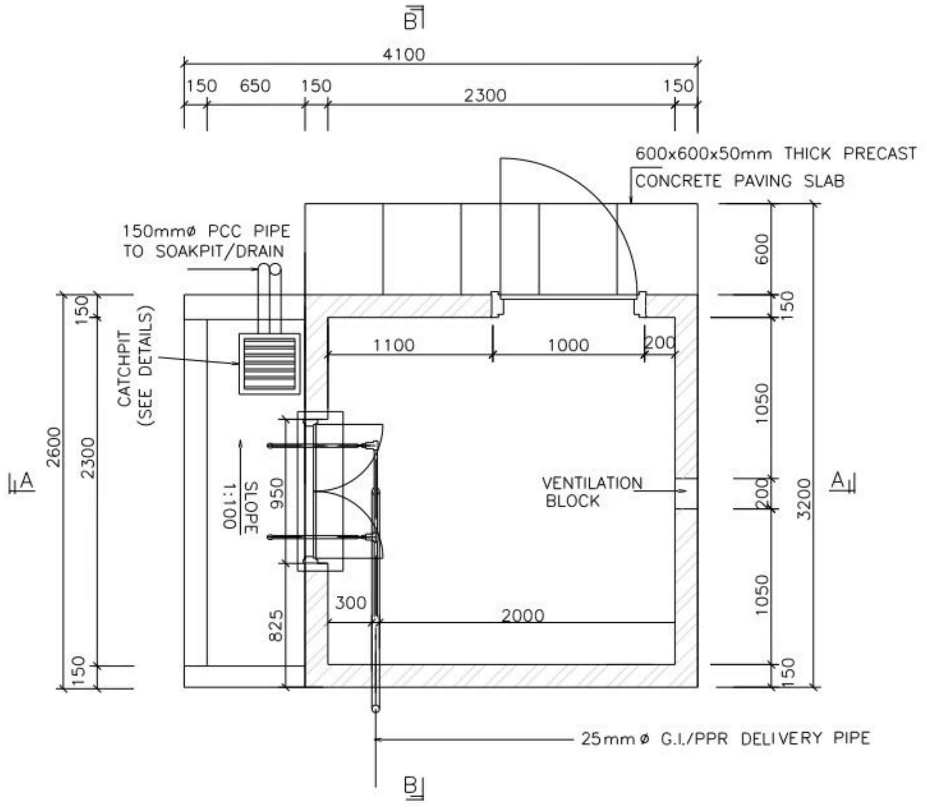


Figure 50: Soakpit and Catchpit details.

For more details see Figure 51 and the bill of quantities in **Appendix C**.



PLAN

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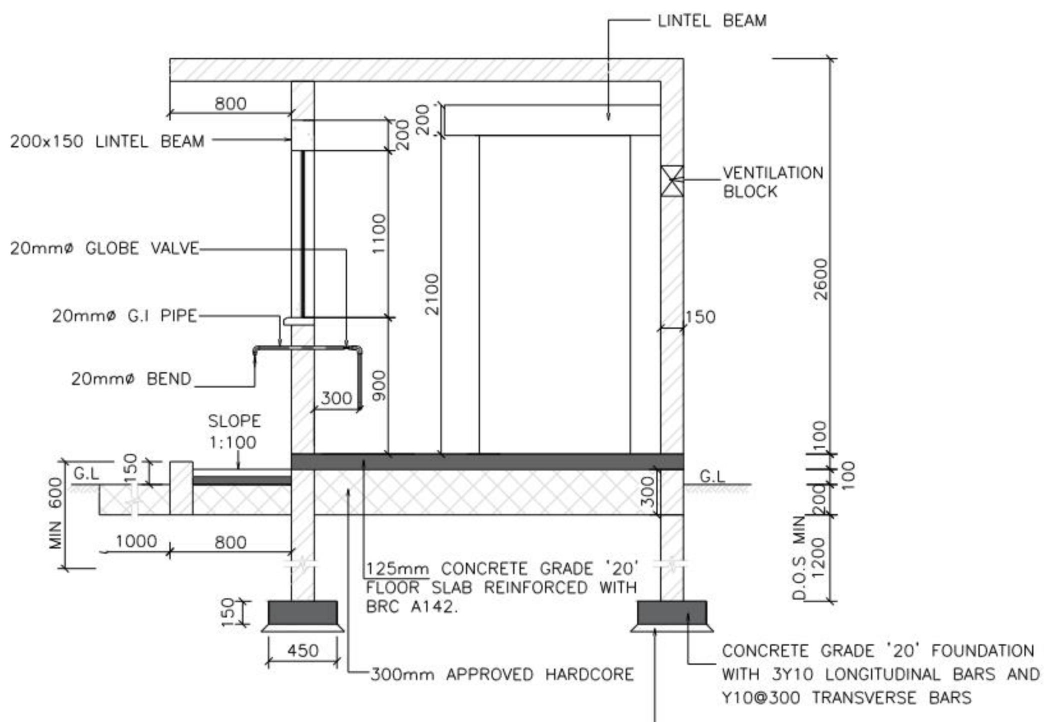

SECTION A–A

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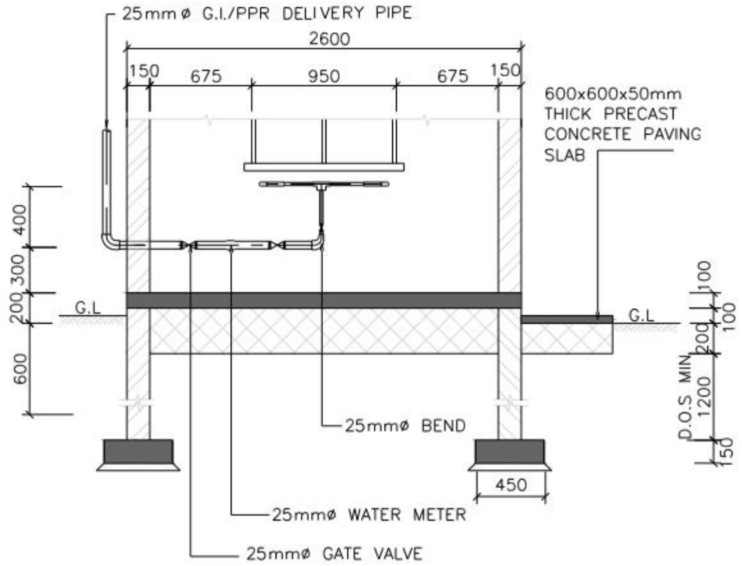

SECTION B–B

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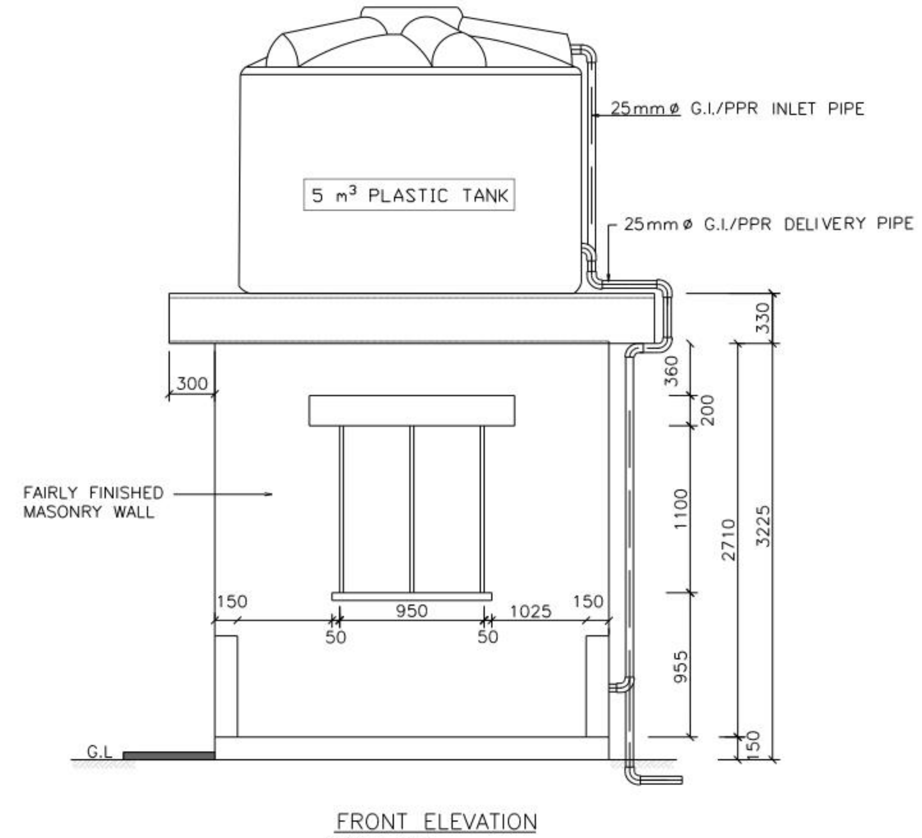

FRONT ELEVATION

SCALE 1:50

Figure 51: Boji water kiosk details.

4.2.2 Management

Boji Water Kiosks are managed by the Water Management Committee trained by LVIA. The operation of each water kiosks is guaranteed by an operator chosen from the community. Kiosk operators can also sell goods at the kiosk to increase their revenue. In other circumstances, kiosks may also be operated by utilities employees or by self-employed operators under contract with utilities.

Generally, beneficiaries collect water from the water kiosk with 20 litres Jerrican. In the case of Boji, a sale price of 2 KSh per Jerrican (about 2-euro cents) was established.

Sustainability of water kiosk systems recharged by boreholes is difficult to guarantee where free water sources such as shallow wells, ponds/pans, dams and rivers are also available. As widely discussed in the previous sections, these water sources have low water quality and may not be reliable sources all year round. It is important to create in the beneficiary an awareness of the importance of using clean water and paying for water service to keep the system active. This reduces the failure risk of water kiosk systems.

For the water kiosk system to be accepted by the beneficiary population, it is very important to involve them in the planning and management choices: the water kiosks location, opening hours and kiosk operators.

Water Management Committee tasks are also to supervise the cleaning of water kiosks, compliance with opening hours and prices applied.

4.2.3 Advantages

The choice to create a common water supply system such as the water kiosks for Boji is linked to the rural context.

As can be seen from Figure 46, the village of Boji is found along the Isiolo-Mandera Road. The houses are built around this road without following an orderly grid and areas with high density of houses alternate with areas with very distant houses. Water kiosks are located along the path of a single pipeline at a few convenient locations.

One of the alternatives to water kiosks could be private connection to a pipeline distribution system. However, this solution would imply an articulated piping network with consequent higher overall system cost. In addition, an articulated distribution network is more at risk of breakages and losses, resulting in greater commitment to maintenance which is difficult to ensure.

Another advantage is related to collection of water fee. As seen, water at Boji kiosks is provided upon payment. This allows a safe and simple collection of water fee much more difficult to do in the case of direct distribution to households. It is very important to ensure water fees collection as total revenues are necessary for each maintenance operation of the kiosks and the supply system in general. This approach is requisite for the system sustainability.

The discussions made for Boji can be made for almost all rural areas in Kenya.

4.3 Solar Pumping System of Boji

This section will deal with the study of a suitable system for the water supply of small communities which involves water pumping from boreholes with solar energy use. Based on the conditions in the area under review, this system is a viable alternative to other water supply means and, therefore, is increasingly used in projects that provide continuous and sustainable access to clean water for rural communities in Kenya.

The source from which water is extracted through such solar energy systems is *borehole*. As discussed in Chapter 2, particularly in section 2.3.1.2, boreholes are the most used water source in the Isiolo County. Unlike other water sources, boreholes guarantee water support over the year, even during dry seasons when other sources are not reliable. In addition, boreholes water is generally less contaminated. According to its hydrogeological features, Isiolo County is rich in boreholes.

There will be a focus on the engineering and hydraulic aspects of the pumping scheme, on the design methods of the various system components, as well as on the right maintenance and technological safeguard procedures. A further aim of the chapter will also be to retrace the management aspects that allow continuity in the use of solar pumping technology, with the main purpose of ensuring sustainability.

All the information necessary to write this discussion is the result not only of careful bibliographical research but also of field visits and discussions with stakeholders, as well as of the experience handed down to me by technicians during the internship at NGO L.V.I.A. in Kenya, which has been working for years on these systems in Isiolo County.

4.3.1 Solar-Powered Groundwater Pumping Systems in Kenya

During the past few years in Kenya, Solar Photovoltaic (PV) Pumping has experienced an accelerated technological development concurrently with cost reduction which led to advanced, robust, affordable, climate-smart, versatile and low-maintenance equipment systems [39]. In addition, governments and donors' policies in favour of solar pumping have allowed its use in many water supplies projects, particularly in rural areas.

It is precisely in these remote areas that solar-powered groundwater pumping systems are beginning to be the main technological systems for supplying water to populations, livestock and crops. Such systems in these areas are the most recommended and preferred choice because they are durable and have great long-term economic advantages compared to other technologies still in use [40].

Moreover, Kenya has abundant solar energy with peak insolation from about 5 to 7 hours per day due to its position around the equator [39]. In most areas where humanitarian organizations carry out their relief and development work, solar radiation is high enough to consider using solar PV pumping solutions, especially in the area between 40 degrees North and South, called Solar Belt [39]. Kenya falls in this area, extending over one of the sunniest globe areas due to its position around the equator.

The country can exploit this resource as a cheaper alternative to diesel or electricity for groundwater extraction in more remote areas. If a long-term cost assessment is carried out, photovoltaic solar pumping would prove now cheaper than diesel systems. In addition, the solar panels cost has fallen by 80% in the last 10 years and is 1% of what it was in the early 80's [39].

However, humanitarian organizations are still suffering from the lack of technical competence and awareness among beneficiaries and this slows down the use of this solution. Solar pumping systems record a great deal of consensus among the host communities, but aspects related to ownership, operation, maintenance, collection and management of water fees generate great complexity. A social approach that involves users is therefore important and should come before the technological choices. In this sense, establishing strong social cohesion in the community and coordinating approaches with government water offices should be a prerequisite.

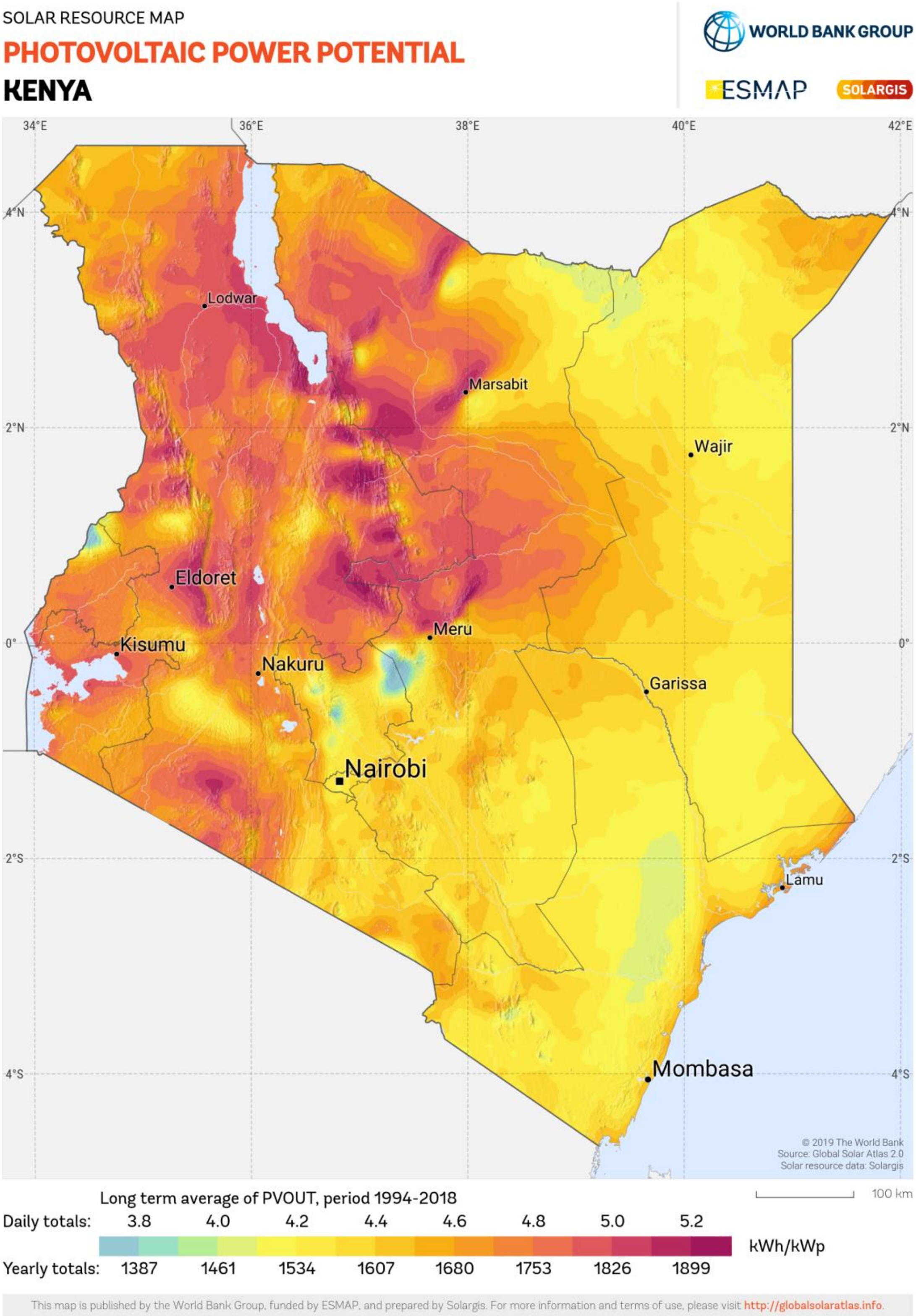

Figure 52: Photovoltaic Power Potential in Kenya.

source: Solargis

4.3.2 Advantages and Disadvantages

The choice of the solar pumping use should be made after a careful evaluation of the aspects that could lead to an inadequate performance, rather than a failure. It is important to understand what the negative aspects could be. All these analyses should also be compared with other existing pumping technologies to understand if the use of solar energy implies real advantages in the specific intervention context. In rural areas of Kenya, as previously mentioned, solar water pumping technology is used as a replacement or as an alternative to pumping with diesel generator. It should be noted that in such remote contexts, it is unlikely that villages are powered by electricity and where it is present is very unreliable.

Listed below are the main advantages and disadvantages of the use of solar water pumping technology for rural communities, also analysing the aspects that differentiate it from the use of a diesel genset.

- *Advantages of solar energy for water pumping*
  - The operation of the solar pumping system does not require any operating cost unlike diesel generator which has high fuel and maintenance costs.
  - It does not produce pollutants for the environment, unlike the diesel engine exhaust fumes.
  - Reliable energy availability even for remote places. A diesel generator in remote areas may not guarantee this.
  - In warm regions, solar systems are not adversely affected by heat unlike diesel engines during operation.
  - Easily installed in remote areas with prefabricated solar structure or on-site welded structures. Diesel generator are quite heavy to transport, and it is a delicate operation considering the bad roads that connect villages in rural areas.
  - Overhauling the diesel motor is more difficult and requires skill and equipment unlike replacing a broken/defective solar panel.
  - Solar systems are becoming cheaper and more convenient every year. Diesel gensets and fuel become more expensive every year.
  - The solar generator system has a longer lifespan of approximately 25-30 years unlike the diesel generator whose average lifespan is less than 10 years due to the delicate maintenance required.

- *Disadvantages of solar energy for water pumping*
  - The solar pumping system has high investment costs compared to diesel generators.
  - Unlike diesel generators, a large area open to the sky is required for solar generators (although this is not a big problem for most remote rural areas).
  - Unlike diesel generators, there is no solar energy at night. This could be remedied with the use of storage batteries, which, however, involve higher costs and additional maintenance. In addition, the operation is strongly influenced by solar radiation that varies from morning to evening with the maximum at noon.
  - On cloudy and rainy days there is little or no pumped water. Therefore, large water storage is required, unlike diesel generators where water can be pumped on demand.
  - The solar panel can be easily vandalized as fragile and the whole system can be subject to theft.

Comparing the advantages and disadvantages, it can again be concluded that the use of a solar pumping system is certainly preferable to the diesel generator use for rural areas water supply, especially in Kenya.

Despite the high initial investment cost, the reduced life cost of the solar system compared to the high life cost of the diesel generator means that solar water pumping technology is much more sustainable in low-income rural areas such as Isiolo County.

The possible intermittent operation linked to unfavourable weather conditions can be solved with a water storage system.

However, it is important to consider that where a diesel generator is already present (as in the case of Boji village), it is possible to integrate it into the pumping system. This allows to make the supply system more reliable as it is possible to ensure the pump operation even when weather conditions or faults would not allow it. In this regard, a diesel-solar *hybrid system* can be considered the best solution for remote rural areas both from an operational and economic point of view.

4.4 Description of the Water Supply System

Solar water pumping system is like other pumping systems but the electricity that allows the pump operation is generated by photovoltaic panels through solar energy.

This system is an alternative to using electricity or diesel generators to power the water pumps. Solar powered pumps are useful where grid electricity is not available, alternative sources (wind) do not provide enough energy or these or other technologies use is complex, very expensive or unsustainable. In addition, solar energy pumps operation is generally cheaper mainly due to lower operating and maintenance costs and has a lower environmental impact than pumping systems powered by an internal combustion engine (ICE), which also have a lower reliability.

A solar energy PV pumping system has the following basic components: *photovoltaic (PV) array*, a *pump*, a *controller*, and a *water storage tank*.

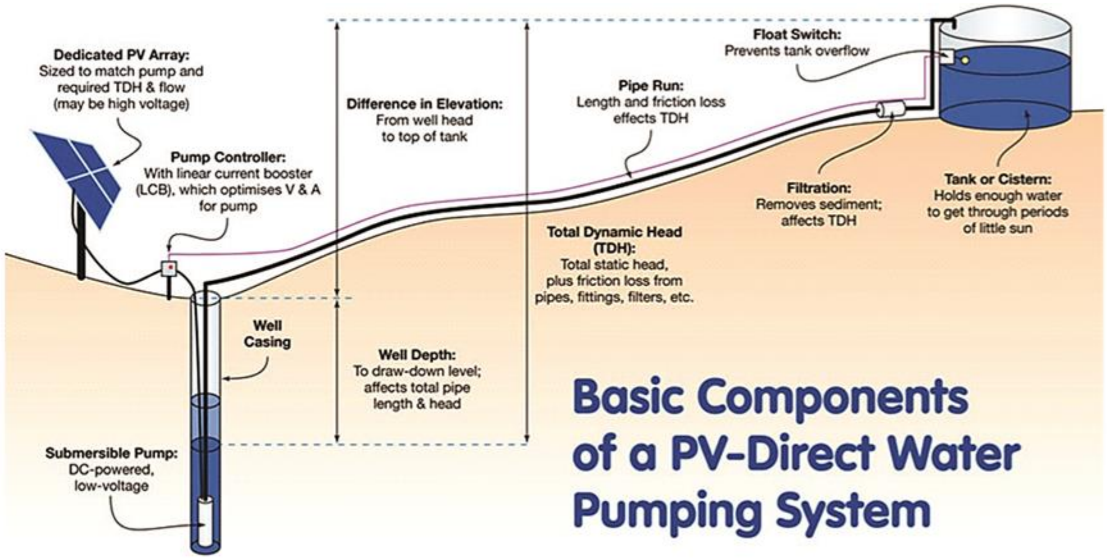

Figure 53: Component of Solar Water Pumping System

source: Home Power Magazine

4.4.1 PV Array

PV array is a PV modules system in which modules are connected to each other and function as a single electricity-producing unit. The PV array basic unit is the single panel. Solar panels make up most of the system costs, up to 80% [41]. The photovoltaic system size depends directly on the pump size, the water required amount and the solar radiation available.

PV panel is made up of solar cells, which are the elementary component of the PV system. Solar cells are a thin sheet of semiconductor material, almost always silicon, with a thickness of about 0.3 mm. Figure 54 shows PV cell, Panel (or Module) and Array.

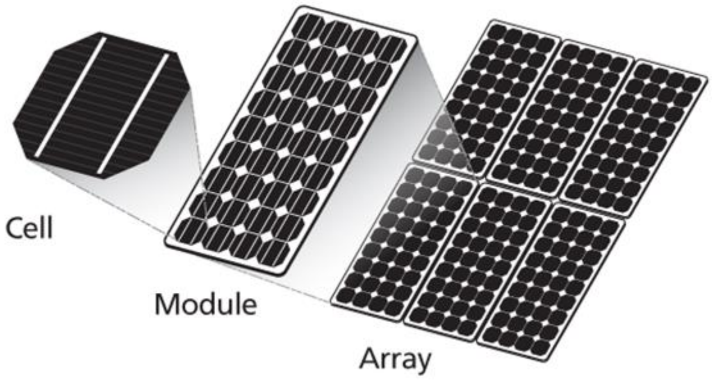

Figure 54: Cell, module, array

source: Samlexsolar

Mono and polycrystalline crystalline silicon cells represent about 90% of the PV market; the rest is divided between thin film cells or destined to special technologies [42]. Of the two types, polycrystalline silicon is the least expensive and has slightly lower yields. To reduce the cost of the cell, new technologies using amorphous silicon or other polycrystalline materials are under study [43].

Photovoltaic (PV) solar panels convert sunlight directly into DC electricity (Direct Current) through the *photoelectric effect* (Figure 55). The silicon that constitutes the cell is "doped" by inserting boron atoms on one face (*P-positive doping*) and phosphorus atoms on the other side (*N-negative doping*). In region N there is an excess of negative charges, in region P there are shortcomings of negative charges, called holes. In the contact area between the two layers with different doping, called P-N junction, an electric field is determined. When the cell is exposed to light, electric charges are generated by the photoelectric effect and, if the two faces of the cell are connected to a user (load), there will be a flow of electrons in the form of direct electric current.

PV panels are classified according to their power, which is based on an incoming solar irradiation of 1 kW/m^2 at a certain cell temperature (generally 25 °C). The panel's output data includes rated power (Watt [W]), voltage (Volt [V]) and current (Amp [A]). The common sizes of panels are 150 W, 195/200 W, 265/270 W, 315/320/330 W.

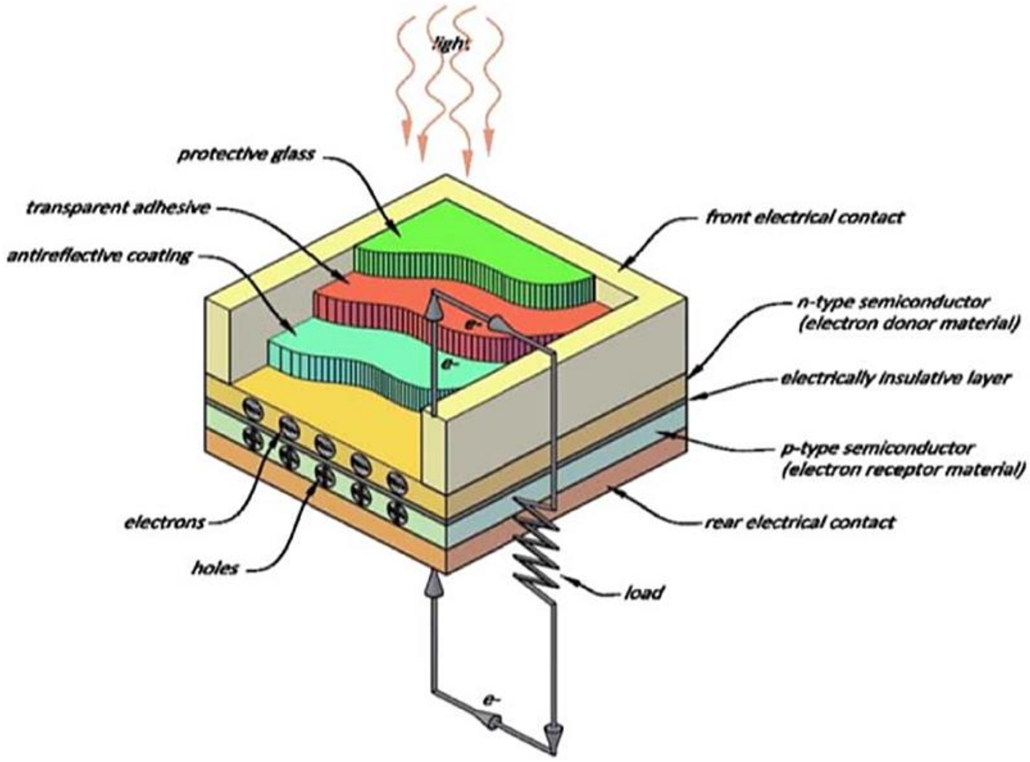

Figure 55: Photoelectric effect.

source: [44]

The panels can be connected in series or in parallel to obtain voltage and current compatible with the requirements of controller and pump motor. When the panels are connected in series, the total output voltage is the sum of the panels individual voltages while the current is the same. Conversely, when the panels are connected in parallel, the voltage is the same while the total current is the sum of the current of the individual panels. The total power output [W] from PV array is obtained by multiplying the total voltage [V] and the total current [A]:

$$PV\ Array\ Total\ Power = Total\ Voltage \cdot \ Total\ Current$$

4.4.1.1 Available Solar Energy

To design a solar pumping system, it is necessary to know the amount of solar energy available in the specific area of intervention. For this purpose, the following concepts are introduced: *solar radiation*, *solar irradiance* and *solar insolation*.

- **Solar radiation** is the energy emitted by the Sun. Travel through space until it reaches Earth. The average annual solar radiation that reaches the outer layers of the atmosphere is about 1361 W/m^2 but the mitigating effect of the atmosphere reduces this value to about 1000 W/m^2 on the Earth's surface [45]. However, the precise value measured through the instruments varies according to location, weather conditions, solar activity and time (during the day and throughout the year).

- **Solar irradiance** is the amount of solar energy that affects one square meter of a specific surface (e.g. solar panel). It is also measured in W/m^2 and its value can consider direct and/or diffuse radiation.
- **Solar insolation** is the amount of solar irradiance that the surface receives in a given time period. The average daily solar insolation in units of kWh/m^2 per day is typically referred to as "*peak sun hours*". This term refers to the insolation that a surface would receive in a day if the Sun shone at its maximum for a certain number of hours. Being the solar radiation of about 1,000 W/m^2, the average daily insolation is equal to the number of peak hours of the Sun (for example, one can say that a place receiving 6kWh/m^2 per day received 6 hours of Sun per day at 1 kW/m^2). It is important to specify that even if Sun is above the horizon for 12 hours on a given day, it could generate energy equivalent to only 6 peak sun hours.

  From Figure 56 the concept can be better observed. The blue curve represents the solar irradiance variation during the day. The area under the blue curve represents the daily total solar isolation. Dividing the latter by 1,000 W/m^2 gives peak sun hours. Note that area under blue curve and area in the white rectangle are the same, according to the previous concepts.

It should be noted that in the technical literature there is much confusion about the use of these terms. Here, we have chosen to refer to the definitions described above.

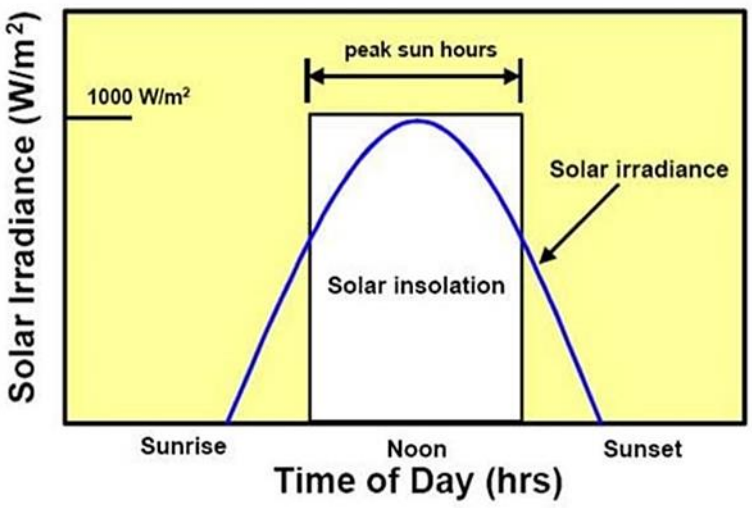

Figure 56: Peak sun hours.

source: [44]

In addition to the variation in the sunlight intensity during the day, it is also necessary to consider the variations that occur in the seasons and in different latitudes. However, Kenya's geographical location implies a not great variation in the intensity of the Sun during the seasons. In fact, the Sun in Kenya is always very high on the horizon and its elevation varies slightly throughout the year, as for all locations with latitudes close to the equator. The situation is different further north or south from the equator (see Figure 57).

Seasonal variation and latitude are important for the choice of panel *orientation* and *tilt angle*[17]. The combination of tilt and orientation determines the module exposure. The search for the best exposure, to maximize the solar energy received by the modules, is among the first concerns of the PV system designer. The most efficient choice is to use a tracking system that follows the Sun movement. In general, and also for the case of Boji, due to the complexity of tracking mechanisms, solar panel installations for water pumping are stationary. Therefore, panels are oriented south in the northern hemisphere and north in the southern hemisphere, considering the Sun direction. However, optimal tilt angle is usually related to latitude and aims to ensure that panel receives the solar radiation as perpendicular as possible.

As it will be seen in the design process, PV array was oriented south for Boji as the village is still slightly north of the equator. According to studies, optimal tilt angle for Kenya for fixed array is about 4° but a slightly greater inclination has been used to allow panels cleaning.

[17] Inclination means the angle that the module forms with the horizontal. Horizontal modules have zero inclination, vertically arranged modules have 90° inclination.

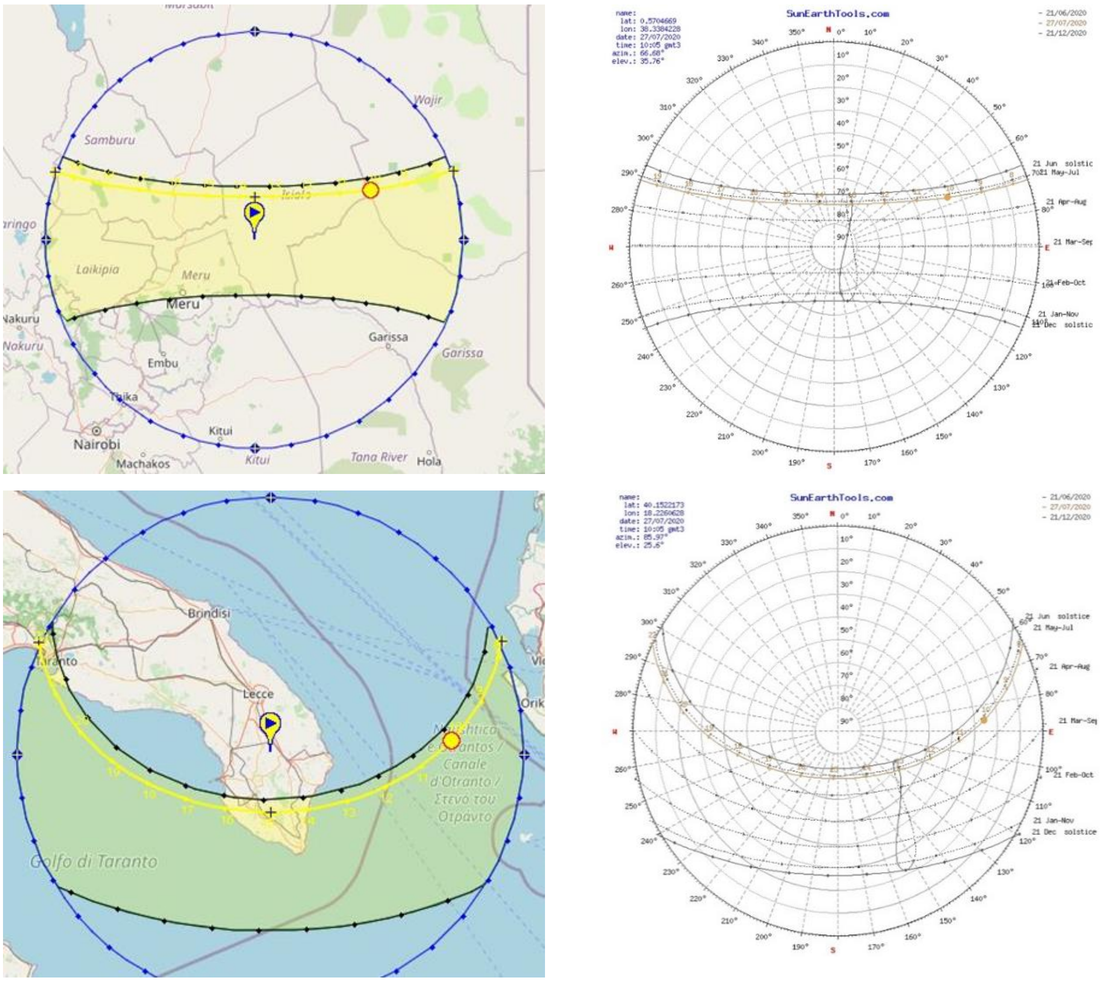

Figure 57: Sun path during the day for different periods of the year; above Boji village, Kenya, under Lecce, Italy.

source: Sun Earth Tool

4.4.2 Pump

Pumping system design is based on the calculation of Total Dynamic Head (TDH) and design flow rate (Q) to be taken from borehole. By matching these system parameters to the manufacturer's pump performance curve, it is possible to determine the suitable pump type. Once the pump that meets hydraulic requirements has been defined, it will be possible to size solar panel system starting from the power required by the pump motor. Other factors that are considered and whose importance is assessed in relation to the case in question are the water demand, the borehole conditions, the water scheme type, and pump electrical parameters.

4.4.2.1 Pump Type

First of all, the pumps can be submerged in the pumped fluid or external to the pumped fluid. The two main types of hydraulic pumps are:

- *Positive-displacement pumps* is a pump type that takes advantage of the change in volume in a chamber to cause suction or thrust on a fluid. The flow rate is independent of the head and is directly proportional to the speed of fluid movement. This pump type is already present in nature, in the heart of humans and animals. Positive-displacement pumps are divided into two types, reciprocating and rotary.

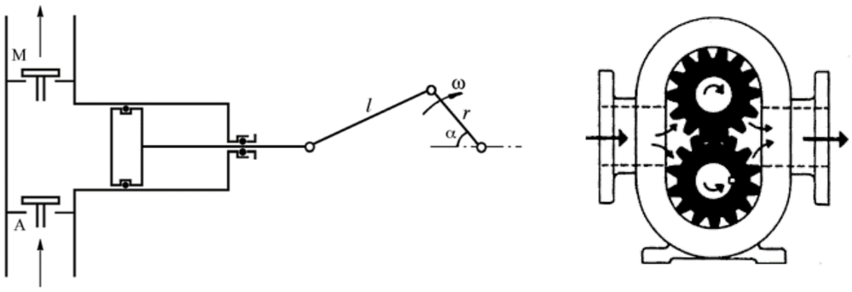

Figure 58: Type of reciprocating pump (left) and rotary pump (right).

- *Rotodynamic pumps* is a pump type in which energy is continuously imparted to the pumped fluid through a rotation of the impeller, propeller or rotor. The flow rate depends on the head at the same rotation speed. They can be classified according to the flow in axial, radial or mixed.

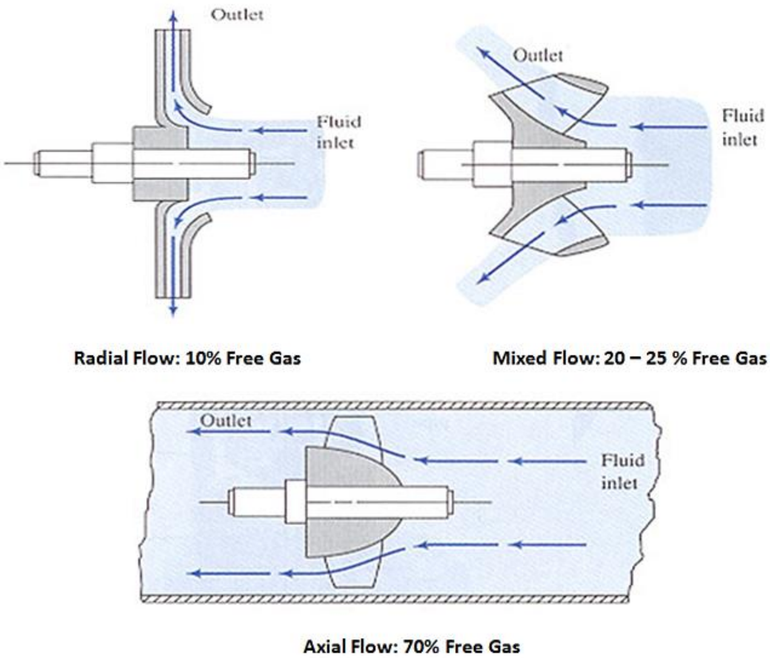

Figure 59: Radial, mixed and axial pump flow.

The most common type of rotodynamic pump is *centrifugal pump*. The main feature of the centrifugal pump is to convert the energy of a movement source (motor) first into speed (or kinetic energy) and then into pressure energy. These pumps use the centrifugal effect to move the liquid and increase its pressure. A bladed wheel (impeller) connected to the motor turns inside a sealed chamber equipped with inlet and outlet. The impeller is the pump element that converts motor energy into kinetic energy. The pump body involves the conversion of kinetic energy into pressure energy and the fluid is channelled into the delivery pipe. The centrifugal movement simultaneously causes a depression capable of constantly sucking up the fluid to be pumped.

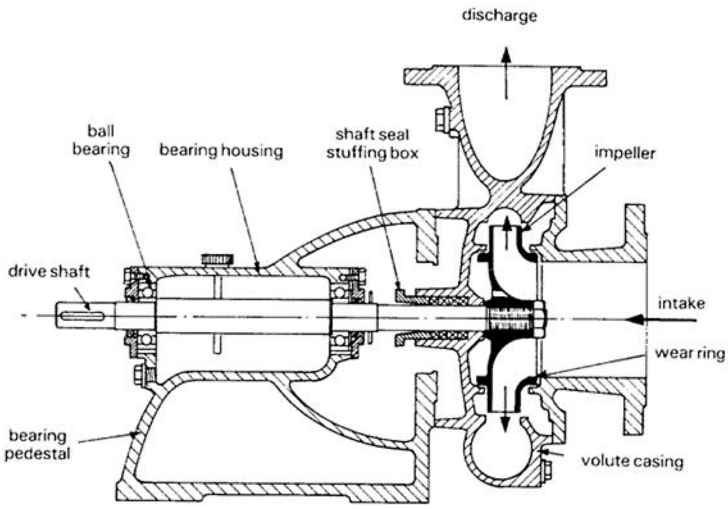

Figure 60:Type of centrifugal pump.

source: FAO

The centrifugal pump impeller can be made according to many construction variants: closed impeller, open impeller, vortex impeller, single and double channel impeller, cutter and grinder impellers, etc. It is important to select the impeller type and materials according to the pumped liquid. Generally, if the water is clean and without suspended solids, a closer impeller is used.

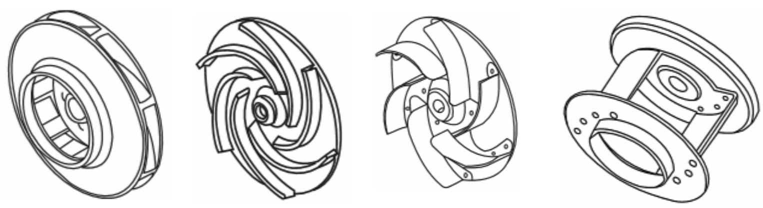

Figure 61: From left to right, closer, open, vortex, channel impeller.

source: Davis and Shirtliff

One can have single-stage centrifugal pumps, equipped with only one impeller. With more impellers (the first impeller discharges the liquid on the second and so on), multistage centrifugal pumps will be obtained, characterized by the sum of the pressures delivered by each impeller.

For the water supply from boreholes, a typology of centrifugal pumps called *submersible pumps* is used. For their correct operation they must always be totally immersed in the pumped fluid. The operating principle is the same as that described for general centrifugal pumps. They are powered by a submerged electric motor. The motor can be powered by Direct Current (DC) or Alternating Current (AC). For solar pumping systems, when motors powered by AC, there is an inverter that transforms the DC generated by photovoltaic panels into AC.

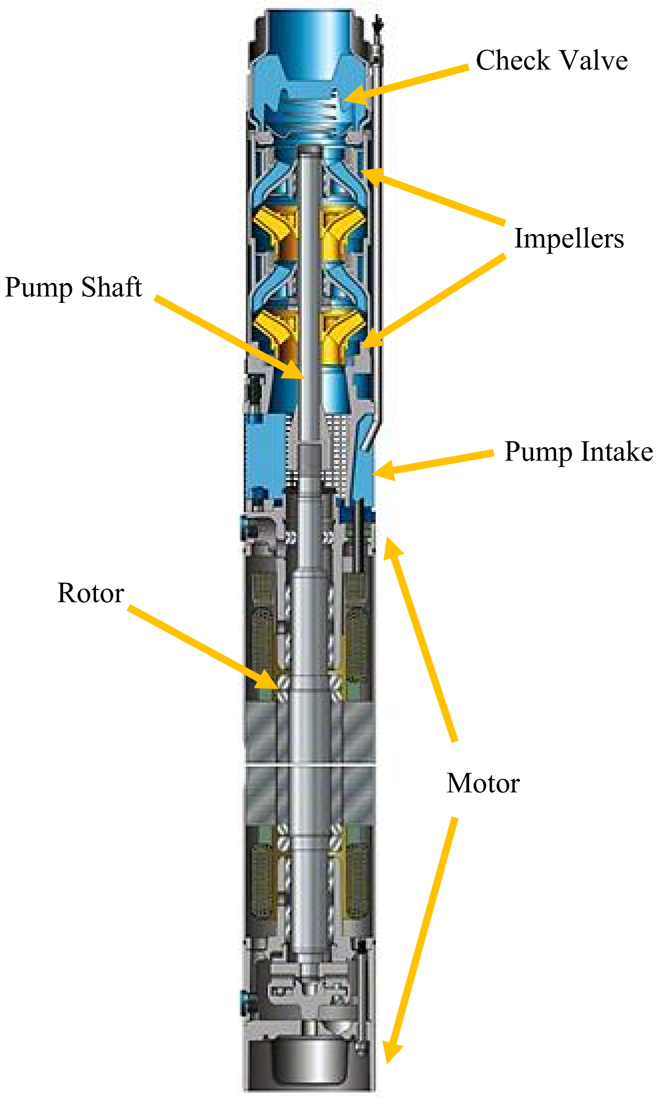

Figure 62: Submersible pumps.

source: KSB

4.4.2.2 Centrifugal Pump Performance

The bond between flow rate Q and the total head H, at constant rpm, is typical of each pump and is represented by a curve in the Cartesian plane $Q - H$ which is called *characteristic pump curve*. It is plotted experimentally. Observing the curve trend, the head decreases with increasing flow rates and vice versa.

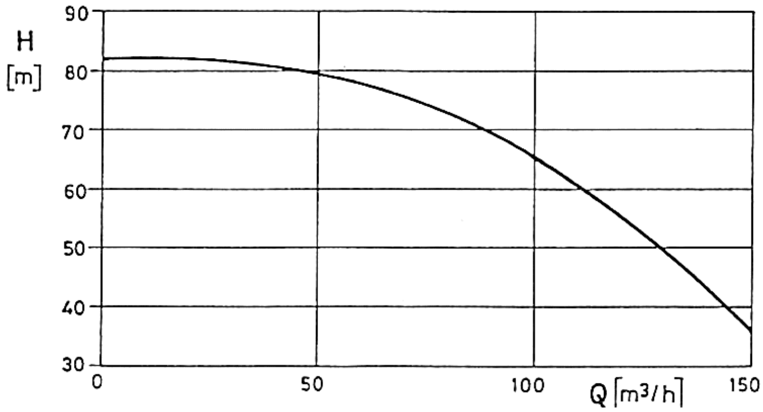

Figure 63: Characteristic pump curve.

Associated with the characteristic curve, two complementary curves are generally reported in the manuals: the *yield curve* and the *power curve*.

The pump yield η is the ratio between available power W_u and absorbed power W:

$$\eta = W_u / W$$

The yield curve has an ascending and then descending trend. At the point of maximum yield (or around it) the pump is operating optimally.

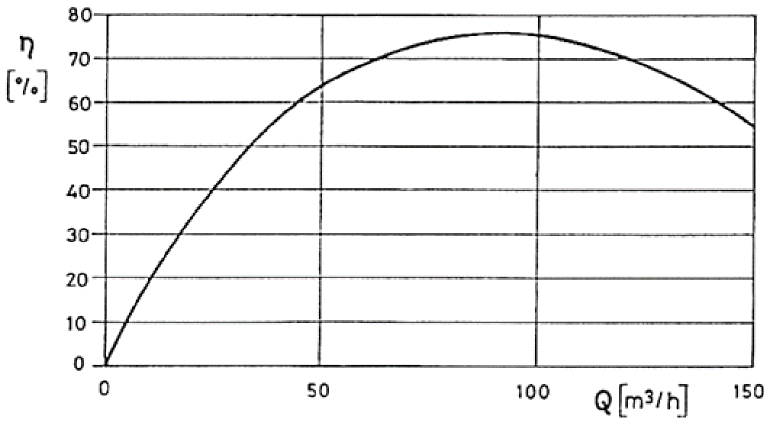

Figure 64: Pump yield curve.

The power W is calculated from the product of the flow rate Q for the head H and for the density ρ of the fluid:

$$W = Q \cdot H \cdot \rho$$

If the flow rate Q on the abscissa axis and the absorbed power W on the ordinate axis are plotted, the flow-power curve is obtained. This curve generally has an upward trend: it rises as the flow rate increases.

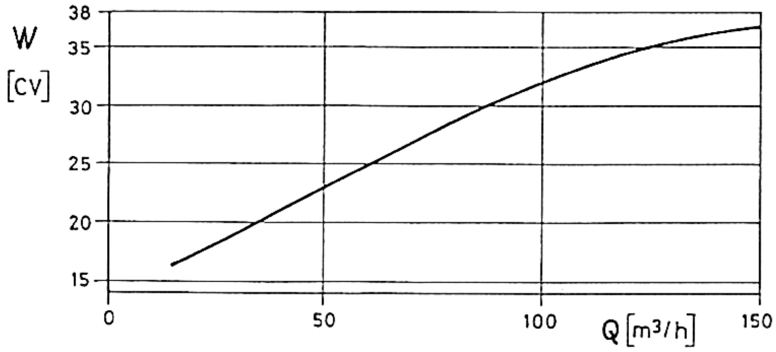

Figure 65: Pump power curve.

Although a pump can operate in different conditions, there is a point on the curve on which (or around which) it would be appropriate to operate it. This point corresponds to the maximum efficiency value of the pump.

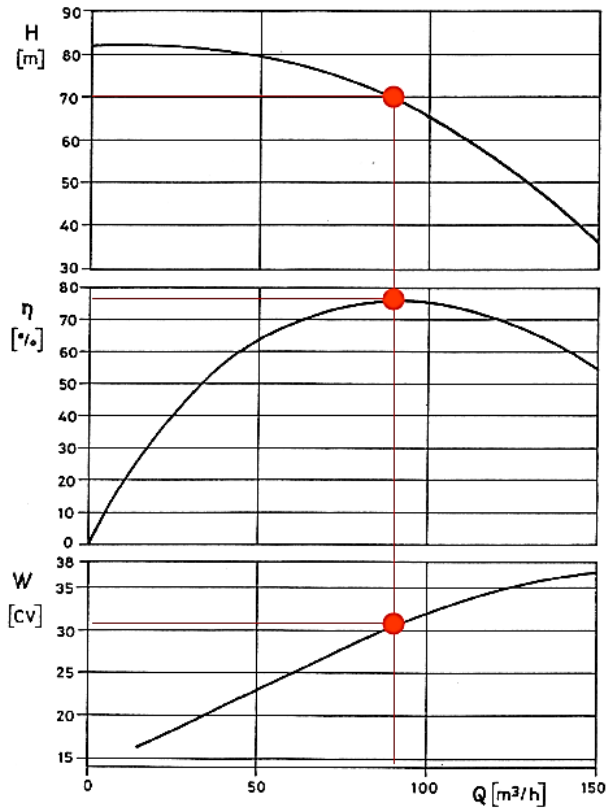

Figure 66: Optimal operating point.

As it will be discussed in more details in the section dedicated to the system design, the system total head is given by the sum of the geodetic head H_g and the friction head $Y(Q)$ in the delivery pipe (and eventually in the suction pipe). Unlike the static head H_g, the term $Y(Q)$ depends on the flow rate and the properties of the liquid and is generally proportional to the square of the flow rate. The TDH equation is therefore the following:

$$TDH = H_g + Y(Q) = H_g + kQ^2$$

This equation in the $Q - H$ plane is represented by a parabola and is called *characteristic system curve*.

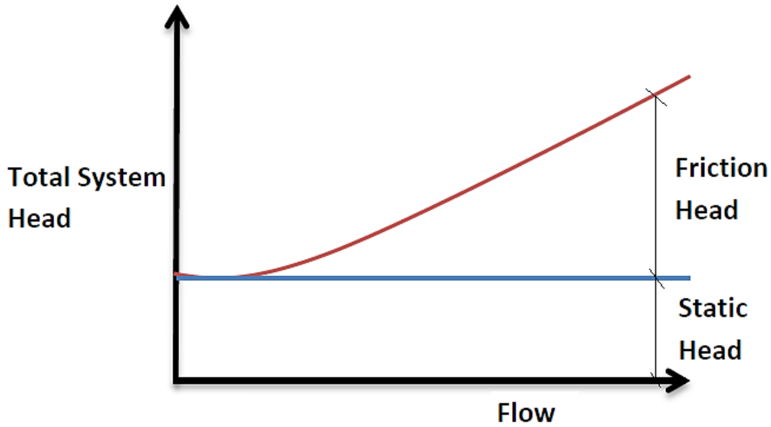

Figure 67: Characteristic system curve

The intersection in the $Q - H$ plane between the characteristic curve of the pump and that of the system is called *characteristic operating point*. If characteristic system curve changes position, for instance due to change in resistance due to the valve opening degree or to an increase in the pipe roughness, then the operating point changes.

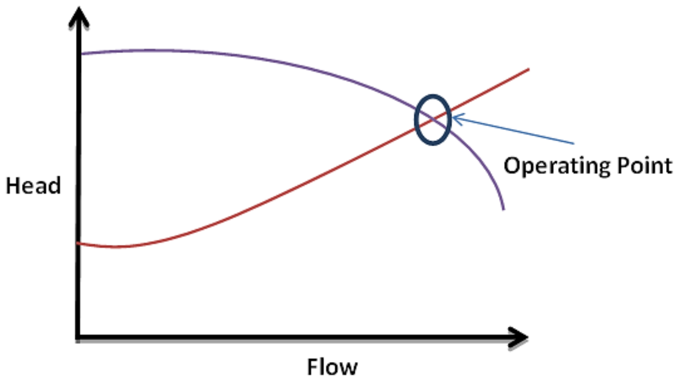

Figure 68: Characteristic operating point

4.4.3 Water Storage Tank

Solar pumping system allows to collect water from boreholes or other water source and to distribute it directly to user or store it in elevated water tank. The latter is the most common option.

The solar panels use may involve the use of batteries that allow to store the energy produced and to use it when the panel does not receive enough solar radiation (for example on cloudy day). The use of batteries, however, is not recommended. Batteries are expensive and may need high maintenance, working temperature problems and operating problems related to an incorrect discharge process and for this reason they are often avoided in humanitarian and rural uses.

It is preferred to install a tank that stores water for days when solar radiation is low. Pumping water to elevated water tanks is a way to store energy that is preferable to using batteries. Solar energy is transformed into potential energy through accumulation in elevated tanks, which guarantee the continuous presence of water even without the use of the solar pump. However, in these cases it is necessary to oversize the tanks to ensure that water is available even if there is a lack of solar energy for several days.

Tank is elevated and the water distribution system works by gravity.

The systems hybridization (solar + diesel generators) is an additional solution typically used when solar energy cannot meet the minimum water requirements in continuity. With this solution, tank can be sized for a smaller volume.

4.4.4 Controller

The main controller functions are two. First, to start the system when the power available from the PV array is equal to the power needed to start the pump. Secondly, controller also provides a system protection: if there are no voltage and current operating conditions suitable for pump operation, it turns off the system. This increases pump life thus reducing the need for maintenance.

If the electric pump has a motor that requires alternating current (AC) power, an *inverter* must be present in the controller. The inverter converts the direct current (DC) produced by the solar panels into alternating current (AC) needed to power the pump.

When a hybrid system (solar + diesel generator/electricity grid) is provided, the controller must allow the pump to be powered even when the solar panels do not generate enough energy.

In addition, the controller turns pump operation on or off in relation to the water level in the tank and borehole (remember that submerged pumps must always operate below the water level in the borehole, preventing dry running).

The newer models of controllers also allow additional functions such as remote control and data collection.

The controller is chosen according to the electrical characteristics of the pump motor and the PV array.

Further details on the controller used in the Boji system will be discussed below.

4.5 System Design

The purpose of this section is to retrace the design steps of Boji's solar pumping system. This allows an indirect verification of the system with particular attention to the hydraulic aspects.

As seen previously, Boji's water supply system consists of two distribution lines. Each gets water from two existing boreholes, BH 1 and BH 2. For completeness *it was chosen to treat only the case of BH 1*, previously not equipped with solar pumping system. This allows to describe a new system design. In fact, the BH 2 was already equipped with a solar pumping system for which it was necessary an upgrade in order to increase the flow rate taken. However, it should be added that the following design considerations related to the BH 1 distribution system may similarly be replicated in a possible BH 2 rehabilitation study.

Sizing of pumping system, elevated tank and PV array will be discussed.

4.5.1 Daily Water Requirement

The design first step is to determine the daily water amount to be supplied to the system to meet the users water demands. This is in order to select a suitable pump. Please note that BH 1 supplies water for four animal drinkers located nearby, primary school and two water kiosks. Water is fed into the distribution system by gravity thanks to the presence of an elevated tank.

As seen in section 3.2.2, preliminary survey showed that the average daily water collection was 120 litres per day per household. Households of Boji village have an average of 5 people. Therefore, daily water amount for drinking, hygiene and domestic use for each inhabitant was estimated at around 24 litres. This daily water amount per person adequately respects the international minimums and considering the rural context it is possible to choose a water supply in line with the previous one. Of course, water supply will now only come from safe water sources. Therefore, design water demand of **25 litres per day per person** was chosen.

To define the daily water requirement (DWR) for humans it was necessary to know the number of users that would be supplied by the BH1 distribution system. About 2,200 inhabitants live in the village of Boji. Estimating that each distribution system would provide water for half the population, the users number to be considered for BH 1 was **1,100 inhabitants**.

From following equation, it is possible to calculate the total water amount that must be fed into the system for human use daily:

$$DWR\ for\ Humans = \#Users\ \cdot Water\ Demad = 1{,}100\ inhab\ \cdot 25\ \frac{l/d}{inhab}$$
$$= 27{,}500\ \frac{litres}{day}$$

The BH1 also feeds 4 drinking troughs for animals. Therefore, livestock contribution must also be included in the total water demand. However, this calculation cannot be done precisely. In section 3.2 a livestock population of around 23,100 animals (shoats, cattle, camels, donkeys) has been indicated. This number was obtained from the average animal possession values per household provided by Isiolo County. However, it is not possible to define precisely the actual number of animals that drink from the troughs every day. In addition, it is not possible to define precisely the livestock water needs in the Boji area. It varies greatly according to the seasons. In the wet season, animals have very little need for water as it is integrated directly with feeding in the grazing area. Conversely, during the dry season they have a greater need for water due to a lack of liquid feeding. In addition, livestock amount in the Boji area and its water demand vary as a result of seasonal migrations. All these factors imply great complexity in defining the Boji daily water requirement for livestock. Therefore, a realistic estimate was chosen considering that from county data it appears that about 2/3 of the total water demand in the Isiolo County concerns to livestock. Then a livestock daily water requirement is considered as follows:

$$DWR\ for\ Livestock = 2\ \cdot\ DWR\ for\ Humans = 55{,}000\ \frac{litres}{day}$$

Adding the contributions just obtained, the total daily water requirement for the Boji water supply system related to BH 1 is calculated:

$$DWR_{BH1} =\ DWR\ for\ Humans +\ DWR\ for\ Livestock = 82{,}500\ \frac{litres}{day} = 82.5\ \frac{m^3}{day}$$

This will be used for sizing the elevated tank and for selecting the pump.

4.5.2 Peak Sun Hours and PV Panels Optimal Tilt Angle

To calculate the pump design flow rate, the average daily solar insolation (kWh/m^2/day) for the Boji village is evaluated. As seen in section 4.4.1.1, this value corresponds to the "peak sun hours" and allows to understand how many hours per day a surface of 1 m^2 receives an average solar energy of 1 kW. The photovoltaic solar modules used are classified for an irradiation of 1 kW/m^2; this data allows to know how many hours per day the panels maintain certain performance and provide energy needed for pumping.

This data for a given location can be easily extracted from numerous databases available online. One of the most popular is the NASA database, available at this link:

https://power.larc.nasa.gov/

By accessing the Data Access Viewer and selecting Boji village, the value of the Insolation on Horizontal Surface was obtained (Figure 69).

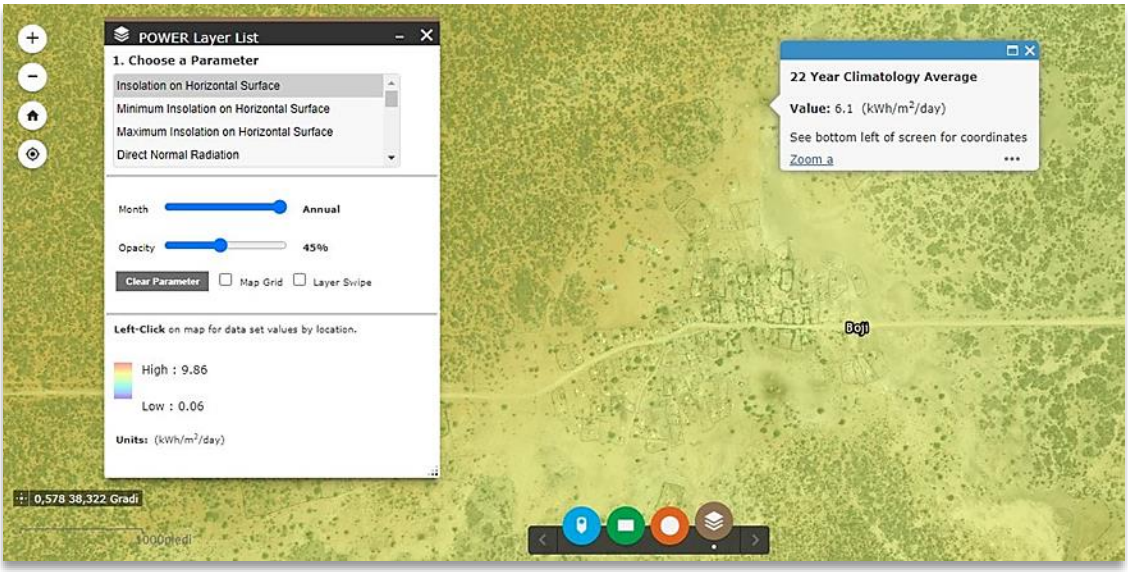

Figure 69: Insolation on Horizontal Surface for Boji.

source: NASA POWER

In addition, Global Horizontal Irradiation map in Kenya was also consulted (see Figure 70) available on the Solargis website (https://solargis.com/).

From the data consulted, it is possible to define the project value of peak sun hours:

$$Average\ Daily\ Solar\ Insolation = 6.1\ kWh/m^2/day\ \rightarrow$$

$$\rightarrow Peak\ Sun\ Hours = 6.1\ hours/day$$

In order to maximize the solar powered system's energy production, it is necessary to define an optimal tilt angle and panels orientation. From studies also conducted for Kenya, an optimal tilt angle of 4° to the horizontal has been found for Nairobi [46]. Being Boji village still slightly north of the equator, the optimal tilt angle is facing slightly south.

However, being the optimal tilt angle between ±10°, it was decided to tilt the panels 10° facing south to allow the rain to clean the panel.

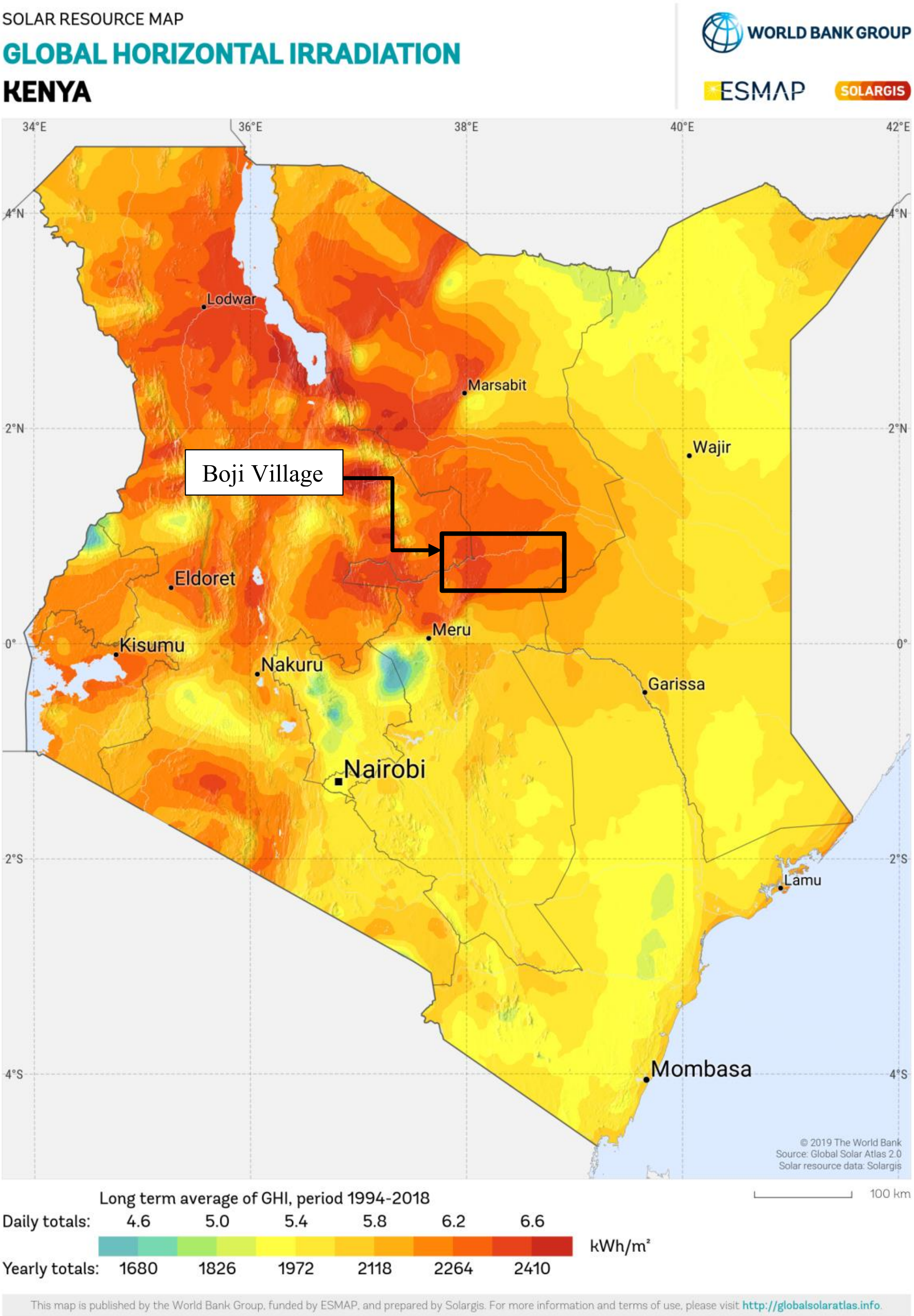

Figure 70: Global Horizontal Irradiation map in Kenya.

source: Solargis

4.5.3 Pump Design Flow Rate

The design flow rate for the pump can be calculated by dividing the total daily water requirement and the peak sun hours (PSH):

$$Flow\ rate\ (Q) = \frac{DWR_{BH1}}{PSH} = \frac{82.5\ \frac{m^3}{day}}{6.1\ \frac{hr}{day}} \cong 13.5\ \frac{m^3}{hr}$$

With this flow rate value and the value of the Total Dynamic Head (TDH), whose calculation will be treated later, it will be possible to choose the suitable pump for the system.

It is useful to specify that, considering the proportion between the DWR for humans and livestock (section 4.5.1), **4.5 m^3/hr** are for population water supply and **9 m^3/hr** are supplied to the water troughs for animals.

4.5.4 Elevated Tank

The task of the elevated tank is twofold. First of all, it is necessary to ensure a sufficient head upstream of the distribution pipe to allow gravity operation. Furthermore, it guarantees a water reserve to be used in case the solar pumping system does not work. In fact, solar panels may not generate enough energy to allow the pump to operate on cloudy days. Or, solar pumping may not work due to a PV system failure.

Unlike other pumping systems with stand-alone solar, in the case of Boji there are stand-by diesel generators for both boreholes. This allows to compensate for PV system non-operations and to activate pump operation.

4.5.4.1 Storage

Generally, tank storage volume should guarantee at least 3 days of water supply system operation. As mentioned, however, in this case there is an 18.5 kVA diesel genset that compensates for the solar non-operating. Of course, the correct operation of the generator must be verified and guaranteed through periodic tests, maintenance and fuel reserve.

Therefore, it is possible to reduce the storage volume by sizing it for 1 day of reserve.

In the distribution system there are 2 water kiosks each with 5,000 litres plastic tank. Therefore, approximately 10,000 litres of reserve are available in the system.

It is considered that on the reserve day at least the daily water requirement for humans of 27,500 litres should be guaranteed.

By subtracting from the latter the storage volume already in the two water kiosks, it is possible to calculate the remaining litres of water that should be guaranteed on the reserve day to meet the population water demand.

$$Min.\ Storage\ Tank = 27{,}500\ l - 10{,}000\ l = 17{,}500\ l$$

Considering a storage excess to have a minimum water supply for livestock even on the reserve day and to have a minimum volume of air in the full tank for inspection, and evaluating the availability on the market, it was chosen to use the following tank:

$$24,000\ litres\ (24\ m^3)\ Pressed\ Steel\ Tank$$

A maximum storage of 34,000 litres are guaranteed in the system.
If, on the other hand, the fault concerns the pump, a single reserve day may not be sufficient to restore the system. If for this emergency situation the water demand is considered reduced to the minimum standard of 15 l/d/p and therefore consider that the daily water requirement is reduced to 16,500 l/d, there would be 2 reserve days. Therefore, in case the failure of the BH 1 pumping system should be serious, it is possible to think of reducing water supply to the minimum standard SPHERE to recover a day of reserve. There is also to add, that in any case there is the BH 2 distribution line which can compensate for the BH 1 shortcomings and vice versa.

A compensation function is also associated with this storage volume. A storage upstream of distribution line allows a decoupling of the pump operation from the user demand.

The pump activation is controlled by a *float switch*. The purpose of a float switch is to open or close the pump circuit when the tank level rises or falls (Figure 71).

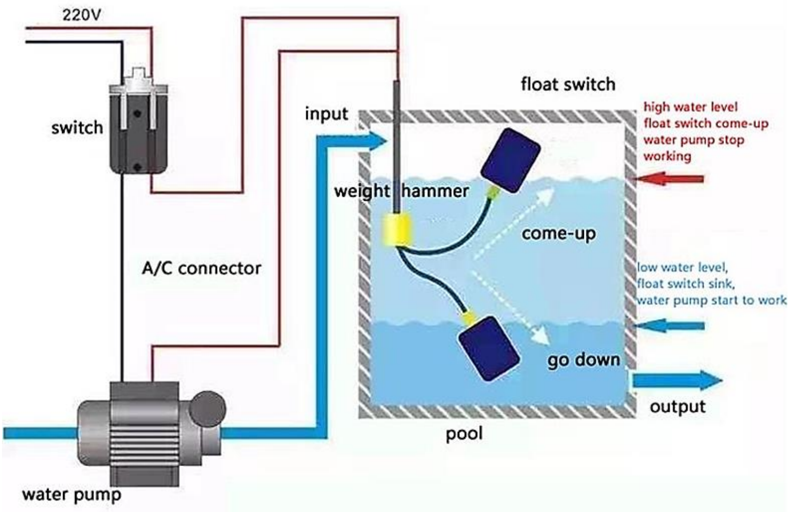

Figure 71: Float switch.

source: GXControl

If the float switch does not work and the pump does not turn off when the maximum level is reached, there is an overflow pipe (2 "dia GI pipe) located just above the maximum level set for the tank to drain excess water.

4.5.4.2 Elevation

The gravity operation of the BH 1 distribution pipe is allowed with an elevated tank, being the altitude of the ground almost constant along the whole pipeline path (615÷618 m above sea level).

The elevation of tank has been sized to ensure a head upstream of the distribution such as to make the water overcome the dissipations generated during the flow. In particular, the free surface level in the tank must allow water to reach the most unfavourable point by gravity, i.e. plastic tank of the Bula Hatari water kiosk located at the end of the distribution pipe. This water kiosk is the most unfavourable point because, being at the end of the pipeline, it is the point with the greatest pressure drops. The inlet pipe of the plastic tank of the Bula Hatari water kiosk is placed at a height of about 4.5 m above ground level. Therefore, to ensure the filling of the plastic tank, the water must have a head at this point at least equal to the inlet pipe elevation (4.5 m). Adding the friction losses along the pipeline at this height, the free surface of the elevated tank will be obtained.

For this purpose, only the friction losses distributed along the distribution pipe are taken into consideration, disregarding concentrated friction losses. Being the pipeline about 700 m long, it is admissible to overlook the concentrated friction losses under the hypothesis of "long pipelines", a definition applicable to pipelines at least 1000 times their diameter ($l/D > 1000$). In long pipelines, the concentrated friction losses, whatever the cause, are generally negligible compared to those distributed (due to the friction exerted by the pipe wall on the flow) and are therefore neglected in the calculations. In addition, the kinetic height of the outflowing currents in long pipes is negligible compared to the piezometric differences in height, because the flow speed does not exceed the value of a few meters per second. Consequently, it is entirely legitimate to consider the hydraulic load line and the piezometric line to be coincident.

To calculate the distributed friction loss in the pipe downstream of the tank, it is necessary to know the flow rates, lengths and diameters.

As mentioned in section 4.5.3, design flow rate of 4.5 m^3/hour is supplied to the distribution pipe. Along the pipeline there are 3 water points (primary school and 2 water kiosk). It is assumed that each water point takes 1/3 of the total flow introduced into the pipeline (1.5 m^3/hr).

The pipeline sections lengths in which there is a different flow have been obtained from the path drawn on Google Earth.

The choice of diameters is based on speed values and cost. In particular, minimum in-line speeds shall not be less than 0.4 m/s in order not to have high lead times and fine material deposition, while the maximum speeds should not exceed 2 m/s in order not to have excessive vibrations and friction in the pipe and valves.

All pipeline sections are in UPVC.

Figure 72 shows the distribution pipeline path.

Table 8: Description of the BH 1 distribution pipeline.

Pipe	**Length** [m]	**Q** [m^3/hr]	**D** [mm]	**D** [inch]	**V** [m/s]
From el. tank to school	340	4.5	50	2”	0.64
From school to Dibu Wara water kiosk	171	3	50	2”	0.43
From Dibu Wara to Bula Hatari water kiosk	218	1.5	32	1” 1/4	0.52

The flow velocity is calculated with the following formula:

$$Q = V \cdot \frac{\pi D^2}{4} \quad \rightarrow \quad V = \frac{4 \cdot Q}{\pi D^2}$$

with Q in m^3/s, D in m and V in m/s.

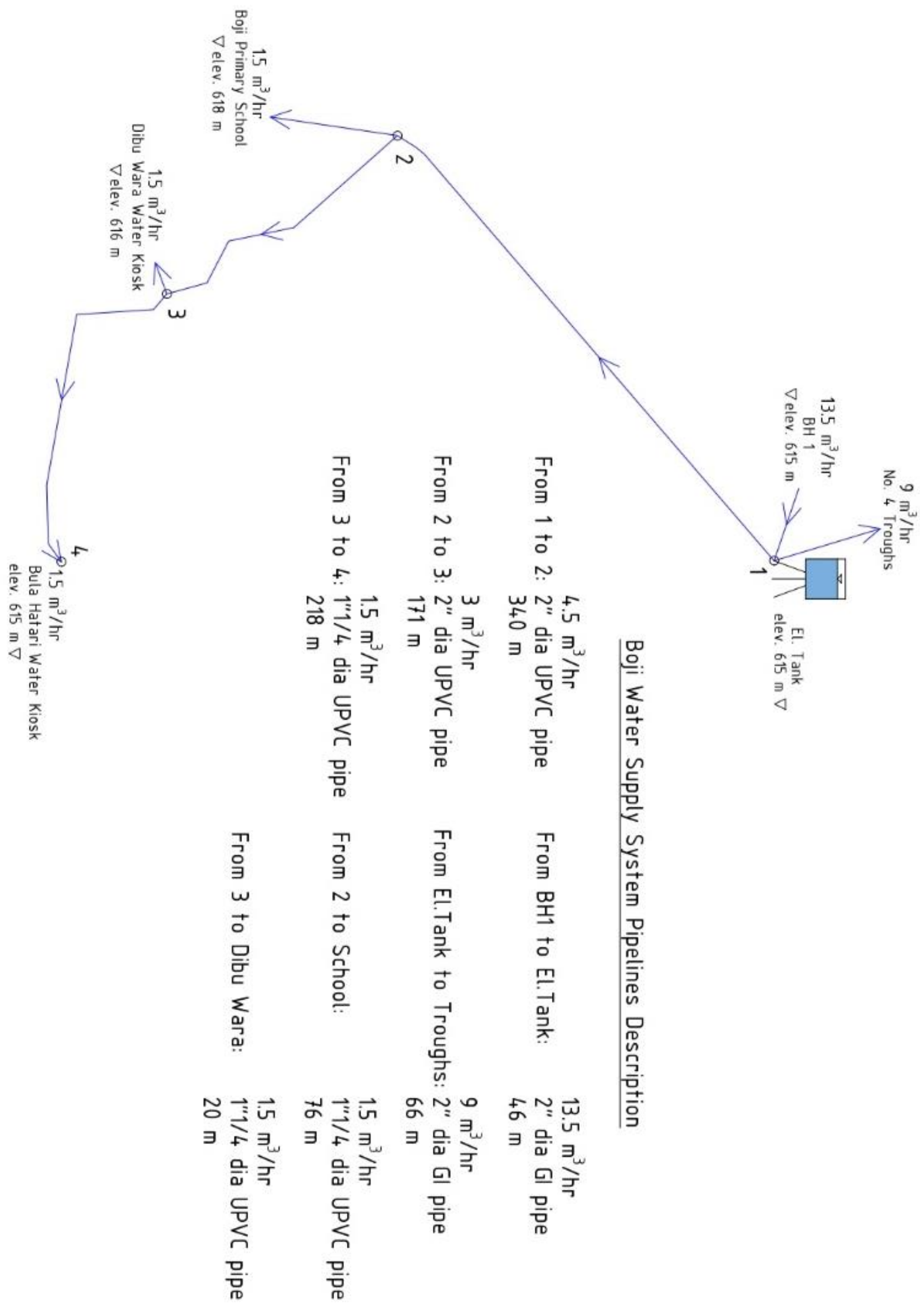

Figure 72: BH 1 water supply system.

Two methods are used to calculate the friction loss: *Colebrook-White formula*, *Hazen-Williams formula*.

In fluid dynamics, the **Colebrook-White formula** is an equation that allows to obtain the Darcy λ friction coefficient of a generic fluid in the pipeline. This mathematical link stems from the combination of empirical results with laminar and turbulent flow studies in pipes [47].

It is defined as follows:

$$\frac{1}{\sqrt{\lambda}} = -2\ log\left(\frac{2.51}{Re\sqrt{\lambda}} + \frac{\varepsilon/D}{3.71}\right)$$

with:

- ◦ λ Darcy friction coefficient;
- ◦ ε/D is the relative roughness (for the values of ε see Table 9);
- ◦ $Re = \frac{\rho VL}{\mu}$ is the Reynolds number with ρ density [kg/m^3], μ dynamic viscosity [Pa·s or N·s/m^2 or kg/(m·s)] (water was assumed as fluid at 20 ° C), $L = D$ [m], V flow velocity [m/s].
- ◦ Logarithm is in base 10.

Table 9: Roughness values.

ε [mm]	
0.00 – 0.02	New PE, PVC, copper, stainless steel pipes
0.05 – 0.15	New gres, coated cast iron, steel pipes
0.10 – 0.40	Concrete pipes or with slight incrustations
0.60 – 0.80	Pipes with incrustations and deposits

In the case under consideration, being the UPVC pipes, a value $\varepsilon = 0.02\ mm$ is used.

Colebrook equation is represented in the Moody diagram, which allows for its graphical solution.

Once known the friction coefficient λ it is possible to calculate the distributed friction losses with the *Darcy - Weisbach formula*:

$$\Delta H = J \cdot L = \frac{\lambda}{D}\frac{V^2}{2g} \cdot L$$

Table 11 shows the results for the three distribution pipeline sections.

The **Hazen-Williams equation** is an empirical relationship that relates the water flow in a pipe with certain physical properties and the pressure drop caused by friction. It is used in the sizing of water pipeline systems such as fire systems, water supply networks and irrigation systems. It is a valid formula for pipes with a diameter of less than 1.8 m (Casey, 1992) with water.

It is defined as follows:

$$\Delta H = J \cdot L = \frac{10.675 \cdot Q^{1.852}}{C^{1.852} \cdot D^{4.8704}} \cdot L$$

with D in m, Q in m^3/s, L in m and where C is a roughness coefficient.

Table 10: Roughness coefficient for Hazen-Williams equation.

C	
100	Concrete pipes
120	Steel pipes
130	Coated cast iron pipes
140	Copper, stainless steel pipes
150	PE, PVC and GRP pipes

In the case under consideration, being the UPVC pipes, a value $C = 150$ is used.

Table 12 shows the results for the three distribution pipeline sections.

Table 11: Colebrook-White equation result #1.

Eq. Colebrook-White								
Pipe	$\boldsymbol{Q}$ [m^3/s]	$\boldsymbol{D}$ [m]	$\boldsymbol{\frac{\varepsilon}{D}}$	$\boldsymbol{Re}$	$\boldsymbol{\lambda}$	$\boldsymbol{J}$ [m/m]	$\boldsymbol{L}$ [m]	$\boldsymbol{\Delta H}$ [m]
From el. tank to school	0.00125	0.050	0.0004	31,641.15	0.02427	0.01003	340	3.41
From school to Dibu Wara water kiosk	0.00083	0.050	0.0004	21,009.72	0.02645	0.00482	171	0.82
From Dibu Wara to Bula Hatari water kiosk	0.00042	0.032	0.000625	16,611.61	0.02830	0.01230	218	2.70
							Total	**6.93**

Table 12: Hazen-Williams equation result #1.

Eq. Hazen-Williams						
Pipe	Q [m³/s]	D [m]	C	J [m/m]	L [m]	ΔH [m]
From el. tank to school	0.00125	0.050	150	0.00894	340	3.04
From school to Dibu Wara water kiosk	0.00083	0.050	150	0.00419	171	0.72
From Dibu Wara to Bula Hatari water kiosk	0.00042	0.032	150	0.01044	218	2.30
					Total	**6.06**

Considering friction losses values obtained by the two methods and adding the water kiosk inlet pipe elevation (+4.5 m), a free water surface elevation in the elevated tank of **12 m** is obtained.

Considering the 24 m^3 pressed steel tank height of about 2.5m, a 10 m high galvanised steel U.B. and U.C.[18] section tower was used to raise the tank.

Figure 73: Boji village elevated tank.

[18] U.C. – universal column; U.B. – universal beam.

Figure 74: 24 m^3 pressed steel tank (front view).

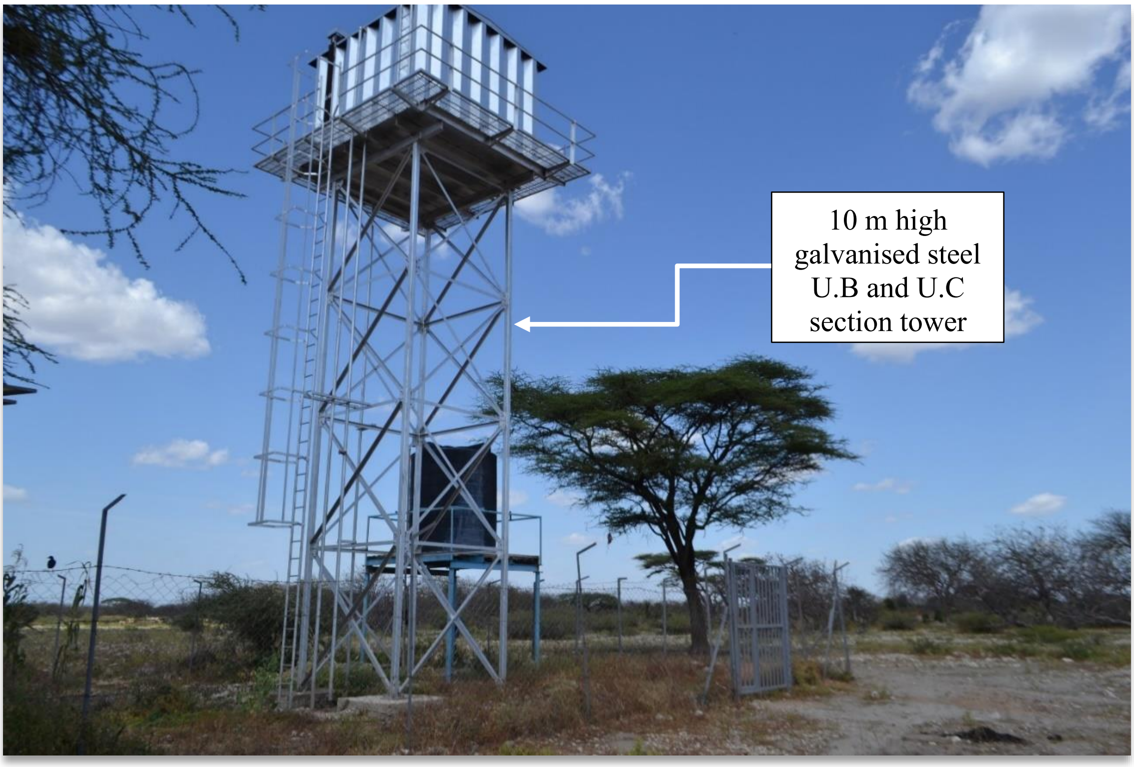

Figure 75:Tank tower.

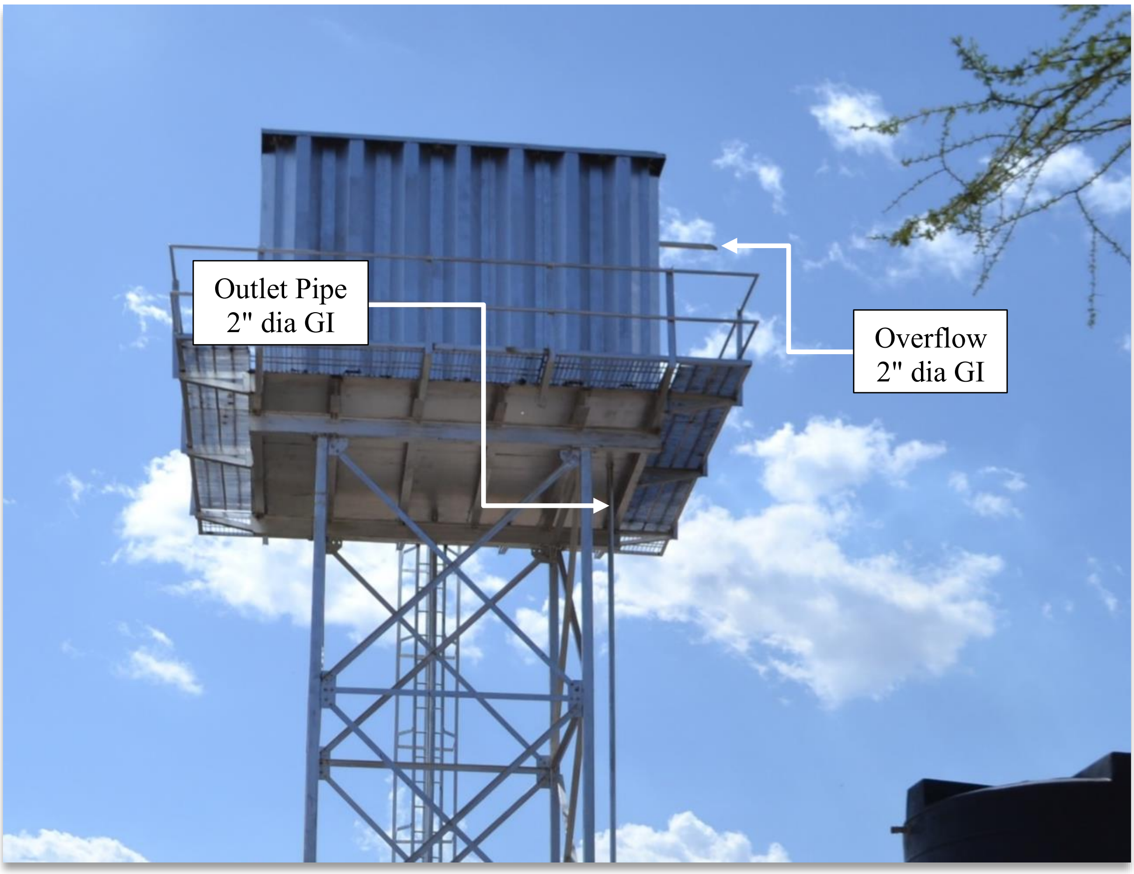

Figure 76: 24 m³ pressed steel tank (retro view)

4.5.5 Total Dynamic Head

Total Dynamic Head (TDH) is necessary, with the design flow rate obtained in section 4.5.3, to select the pump type. TDH represents the necessary energy that pump must transfer to water to make it overcome the geodesic jump (*Static Head*) and the pressure drops (*Friction Loss*). In some cases there is also a contribution related to the delivery pressure (*Pressure Head*) but in this case it is zero because the water arrives in a tank with a free surface.

In the case of a submersible pump in a borehole that sends water to an elevated tank, the TDH is calculated with the following equation:

$$TDH = Static\ Head + Friction\ Loss$$

Below is discussed how to calculate each input.

4.5.5.1 Static Head

The Static Head in the case of a pump submerged in a borehole with elevated tank is the gravitational energy that must be given to the pumped water to overcome the geodetic jump. It is the distance between pumped water level and tank inlet point or tank water level, whichever is greater. Note that in the case of a submerged pump, it is evaluated starting from the pumping water free surface and not from the pump level. Pump depth does not determine the static head.

It can be calculated as follows:

$$\begin{aligned} Static\ Head &= Drawdown + Static\ Water\ Level + Elevation\ Tank = \\ &= Dynamic\ Level + Elevation\ Tank = 26.55\ m + 12\ m = \mathbf{38.55\ m} \end{aligned}$$

The dynamic level is the sum of the static water level and the drawdown (see Figure 77). This information was obtained from pumping test, the results of which are summarised in Table 5.

4.5.5.2 Friction Loss

In this case, the hypothesis of "long pipelines" due to the short length is *not* considered for the friction loss calculation. Therefore, the total value is given by the sum of the friction loss in the pipe going from pump to tank and the concentrated friction losses due to fittings and valves.

- **Friction Loss for Pipe Flow**

To calculate the distributed friction loss, it is necessary to know flow rate, diameter and length of the pipe. Pump design flow rate calculated in section 4.5.3 is 13.5 m^3/hr. The approach pipe to tank is a 2" G.I. existing pipe (D = 50 mm). To calculate the length, the pipeline sections contributions are added (see Figure 77). In particular, lengths of the pipe that goes from the pump delivery to borehole outlet, the pipe that goes from BH 1 to the base of the elevated tank and the pipe that introduces the water into the tank are added (Table 13).

Table 13: Pipe length from BH 1 to elevated tank.

Pipe	**Length** [m]
Inside BH 1	50
From BH 1 to El.Tank	46
El.Tank Inlet pipe	12
Total	**108**

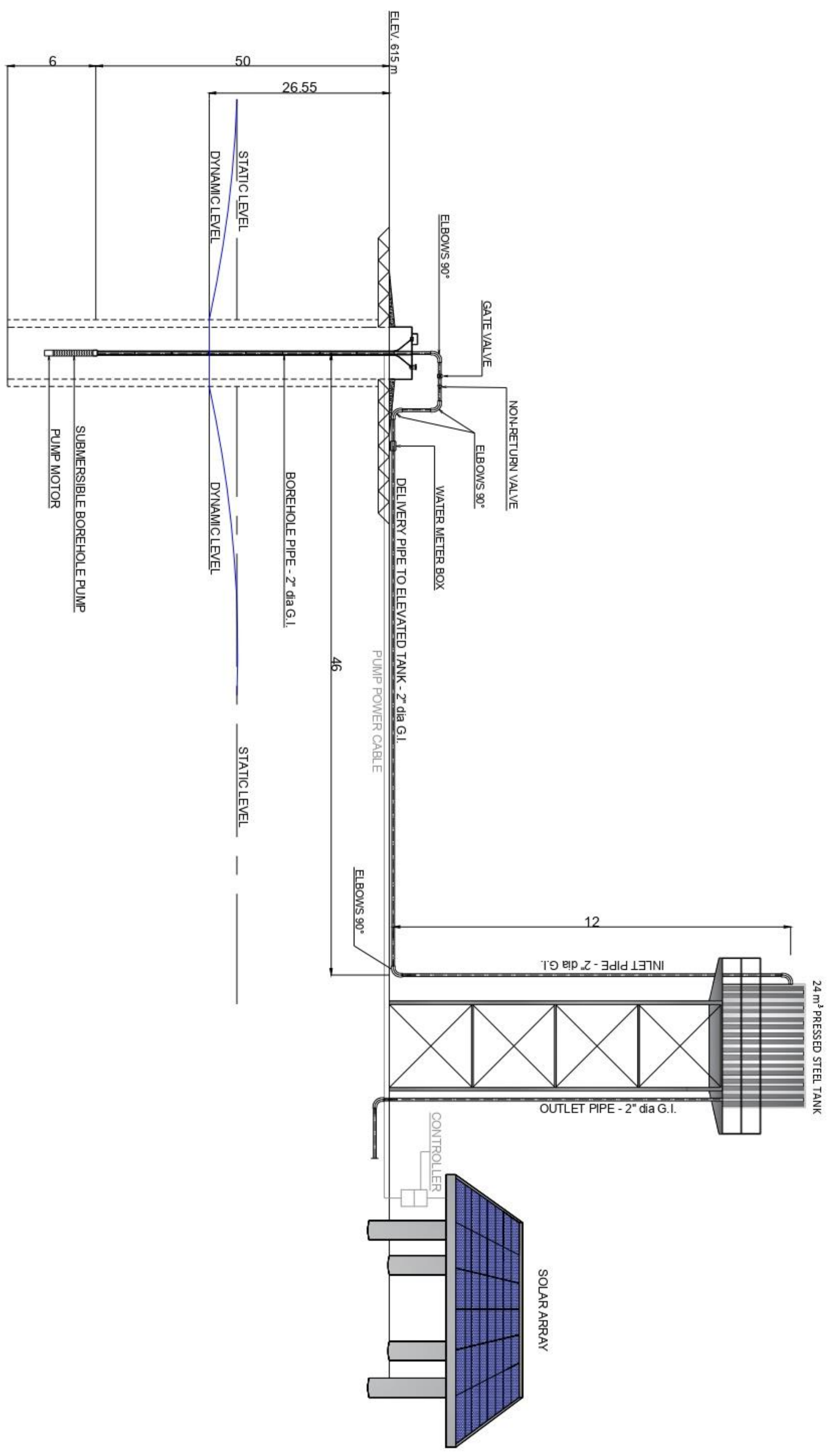

Figure 77: Description of Boji solar pumping system.

The two methods seen in section 4.5.4.2 are used.

In addition, a new method is used that allows the distributed friction loss calculation through a table (Table 17), knowing flow rate, diameter and pipe material (PVC or GI). Calculated the head loss value for 100 m (F), the total friction loss (FL) for a pipeline is equal to:

$$FL = \frac{F \cdot L}{100} \quad with\ L = \text{pipe length [m]}$$

Table 14: Colebrook-White equation result #2

Eq. Colebrook-White								
Pipe	$\boldsymbol{Q}$ [m³/s]	$\boldsymbol{D}$ [m]	$\boldsymbol{\frac{\varepsilon}{D}}$	$\boldsymbol{Re}$	$\boldsymbol{\lambda}$	$\boldsymbol{J}$ [m/m]	$\boldsymbol{L}$ [m]	$\boldsymbol{\Delta H}$ [m]
Inside BH 1	0.00375	0.050	0.002	94,923.45	0.02517	0.09364	50	4.68
From BH 1 to El.Tank	0.00375	0.050	0.002	94,923.45	0.02517	0.09364	46	4.31
El.Tank Inlet pipe	0.00375	0.050	0.002	94,923.45	0.02517	0.09364	12	2.70
							Total	**11.70**

A value of $\varepsilon = 0.10\ mm$ (0.05 - 0.15, see Table 9) is considered.

Table 15: Hazen-Williams equation result #2

Eq. Hazen-Williams						
Pipe	$\boldsymbol{Q}$ [m³/s]	$\boldsymbol{D}$ [m]	$\boldsymbol{C}$	$\boldsymbol{J}$ [m/m]	$\boldsymbol{L}$ [m]	$\boldsymbol{\Delta H}$ [m]
Inside BH 1	0.00375	0.050	120	0.1030	50	5.15
From BH 1 to El.Tank	0.00375	0.050	120	0.1030	46	4.74
El.Tank Inlet pipe	0.00375	0.050	120	0.1030	12	1.24
					Total	**11.13**

For C value see Table 10.

Table 16: Friction loss table result.

Q [m^3/hr]	***D*** [inch]	**Material**	***F*** [m/100m]	***L*** [m]	***FL*** [m]
13.5	2”	G.I.	11.5	108	**12.42**

Table 17: PVC and GI friction loss table.

Section D

Data Tables

TABLE 1: PVC AND GI FRICTION LOSS TABLES

HEAD LOSS IN METRES PER 100m FOR DIFFERENT CLASSES OF PVCAND GI PIPES

Flow (m^3/hr)	3/4"			1"			1 1/4"			1 1/2"				2"				2 1/2"				3"				
	PVC		GI	PVC		GI	PVC		GI	PVC			GI		PVC		GI		PVC		GI	PVC				GI
1	D	E		D	E		D	E		C	D	E		C	D	E		C	D	E		B	C	D	E	
1.5	2.4	3.2	8.0			1.9			1.5																	
2	5.0	6.8	17.8	1.6	2.2	4.2			2.6																	
2.5	8.6	11	31.9	2.8	3.8	7.5	1.3	1.8	3.9				1.5													
3	12.9	17.4	49.8	4.2	5.7	11.6	2.0	2.7	5.7				2.3													
3.5	19.0	25.8	71.7	6.2	8.4	17.7	2.7	3.7	8.0	1.2	1.4	1.9	3.3													
4				8.5	11.6	25.2	3.5	4.7	10.3	1.5	1.8	2.4	4.3				1.0									
5				10.8	14.8	32.7	4.9	6.7	15.5	2.2	2.6	3.5	6.3				1.5									
6				15.5	21.3	50.5	6.9	9.3	21.7	3.1	3.6	4.9	9.0	1.0	1.2	1.6	2.1									
7				21.6	29.6	72.7	9.2	12.5	29.3	4.1	4.7	6.5	12.3	1.4	1.6	2.2	2.9									
8				28.8	41.8	98.9	11.5	15.6	38.8	5.1	5.9	8.1	15.6	1.7	2.0	2.7	3.7				1.2					
9							14.4	19.6	49.1	6.4	7.5	10.2	20.0	2.1	2.5	3.4	4.7				1.6					
10							17.5	23.8	60.7	7.8	9.0	12.4	24.6	2.6	3.0	4.1	5.8				1.9					
12								33.3	87.4	10.8	12.6	17.3	35.3	3.6	4.2	5.8	8.4	1.2	1.4	1.9	2.7					1.1
14										14.3	13.9	22.9	48.3	4.8	5.6	7.6	11.5	1.6	1.8	2.5	3.7					1.5
16										18.3	25.9	29.3	63.0	6.1	7.2	9.8	16.2	2.0	2.3	3.2	5.0					2.0
18														7.6	8.9	14.4	20.9	2.5	2.9	4.0	6.3	1.0	1.0	1.3	1.8	2.5
20														9.2	10.8	18.7	25.6	3.0	3.5	4.9	7.6	1.2	1.4	1.6	2.2	3.1
					2"				21/2"				3"					4"					6"			
					PVC			GI	PVC			GI	PVC				GI	PVC				GI	PVC			GI
					C	D	E		C	D	E		B	C	D	E		B	C	D	E		B	C	D	
20					9.2	10.8	18.7	25.6	3.0	3.5	4.9	7.6	1.2	1.4	1.6	2.2	3.1									
25					13.9	16.2	28.7	37.3	4.5	5.3	7.4	12.0	1.8	21	2.4	3.3	4.8					1.1				
30									6.4	7.5	10.4	17.2	2.5	2.9	3.4	4.7	6.9					1.7				
35									8.5	9.9	13.8	23.2	3.4	3.8	4.5	6.2	9.3	1.0	1.1	1.3	1.8	2.3				
40									10.9	12.5	17.7	30.3	4.3	4.9	5.8	8.0	2.2	1.2	1.4	1.7	2.3	2.9				
45									13.6	16.3	22.0	38.2	5.4	6.1	7.2	9.9	15.4	1.5	1.8	2.1	2.9	3.7				
50														7.5	9.2	12.0	19.0	1.9	2.2	2.5	3.5	4.6				
60														10.7	13.1	17.2	27.6	2.7	3.1	3.6	5.0	6.5				
70														14.3	17.8	23.0	37.3	3.6	4.1	4.8	6.7	8.8				1.2
80														17.8	23.3	28.8	48.7	4.5	5.2	6.1	8.4	11.5				1.5
90																		5.6	6.5	7.6	10.9	14.6				1.9
100																		6.8	7.9	9.2	13.5	18.0	1.0	1.2	1.4	2.4
120																		9.5	11.0	13.6	19.5	25.9	1.4	1.7	1.9	3.4
140																							1.9	2.2	2.6	4.7
160																							2.4	2.8	3.3	6.3
180																							3.0	3.5	4.1	7.9
200																							3.6	4.2	5.0	9.5
225																							4.5	5.3	6.2	11.4
250																							5.5	6.4	7.8	15.0

source: Davis and Shirtliff

❖ Friction Loss for Pipe Fittings

The concentrated friction losses are due to obstacles such as, for instance, bends, elbows, valves, sudden changes in pressure (section changes), which the fluid may encounter as it flows inside the pipe. They arise because of the turbulence caused by these obstacles.

Typically, for piping sizing, a **direct method** is used in which the concentrated friction loss is a portion of the fluid's kinetic height. In fact, it can be considered that the head loss caused by turbulence that occurs at such discontinuities is linked to the kinetic energy loss of fluid. With this method, localized head losses can be calculated with the following formula:

$$\Delta H = k \cdot \frac{V^2}{2g}$$

In which $V\ [m/s]$ is the average velocity that occurs at the discontinuity and k is a dimensionless parameter which mainly depends on the discontinuity geometric configuration.

Considering the number and type of fittings, valves and outlets of the case in question (see Figure 77) and consulting the technical literature to obtain the relative coefficient values, the following table is associated with this information:

Table 18: Fittings, valves and outlets.

N°	Type	k
4	2" dia Elbows 90°	0.29
1	2"dia Non-Return Valve	2.7
1	2" dia Gate Valve	0.2
1	Tank Inlet	1

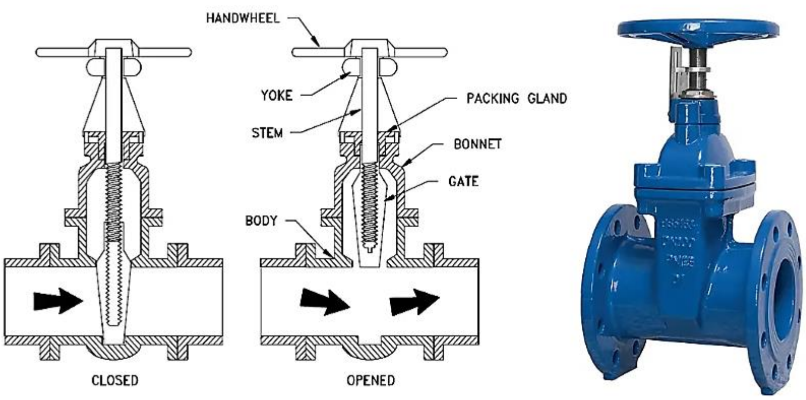

Figure 78:Gate valve.

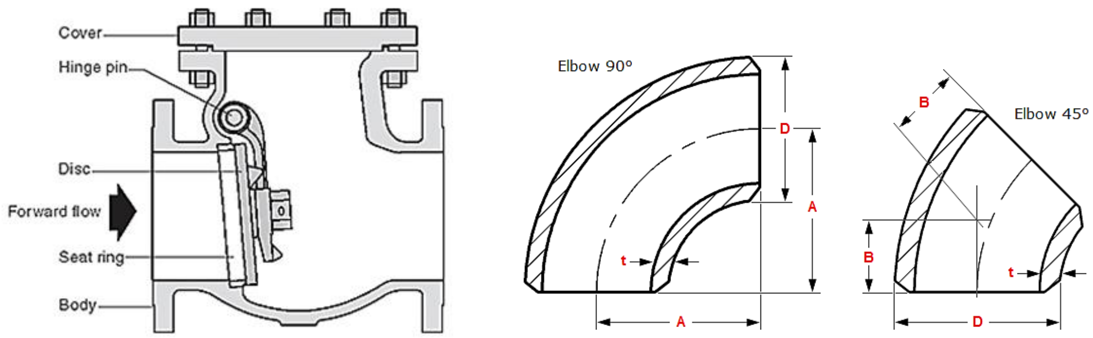

Figure 79: Non-return valve (left) and elbow (right).

The following table summarizes the results obtained from the calculation of concentrated friction losses through the direct method.

Table 19: Direct method result.

Q [m^3/s]	D [inch - mm]		V [m/s]	Type	k	$\Delta H'$ [m]	N°	ΔH [m]
13.5	2”	50	1.91	2" dia Elbows 90°	0.29	0.054	4	0.216
13.5	2”	50	1.91	2"dia Non-Return Valve	2.7	0.186	1	0.186
13.5	2”	50	1.91	2" dia Gate Valve	0.2	0.502	1	0.502
13.5	2”	50	1.91	Tank Inlet	1	0.037	1	0.037
							Total	**0.941**

Adding the contribution obtained with the previously calculated distributed friction losses, we obtain the following results related to the total friction loss:

Table 20: Total friction loss with direct method.

Method	ΔH_{flow} [m]	$\Delta H_{fittings}$ [m]	ΔH_{tot} [m]
Eq. Colebrook-White	11.70	0.941	**12.64**
Eq. Hazen-Williams	11.30	0.941	**12.24**
Table 17	12.42	0.941	**13.36**

As an alternative to the method just used, it is possible to use an **indirect method** that uses the *equivalent lengths*, i.e. it replaces each special piece with a linear pipe that generates the same pressure drops. It is therefore possible to incorporate the concentrated head losses in the calculation of the distributed head losses, by replacing in the methods previously seen a total length that is the sum of the real pipe length and the equivalent one. Table 21 indicates the equivalent pipe lengths relating to specific diameters and for different hydraulic components or parts. This table is valid for a speed flow of 1.0 m/s and for medium roughness components (acceptable for the GI pipes of the case in question). If the flow in the pipeline has a speed other than 1.0 m/s, the equivalent length will be calculated as follows:

$$L'_e = L_{e(table)} \cdot V^2$$

Table 21: Equivalent length for different diameters and components.

DN	Elbows		Fitting		Gate Valve		Non-Return Valve
					Open		
	45°	90°	T Junction 90°	T Straight Junction	100%	50%	
	Equivalent Length [m]						
25	0.3	0.6	0.5	1.5	0.3	3.7	1.5
32	0.3	0.9	0.6	1.8	0.3	3.7	2.1
40	0.6	1.2	0.8	2.4	0.3	3.7	2.7
50	0.6	1.5	1.0	3.0	0.3	3.7	3.3
65	0.9	1.8	1.2	3.6	0.3	3.7	4.2
80	0.9	2.1	1.5	4.5	0.3	3.7	4.8
100	1.2	3.0	2.0	6.0	0.6	7.4	6.6
152	1.5	3.6	2.5	7.5	0.6	7.4	8.3
150	2.1	4.2	3.0	9.0	0.9	11.1	10.4
200	2.7	5.4	3.5	10.5	1.2	14.8	13.5
250	3.3	6.6	5.0	15.0	1.5	18.5	16.5
300	3.9	8.1	6.0	18	1.8	22.2	19.5

source: Oppo

In the present case:

Table 22:Equivalent length result.

N°	Type	L_e [m]	V [m/s]	L_e' [m]
4	2" dia Elbows 90°	1.5	1.91	21.86
1	2"dia Non-Return Valve	3.3	1.91	12.04
1	2" dia Gate Valve	0.3	1.91	1.10
1	Tank Inlet	*	1.91	*
			Total	**35**

** there is no information on the equivalent length therefore the head loss value obtained from the previous method (direct method) is considered for the overall calculation.*

Considering the equivalent length in the methods for the distributed friction losses calculation seen above, the following results are obtained.

Table 23: Total friction loss with indirect method.

Method	J [m/m]	$L + L_e$ [m]	ΔH_L [m]	ΔH_{L_e} [m]	ΔH_{inlet} * [m]	ΔH_{tot} [m]
Eq. Colebrook-White	0.09364	143	11.70	3.28	0.037	**15.02**
Eq. Hazen-Williams	0.1030	143	11.30	3.61	0.037	**14.95**
Table 17	0.1150	143	12.42	4.03	0.037	**16.49**

From the result comparison of Table 20 and Table 23, it was chosen to consider the total friction loss highest value:

$$Total\ Friction\ Loss = Friction\ Loss\ for\ Pipe\ Flow\ + Friction\ Loss\ for\ Pipe\ Fittings$$
$$= \mathbf{16.49\ m}$$

Adding the static head and total friction loss, the TDH value that the pump must guarantee is obtained.

$$TDH = Static\ Head + Total\ Friction\ Loss = 38.55 + 16.49 \cong \mathbf{55\ m}$$

4.5.6 Pump Characteristics

Once noted the design flow rate and TDH data, it is possible to select the suitable pump for the system through the manufacturer's pump curves.

Table 24: Design parameters of the pump.

Design Flow Rate (Q)	13.5 m^3/hr
TDH	55 m

Some manufacturers provide online software to select the most suitable pump. For this scenario, the Grundfos online tool is used, available at the following link:

https://product-selection.grundfos.com/

This with the aim of retracing one of the methods used for choosing the pump. In addition, as it will be seen, it will allow the choice of the pump actually used for the BH 1.

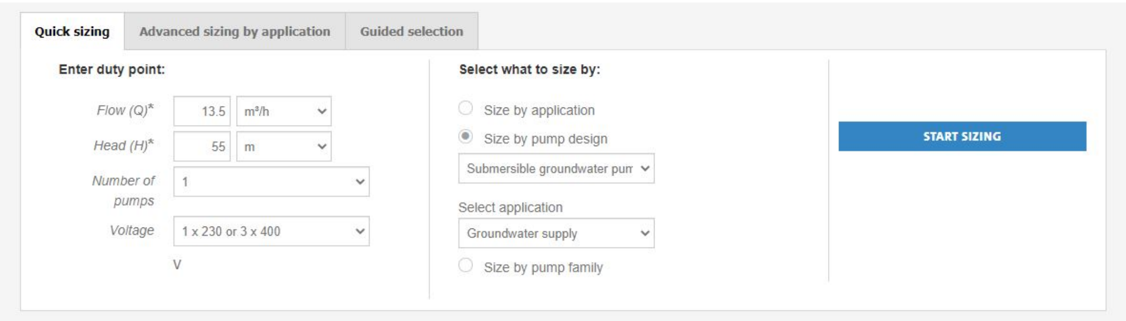

Figure 80: Grundfos online tool.

source: Grundfos

The sizing parameters can be set via the screen in Figure 80. Furthermore, in the "*Advanced sizing by application*" section it is possible to define additional and detailed system parameters (such as the presence of an open tank, see Figure 81). Using the "*Start Sizing*" command, the tool will search for the pump that best suits the needs defined with the input data.

The result shows how multiple pumps can be suitable for the case under consideration. Therefore, further considerations are added for the choice. In this regard, the search results tables allow a detailed comparison of the various characteristics. Furthermore, the tool allows to set an evaluation criterion (system price, energy consumption, duty point deviation, etc.) showing as a solution the pumps types that best respect it. For more details see **Appendix D**.

Certainly, the cost of the pump also affects the choice. However, the cheapest pump is not necessarily chosen, but a cost-performance evaluation is carried out. For a solar pumping system, pump motor power is linked to the cost of the entire system. Motors with lower rated power, imply lower absorbed powers. A photovoltaic system that generates less power and therefore less expensive will be needed.

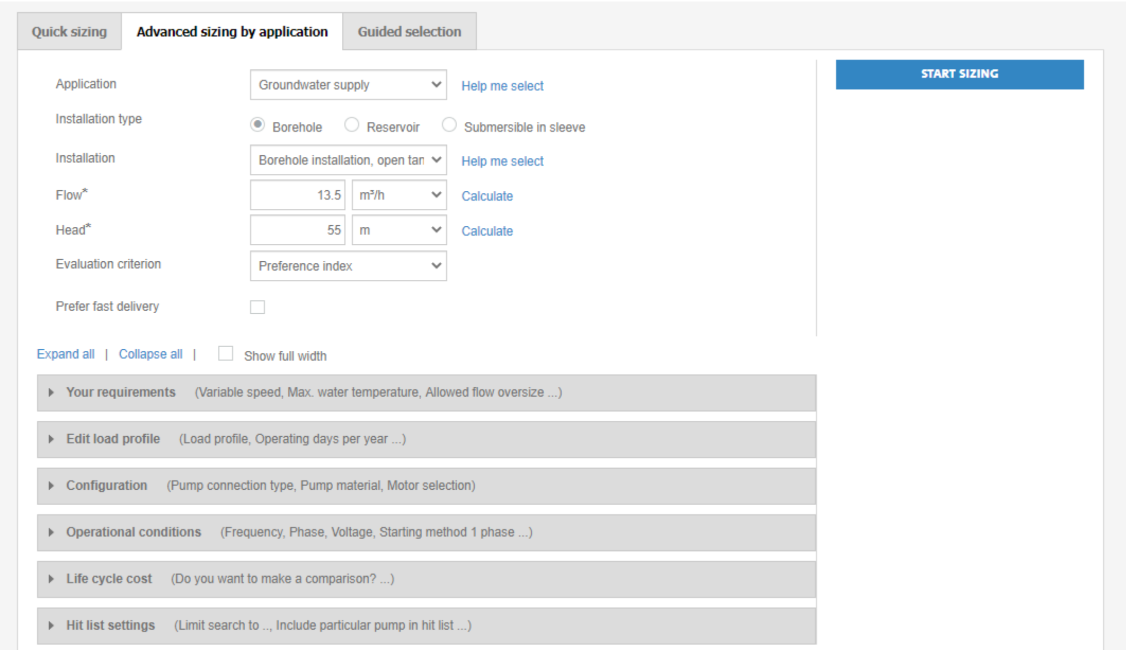

Figure 81: Advanced sizing by application.

source: Grundfos

If there are no specific reasons for a different choice, it is preferable to have a pump with an operating point (given by the design flow rate and TDH) close to the optimal operating point, given by the "flow rate-total head" that maximizes the pump performance. At the point of maximum yield (or close to it) the pump operation is optimal. Keep in mind that if the design conditions are very far from the optimal operating point, the functioning could be adversely affected. Of course, the choice is also influenced by the value of performance itself, preferring pump models to higher yields.

In this case, having already an existing 2 "dia GI lifting pipe, a pump with an outlet of this size is preferred.

4.5.6.1 Pump Performance

The performances of the pump that best suits the system in question and which was actually installed in the Boji BH 1 are shown below.

Description	Value
General information:	
Product name:	SP 14-13
Product No:	On request
EAN number:	On request
	On request
Technical:	
Pump speed on which pump data are based:	2900 rpm
Actual calculated flow:	13.66 m³/h
Resulting head of the pump:	55 m
Stages:	13
Impeller reduc.:	NONE
Shaft seal for motor:	HM/CER
Approvals on nameplate:	CE,EAC
Curve tolerance:	ISO9906:2012 3B
Model:	A
Valve:	YES
Motor version:	T40
Materials:	
Pump:	Stainless steel
	EN 1.4301
	AISI 304
Impeller:	Stainless steel
	EN 1.4301
	AISI 304
Motor:	Stainless steel
	DIN W.-Nr. 1.4301
	AISI 304
Installation:	
Pump outlet:	RP2
Motor diameter:	4 inch
Liquid:	
Pumped liquid:	Water
Maximum liquid temperature:	40 °C
Max liquid t at 0.15 m/sec:	40 °C
Electrical data:	
Motor type:	MS4000
Applic. motor:	NEMA
Rated power - P2:	3 kW
Power (P2) required by pump:	3 kW
Mains frequency:	50 Hz
Rated voltage:	3 x 380-400-415 V
Rated current:	7.70-7.85-8.10 A
Requested voltage:	400 V
Rated current at this voltage:	7.79 A
Starting current:	460-490-500 %
Cos phi - power factor:	0.82-0.77-0.73
Rated speed:	2850-2865-2875 rpm
Enclosure class (IEC 34-5):	IP68
Insulation class (IEC 85):	F
Motor protec:	NONE
Thermal protec:	external
Built-in temp. transmitter:	no
Motor No:	79194508
Others:	
Minimum efficiency index, MEI â‰¥:	0.50
ErP status:	EuP Standalone/Prod.
Net weight:	32.3 kg
Gross weight:	37.9 kg
Shipping volume:	0.068 m³

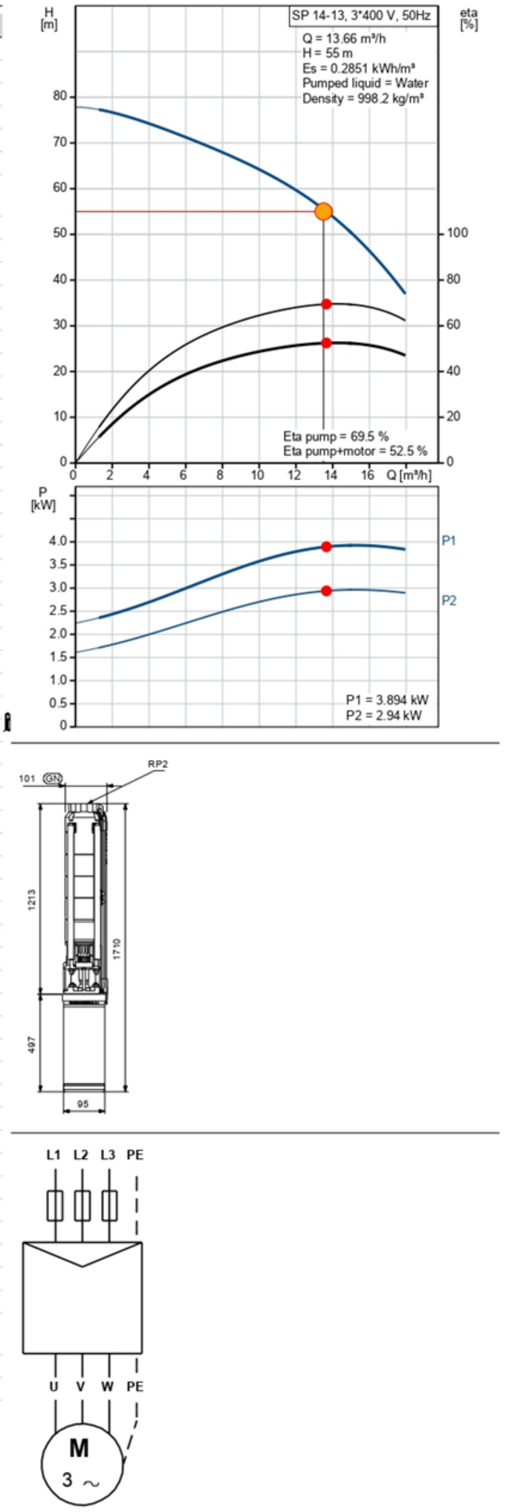

Figure 82: Pump specification

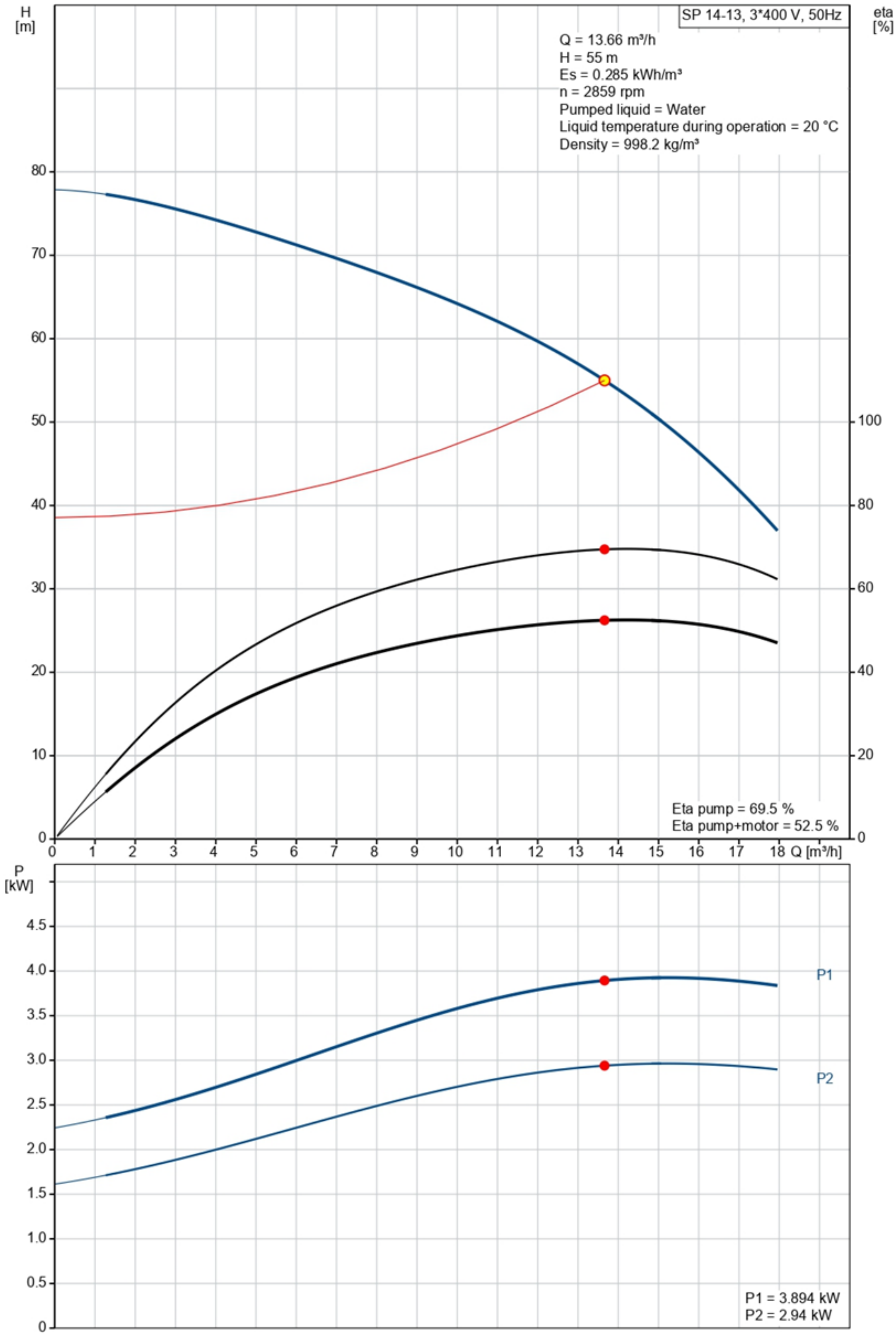

Figure 83: Performance curve.

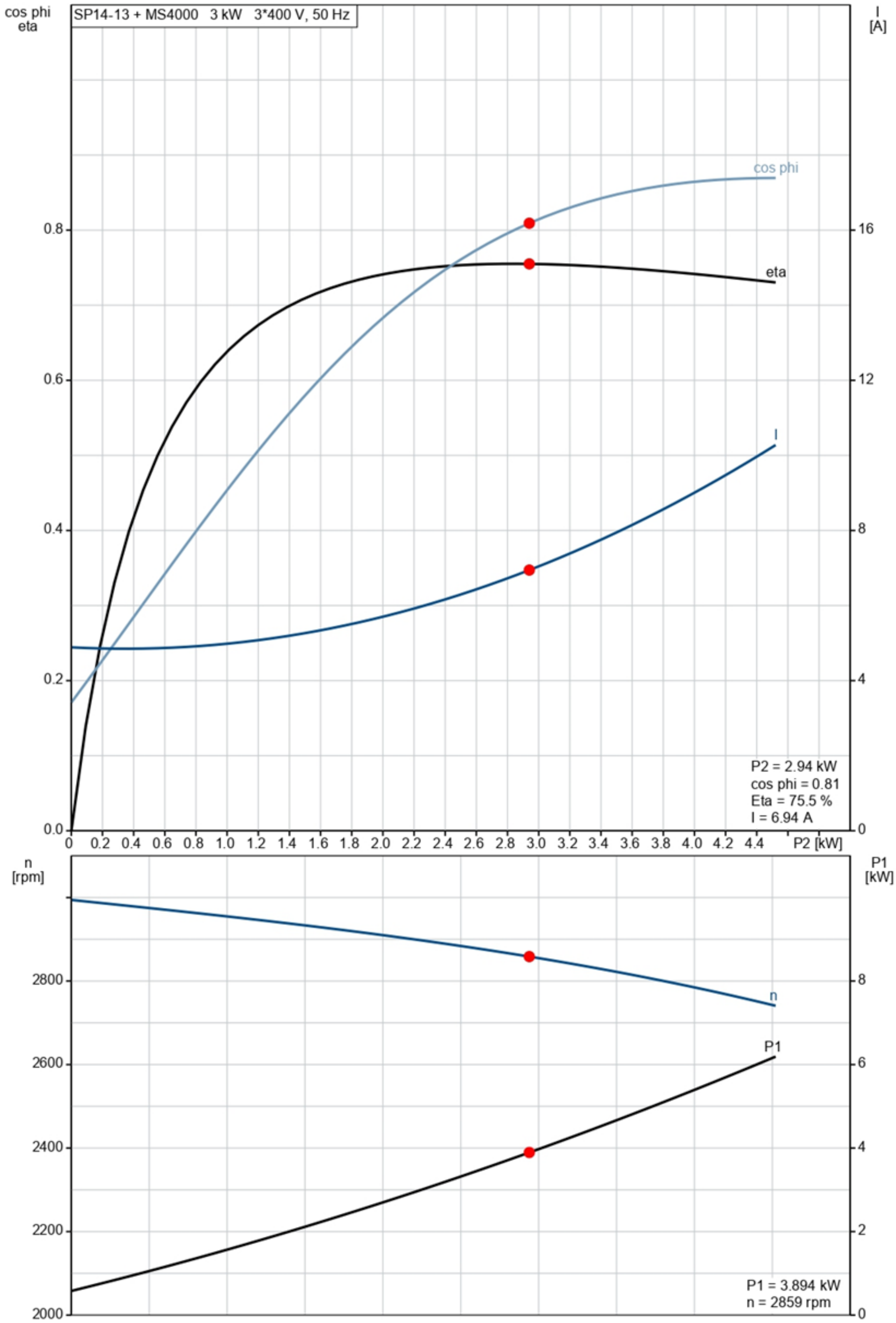

Figure 84: Motor curve.

4.5.6.2 Motor Power Requirement

Observing the selected pump performance data in the previous section 4.5.6.1, it is possible to define two different power values:

- **P1**, *induced power to the pump system*. This is the power absorbed by pump motor.
- **P2**, *rated power*. This is the power that comes to pump from motor. Lower than the previous one due to internal motor dissipation.

For the selected pump, rated power – P2 – is 3 kW. But the power P2 required in the duty point 2.94 kW (Figure 83). Power P1 is 3.894 kW. The latter value is the one that will be used to define the number of solar panels needed to power the motor.

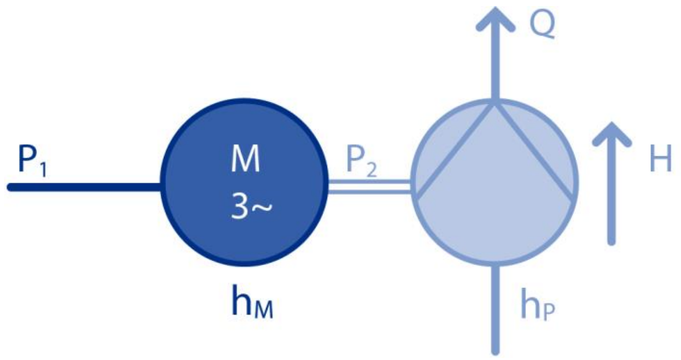

Figure 85: Pump electrical scheme.

4.5.7 PV Panels

It is necessary to select the type and number of solar panels in order to provide adequate electrical power to the motor for pumping system operation. As determined in section 4.5.6.2 above, the minimum power required is **3.894 kW**.

A common practice is to mark-up this requirement by at least 30% in order to determine the solar system required. This mark-up is to cater for power losses and intermittent irradiation from the sun due to cloud cover to attain at least 6 full sunshine hours for the pump operation in a day. In addition, this increase also considers potential power reductions generated due to high head, dust, age. Sometimes the mark-up can be up to 80% in effort of increasing daily water output from the system.

In this case the panels are sized to provide a minimum output of:

$$Min. Output\ Power = P1 + 30\%\ P1 = 1.3 \cdot 3.894 \text{ kW} = \mathbf{5.06\ kW}$$

The selected PV panels are made up of polycrystalline silicon solar cells and have the characteristics defined in Table 25 and Table 26.

Table 25: Panel electrical data. Data is given at Standard Test Conditions: Irradiance 1000W/m², spectrum AM 1.5 and 25°C cell temperature.

Rated power [W]	**Nominal Voltage** [V]	**Peak Voltage** [V]	**Open Circuit Voltage** [V]	**Short Circuit Current** [A]	**Number of Cells**	**Nominal Operating Cell Temp.**
270	24	30.8	37.7	9.28	60	46+/-2°C

Table 26:Panel physical data.

Dimensions [mm]						**Weight** [kg]
A	B	C	D	E	F	
1650	992	990	948	330	35	18.5

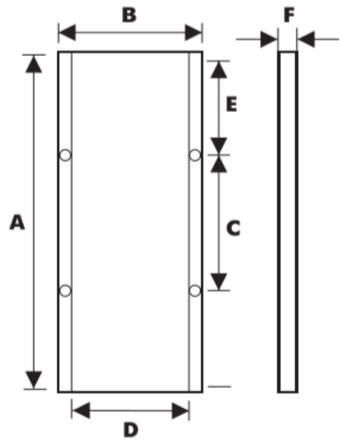

Figure 86: Panel physical data.

source: Davis and Shirtliff

As shown in Table 25, the panel's Short Circuit Current is sufficient for the pump motor absorption current of $7.79\,A$ (see in Figure 82 "*reated current at this voltage-400 V"*). Therefore, parallel connections between panels are *not* required to increase the output current value.

To obtain the necessary number of panels, divide the minimum output power and the panel rated power:

$$N°\ Panels = \frac{Min.\,Output\ Power}{Panel\ Rated\ Power} = \frac{5060\ W}{270\ W} \cong \mathbf{19\ Panels}$$

Nineteen panels are required to meet the pump power requirement.

To obtain the requested voltage of the pump motor (400 V), the 19 panels are connected in series. The output voltage for 19 panels wired in series is the sum of their individual voltages (19 panels ·24 V).

4.5.8 Solar Controller

Once the solar system size is determined, pump controller is selected. One of the controller's main tasks is to operate the pump when the PV array provides adequate current and voltage values. It also protects the system against over and under voltage, over current, system overload and module over temperature. In this case, another task is the conversion of the DC current produced by the panels into AC current of pump power through an *inverter*.

The choice of the controller is based on checking the best correspondence between the solar array characteristics and the pump operating requirements.

The most important requirements of a solar controller will be:

- **Maximum Power Point (MPP) Voltage VDC**–this is determined by the total peak voltage of the panels connected in series of each string. It must be within the range provided for the controller. In this case:

$$MPP\ Voltage\ VDC = Panel\ Peak\ Voltage \cdot N°\ Panels\ in\ Series = 30.8\ V \cdot 19 = 585\ V$$

- **Max DC Input Voltage** – this is the maximum open circuit voltage a string can have. In this case:

$$\begin{aligned} Max\ DC\ Input\ Voltage &= Panel\ Open\ Circuit\ Voltage \cdot N°\ Panels\ in\ Series \\ &= 37.7\ V \cdot 19 = 716.3\ V \end{aligned}$$

- **Pump Motor Rated Power**: 3 kW
- **Solar Input Power**: 19·270 W≅5.1 kW
- **Output Current** (A) – which must be compatible with the pump motor absorption current, in this case equal to 7.79 A.

In the present case, it was also necessary to have a controller with hybrid capacity that allows the connection to the diesel generator stand-by power supply.

Based on the requirements described, a controller with the following characteristics was chosen:

Table 27: Controller electrical data.

Motor Rated Power [kW]	**Rated Voltage** [V]	**Max Input Power** [kW]	**Output Current** [A]	**Max DC Input Voltage VDC** [V]	**MPP Voltage VDC** [V]
3.7	3x415V	5.0	9	850	500-700

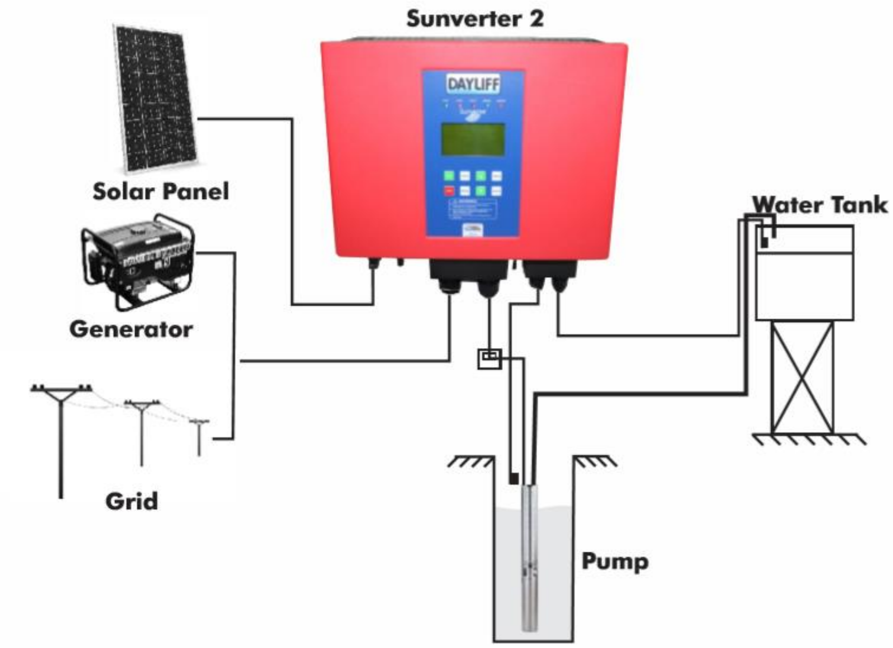

Figure 87: Solar controller.

source: Davis and Shirtliff

As it can be seen from Figure 87, pump operation is also controlled by a float switch in the elevated tank (see section 4.5.4.1). The controller activates or deactivates pump operation according to the level in the tank. In this controller there is also the possibility of providing a switch for low water dry run protection that activates or deactivates the pump according to the level in the borehole. In this case, it is not necessary because the pump depth (50 m) is much greater than the water depth in the borehole (about 26 m).

This controller type supports motor soft start. *Soft starters* are devices that allow a gradual start of electric motors, preventing a series of mechanical and electrical problems. A direct and immediate motor start – Direct Online Starter (DOL), the entire voltage immediately insists on the motor still stopped – implies high initial current absorption which can induce voltage drops. The starting current can be from 4 to 8 times the current absorbed during normal operation (for the pump motor in question, as it can be seen from the specifications in Figure 82, the starting current can be 500% more). Soft starters, in addition to being used to manage the motors starting, can also be useful in the shutdown phase to avoid too abrupt stops. This feature is useful in that it prevents damaging *water hammers*.

In addition, this controller model uses the innovative MPPT (Maximum Power Point Tracking) technology, which through internal algorithms allows to obtain the maximum energy produced at varying operating conditions (in particular at varying the irradiation and temperature of the panel).

4.6 System Summary and Sustainability

Boji BH1's solar pumping system design led to the installation of the following devices:

- Submersible borehole pump to take a flow rate of about 13.5 m^3/hr with a TDH of 55 m. The pump is fitted with a 3kW motor.
- 24 m^3 elevated tank on 10 m high galvanised steel tower (tank head is 12 m from the ground level).
- 19 solar panels of 270 W each connected in series (5.1 kW max output power).
- Solar Controller with pump control function, inverter, system protection, hybrid capacity, switching.

Figure 88: Solar pumping system of BH 1.

PV array is mounted on the ground steel support structure. Solar panels are located in an existing fenced area where there is also elevated tank and a room where the controller and the stand-by diesel generator are located. The borehole 1 is located about 40 m from the fenced area. This high distance is not convenient both for greater hydraulic friction losses in the pipe between the BH 1 and the elevated tank and for greater cable electrical dissipations between the pump and the controller. However, the existing situation implied this provision. It was in fact a priority to place the solar system inside the existing fence to avoid vandalism, theft and animals attack. There is still the old unused plastic tank.

4.6.1 Technical Sustainability

In addition to correct design, a further requirement for long-term sustainability of solar pumping systems is the guarantee of the application of damage prevention and malfunction techniques during the system lifecycle. This benefits the entire water supply system and also affects it.

Generally, a solar pumping system has a long service life, which is on average around 20 years. According to manufacturers' specifications, it can be considered that a high-quality panel has a life cycle of about 25 years, a submersible pump of about 10-15 years and the inverter / controller of about 10 years. To understand the effective extension of the solar pumping system life cycle, just think that a diesel generator has a life normally between 3 and 5 years in case of continuous operation. In hybrid systems, by greatly reducing its use, the life span is up to 20 years. In addition, solar water pumping systems are advantageous as they can operate without supervision and require very little maintenance compared to diesel equipment.

However, solar pumping system long life can only be guaranteed with adequate periodic maintenance and technical measures to reduce the risk of components breakage.

Although solar panels have a long life, they are easily damaged as they are fragile. For instance, in some villages visited there was damage to the PV panels due to children playing. To avoid this, most community projects have solar panels that are located at least 4 m above the ground and a fence around the system, which protects it from theft, vandalism, wildlife and livestock. It is important to periodically check the health of the panels, clean their surfaces, check the electrical connections.

For electronic devices such as the pump controller, unless there are electrical faults such as short circuits, damage caused by lightning, water infiltration, accumulation of dust etc., the system can operate for a long time without failure. It is therefore necessary to install these electrical components in places protected from atmospheric agents and tampering, such as technical rooms.

The components that can more easily break are motor and pump, as they work for a long time. Occasional maintenance of the submersible pump would involve annual removal of the pump from the borehole, cleaning of the pump, checking the motor condition, replacing the defective components on the controller, replacing worn pipes and checking the electrical components in general.

As mentioned, this approach impacts the entire water supply system of the village. It is necessary to repair any damaged and worn taps and valves, monitor the correct operation of the water points, check the integrity of the tanks and perform periodic cleaning and disinfection, monitor the health of the pipes by carrying out immediate repairs where there are leaks. It is preferable to have underground pipes to avoid damage (for example due to livestock). Where they are above ground, it is necessary to stabilize them with anchor blocks and/or gabions, the latter in particular if the pipes cross a seasonal river.

In order to ensure this, as it will be seen in the case of Boji, it is important that a water management committee is set up to take responsibility for maintenance and repair of the community's water supply system. It is important that the committee members and the craftsmen of the village have knowledge on how to access spare parts, on what routine maintenance operations to perform and how, and on the technicians to contact in case of need.

There is also a need for proper economic management of the water supply system. It is important to raise awareness about the water fees payment (minimum and in line with the economic level of the village) and to have a water committee that knows how to properly manage the revenues of fees, exploiting them to ensure the sustainability of the system.

To this end, it is important that NGOs involve the entire village in the sustainable use of the supply system created, otherwise in a few years it will no longer be functional.

4.6.2 Economic Assessment

In conclusion, it is interesting to assess the economic impact that the solar pumping system has on the Boji village. In fact, the implementation of these systems in rural areas, in addition to technological advantages, has great economic advantages. They are also essential to ensure the intervention sustainability.

In this regard, it is useful to understand how in the Boji village the installation of a solar system to power the BH 1 pump has generated long-term economic benefits compared to the possibility of using the existing 18.5 kVA genset. However, it is necessary to keep in mind that the system is hybrid in the assessment.

The two analysis scenarios are:

- **Hybrid System** (solar + diesel generator stand-by).
- **Diesel Generator System.**

The initial investment cost for the two scenarios should be considered first. For hybrid system, it corresponds to the cost of building the system including the cost of components, transport and installation. For the diesel generator scenario, which already existed in the village, the only considered cost are the pumping components that have been renewed. However, the rehabilitation of the Boji village is an international cooperation project and the funds allocated are not borne by the village, so the initial investment cost for both scenarios is zero. It is necessary to consider the operating costs that will be fully covered by villagers through the water fees revenues.

We consider as analysis period 25 years, which is the longest lifespan among the various components (*solar panels*). For diesel generator, typically the life span considered is approximately 35,000 hours. Therefore, in a 25-year cost-comparison analysis it is also necessary to consider the repair/replacement costs of the diesel generator. In particular, for a good quality engine the following general references for maintenance and replacement of gensets for Isiolo County can be considered (prices are estimates suggested by sector experts):

Table 28: General references for maintenance and replacement of gensets for Isiolo County.

Maintenance and Replacement	Frequency of change [h]	Price [KSh]	Price [€]
Minor Service	250	2,000	16
Major Service	1,000	20,000	160
Overhaul	10,000	30% of new	30% of new
Replacement Cost of new same gensets (18.5 kVA)	35,000	900,000	7,100

Similarly for the inverter/controller of the hybrid system, a replacement is considered every 10 years, considering that the cost of the controller model used for the BH 1 is about KSh 110,000 (about € 900).

For solar system, one maintenance per year is taken into account, including panels cleaning. The average cost of the intervention is around KSh 10,000 (about € 80).

With regard to the diesel generator operating hours, for the stand-alone system an average of 9 hours per day – 3,285 hr/year – is calculated, and for the hybrid system a genset operation of 540 hr/year, which is equivalent to 60 days of 9 hours per day of operation during the year, in days when solar does not generate enough energy for pumping or has faults.

For both scenarios, pump replacement should be considered. A life span of 15 years and an average cost of KSh 250,000 (approximately € 2000) are taken into account.

A fuel cost for diesel generator of 110 KSh/litres (approximately 0.90 €/litres) is considered, obtained as an average over 5 years of the fuel price in Kenya (*source Trading Economics*). Generator fuel consumption is estimated at 4 litres/hour.

Comparative analysis results of the two scenarios are shown in Figure 89 and in **Appendix E**.

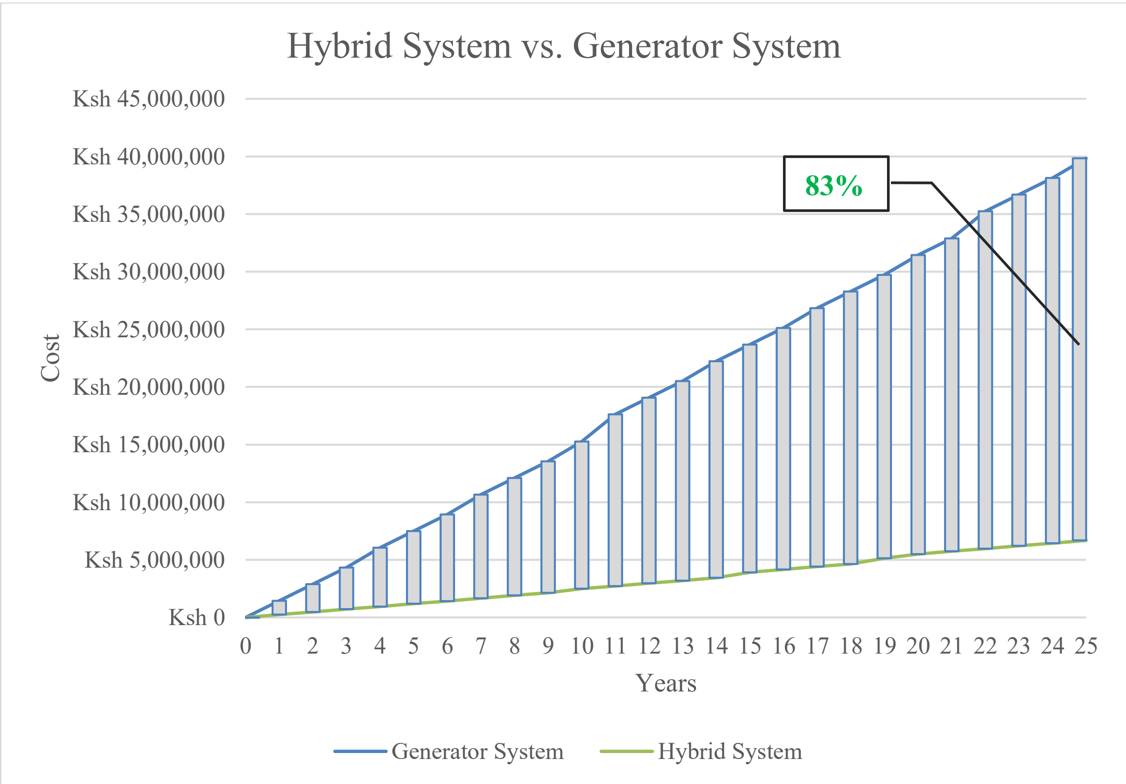

Figure 89: Comparative analysis results of the two scenarios: Hybrid System vs. Generator System.

From the graph in Figure 89, it is possible to note the great economic advantage over time that there is in using a hybrid system instead of a diesel generator in the Boji village. Comparing operating costs to the 25th year of analysis, an economic saving of 83% is observed. This value is in line with the literature data which record savings for the use of solar energy ranging between 40% and 90% in 25 years compared to the diesel generator use [39].

It is possible to understand the advantage of solar pumping system use for Boji village, which over the years will have to face reduced management costs and this will result in a lower water supply system taxation and therefore easier to sustain from this low-income population. The probability of success of the intervention will therefore be greater in the long term.

Thinking from the donors' side, if the economic assessment was based only on life cycle costs, high cost reduction that solar photovoltaic technology offers in many cases compared to the use of other pumping systems would in any case favour its use. The choice would be different if only the capital costs of the installations were analysed. Solar pumping system investment cost is much higher than diesel generation system. However, these non-profit interventions imply mainly a long-term vision that aims at the sustainability of the projects.

Chapter 5

Activities Results

5.1 Results of Water Sources Rehabilitation.

The rehabilitation activities of the Boji water supply system were completed within the 18 months project lifetime. The project achieved 100% of the targets set at the baseline which were measured through key indicators. This implies that the project achieved the overall objective of strengthening drought resilience of the agro-pastoral communities of Isiolo County. The rehabilitation of the village's water sources has made it possible to improve the availability of safe water, while the construction of pipelines and four water kiosks has improved the accessibility to safe water at household level.

The project was implemented through a participatory approach with active community engagement throughout the period. The community members were involved in the project design and clearly described the kind of interventions to be carried out to address persistent water challenges in the village.

The activities carried out in the Boji village brought the following results.

- ***Rehabilitation of BH 1***

First, a test pump was carried out on the borehole with which a safe yield of 18 m^3/hr was recorded. The borehole was equipped with a submersible water pump with a capacity of 13.5 m^3/hr and an electrical motor 3 kW. A total of 19 solar panels of 270 W were installed to power the pump. The system was integrated with the existing 18 kVA genset to complement the solar system during low sunshine hours or breakdowns. The borehole was connected to the 24 m^3 steel elevated tank from where it serves by gravity two of the new water kiosks each equipped with 5,000 litres plastic water tank, the school and also provides water for livestock through the constructed four cattle troughs.

Figure 90: Rehabilitation of BH 1, before (left) and after (right).

A total of four troughs were constructed, two for cattle/camels and two for shoats. The troughs were constructed to separate human water and livestock water, unlike the situation before where animals were sharing water points with humans. Now human water supply takes place only at water kiosks. Water kiosks were constructed at strategic locations to provide access to water near the households.

Figure 91: New water kiosk (left), new livestock troughs (right).

Rehabilitation of BH 2

The pumping tests carried out on this borehole recorded a safe yield of 12 m^3/hr. A 7m^3/hr submersible pump with a 2.2 kW motor was installed, together with 14 solar panels 195 kW. Note that the BH 2 was already equipped with a solar pumping system and therefore it was necessary to update the system only by adding new panels. The borehole was connected to two constructed water kiosks each equipped with 5,000 litres plastic water tank and the dispensary.

Figure 92: Upgrade of BH 2 solar pumping system.

Rehabilitation of Spring Wells

Two springs were rehabilitated through renovation and cleaning of the sump tanks. The sumps were protected to prevent contamination from surface water. The springs are mainly used for watering small stock livestock that grazes near the homesteads.

5.2 Exit Strategy and Sustainability

In addition to the rehabilitation of the village's water sources and the construction of new infrastructures, it was necessary to guarantee the long-term sustainability of the water supply system through an exit strategy. In fact, in rural contexts of this type it is important to develop an adequate management system in the community that allows over time to operate all that has been achieved by the project implementation. Underlying all this is the NGO's ability to create a sense of ownership and acceptance of the project in the community, through the involvement and training of the villagers and in particular their representatives.

Very important for the sustainable management of Boji water supply system was to set up a *water management committee*. The water management committee was trained by LVIA on governance, group dynamics, financial management, operations and maintenance. The committee consists of 12 members from the community. The members were chosen from among the inhabitants and suggested by the village representatives based on their skills. The task of the water management committee is the proper management and operation of the entire village water supply system. They are responsible for the maintenance and repair of the water infrastructure. In this regard, the members were trained to carry out small repairs and maintenance also with the help of village craftsmen and have the task of contacting the competent technicians in case of need. They have the task of ensuring the water supply from the water kiosks at scheduled times, their cleaning and the collection of water fees. Committee members will contact the Isiolo County Water Offices if there are any important issues to be resolved. They are required to take an interest in any conflicts between the population regarding water resources. LVIA technicians will periodically visits the village to monitor the correct management by the committee.

As said several times during the discussion, it was necessary to collect water fees with the aim of creating an economic fund for the system management. Water users pay for the water through a newly established tariff system where a 20 litres Jerrican is charged at KSh 2. Based on the water demand defined in section 4.5.1, each household on average collects 6 Jerricans per day. Water use for livestock is also charged as follows: Cattle KSh 10 per head, shoats KSh 2 per head, Camels KSh 10 per head. The revenues are collected by the treasurer and put in a bank account. The operational expenses mainly include repairs costs and staff wages. The installation of the solar system was a major reprieve as fuel costs were drastically reduced, since water pumping system is fully solarized except for the days when the stand-by diesel generator is required to operate.

Table 29:Average water charges - household use.

	Daily		Monthly		Yearly	
	Per HH	*Total village (300 HHs)*	*Per HH*	*Total village (300 HHs)*	*Per HH*	*Total village (300 HHs)*
Average water charges - household use (6 Jerrycans per day per HH)	KSh 12	KSh 3,600	KSh 360	KSh 108,000	KSh 4,320	KSh 1,296,000

Table 30: Average water charges - livestock use.

		Monthly	Total Monthly	Yearly	Total Yearly
Average water charges – livestock use	*2,600 Cattle*	KSh 26,000	KSh 101,000	KSh 312,000	KSh 1,212,000
	15,000 Shoats	KSh 30,000		KSh 360,000	
	4,500 Camels	KSh 45,000		KSh 540,000	

It was important to eliminate the assumption that drinking water is free. This way of thinking absolutely does not guarantee the sustainability of the project. All the infrastructures built, and the equipment installed to ensure drinking water for all had no initial costs for the village. However, it is important to make it clear that they need maintenance, repair and management over time to allow operation. All this implies management costs that must be constantly sustained by the village itself. Once the project has been successfully completed in all its aspects, it is up to the inhabitants to make the system work. Obviously, in order for the payment to be accepted by the population and therefore the taxes collected correctly, it is necessary that they are adapted to the village economic level in order to be sustained without efforts. This will allow for a complete fees collection and a population that supplies itself entirely from safe water sources.

5.3 Achievements

As seen in section 3.2.3, outcome indicators were defined through the information collected with the preliminary surveys. The baseline values gave important information about the challenges to be faced and the goals to be achieved with the aim of improving access to water in the Boji village.

At the end of the project, final monitoring and evaluation were carried out in order to understand the results and improvements achieved. The final evaluation took place a few months after the conclusion of the project through a visit by the LVIA technicians to the village. During this visit, the operations of the works and the impact they had on Boji water supply were observed. Surveys have also been carried out among the population with the aim of understanding their perception of the functionality and management of the water supply system and the improvement of living conditions that involved the intervention as well as possible problems encountered. On the basis of this it was possible to define the outcome indicators values at the end of the project and compare them with the values at the beginning of the project to understand the results obtained.

The project was able to realize its objectives with a positive impact on the community. This is demonstrated by a comparison between the initial baseline survey key indicators at the start of the project and after the project completion (see Table 31).

Access to safe water for the community improved by 76% through the two rehabilitated borehole water sources. The average distance covered per household to collect water was reduced to between 0-100m. This was achieved through the construction of four water kiosks, strategically located to serve about 300 households. In addition, the average time taken to the primary water source reduced to less than 30 minutes, while queuing is now taking less than 5 minutes. The community management was strengthened to improve the management of the water scheme and ensure its sustainability. This was achieved through trainings and engagements during the implementation period. Under this result area a total of 2,175 (1,110 males, 1,065 female) people benefited from the rehabilitated water sources, out of which 236 (127 boys, 109 girls) are school children.

Table 31: Baseline outcome indicators after project completion

Indicator	Baseline	End of Project	Remarks
% of community using safe water sources	24%	100%	Safe water sources were improved through rehabilitation of 2 boreholes.
Average distance covered to primary water source	0-1km	0-100m	The distance was reduced through construction of water kiosks.
Average time taken to primary water source	0-60 minutes	< 30 minutes	The distance was reduced through construction of water kiosks at convenient distances.
Average queuing time at primary water source	10-20 minutes	< 5minutes	The time was reduced through construction of water kiosks at strategic locations with the village.
% water reliability	62%	100%	High capacity water pumps and solarization of the pumping systems were installed.
Waiting time for livestock	>60mins	0mins	All livestock categories are able to water from the new constructed water troughs.
# of water management committees	0	1	Training of management committee.

Chapter 6

Conclusions

Participation in the activities carried out by LVIA technicians during the internship in Isiolo County in Kenya allowed me to relate to a different approach to the water infrastructure construction compared to the one commonly adopted in high-income countries. Although technical notions and technologies are roughly the same in all circumstances, their implementation is strongly affected by the social context. The objectives underlying the implementation are different and therefore different challenges need to be addressed for the success of the projects. It is possible to conclude that direct experience in the country is necessary to understand them better.

The main issues identified during the collaboration in the activities concern water infrastructure management. Technical problems can be easily solved by a technical team. In addition, in most villages where the projects studied were implemented, water is sufficient to ensure compliance with LVIA objectives and international standards. On the other hand, ensuring a correct management proved to be difficult. Local village water management committees do not usually have adequate skills in water infrastructure management. Furthermore, there is a widespread misunderstanding that in case of problems they can ask for funds and support from NGOs or the County Government. This management approach greatly reduces the reliability of the water supply. According to the above, the main improvements to be achieved and key future challenges relate to water management.

Regarding the construction/rehabilitation of water supply systems in rural areas of Kenya, it is essential to focus on the following aspects:

- **Technical**
    - *Water sources.* Water supply from boreholes should be preferred to other water sources due to their reliability and low level of contamination.
    - *Energy with integrated systems.* The use of renewable energy as a source of energy for pumping is convenient both from a technological and an economic

and management point of view. In this discussion it has been shown how the use of a solar pumping system is preferable. It has also been illustrated that solar panels are not enough, and therefore it is important to consider backup systems (e.g. diesel generator set).

- *Distribution.* The installation of water kiosks in strategic places is preferable, more manageable compared with direct connection to the households.
- *Storage.* It is important to include in each project a storage component that can guarantee the availability of water even in case of power failure or interruptions of pumping systems.

- **Managing**
  - *Water fees.* The beneficiary community needs to be aware that it is important to pay a water fee in order to ensure the sustainability of the water supply system. Obviously, fee must be affordable for the community.
  - *Water management committee* should be established in the village and trained with technical and business skills for managing the water system. It is important that members are salaried with income from water fee collection and not from an NGO (welfare) or County Government (unreliable). This increases the possibility of proper tax collection. Each water committee should develop a business plan in order to anticipate future investments, equipment replacement, maintenance, etc. In addition, water committees should report revenue, costs and activities to communities for transparency and trust building.

Unlike other contexts, technological choices are as important as social aspects; both aspects are critical and interrelated. The implementation in these contexts of improved water schemes from a technological point of view may not allow successful management by local committees. At the same time, a traditional water scheme may not be efficient or may be useless, especially considering logistical issues or climate change. It is important to consider social and technical issues together. As it has been seen, installing a solar pumping system in a rural area of Isiolo County can be the best technical solution both for the availability of solar energy and for fuel supply difficulties for the diesel generator use. On the other hand, the population is convinced that a solar pumping system has no running costs and therefore can refuse to pay water fees, affecting the long-term sustainability of the water program. When choosing to use this type of technology, one must also consider implementing activities to explain their operational costs in detail.

Therefore, an assessment of the life-cycle cost of water supply system equipment is also essential. If the best water scheme is constructed using equipment that has a high cost of replacement or maintenance, it will not be affordable for management committees and in the medium to long term the water scheme will not be working. Furthermore, a water scheme with a long-life cycle can allow the water management committee to raise sufficient funds for maintenance and repairs and to test the sustainability of the business model they have chosen.

References

[1] WHO and UNICEF, “Progress on Drinking Water, Sanitation and Hygiene 2017,” 2017. [Online]. Available: https://washdata.org/sites/default/files/documents/reports/2018-01/JMP-2017-report-final-highlights.pdf.

[2] United Nations, “World Urbanisation Prospects 2014.” [Online]. Available: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf.

[3] R. Eberhard, “Access to Water and Sanitation in Sub-Saharan Africa.,” 2019. [Online]. Available: http://www.oecd.org/water/GIZ_2018_Access_Study_Part I_Synthesis_Report.pdf.

[4] O. para a C. e D. E. OCDE, “Financing water: Investing in sustainable growth,” 2018.

[5] United Nations, “The Sustainable Development Agenda,” *17 Goals to Transform Our World*, 2019. .

[6] M. R. Goyal and R. K. Sivanap, *Engineering practices for agricultural production and water conservation: An interdisciplinary approach*. 2017.

[7] M. Mwangi, B. Gichangi, B. Kinuthia, J. Samo-Project Manager, and I. Githu-Project Director, “Evaluation of the Sustainability of Solar Powered Water Supply Systems in Kenya Acknowledgement,” 2018. [Online]. Available: www.solarzzy.comwww.eedadvisory.com.

[8] WHO and UNICEF, “Progress on Drinking Water, Sanitation and Hygiene - Joint Monitoring Programme 2017 Update and SDG Baselines,” 2017. doi: 10.1111 / tmi.12329.

[9] USAID, “USAID water and development country plan for Haiti,” 2016. [Online]. Available: https://dec.usaid.gov/dec/content/Detail.aspx?vID=47&ctID=ODVhZjk4NWQtM2YyMi00YjRmLTkxNjktZTcxMjM2NDBmY2Uy&rID=MjM1MTM5.

[10] IFDC, “Kenya Country Plan,” 2012.

[11] NWMP, “The Project on the Development of the National Water Master Plan (NWMP) 2030,” 2012.

[12] R. Connor, *The United Nations World Water Development Report 2015: Water for a Sustainable World*, vol. 4, no. 2. 2016.

[13] Republic of Kenya, “Regional Pastoral Livelihoods Resilience (Kenya).” http://www.resilience.go.ke/isiolo/.

[14] I. C. Government, “County Government of Isiolo,” 2020. https://isiolo.go.ke/.

[15] United Nations Statistics Division, “Demographic Yearbook—Table 3: Population by sex, rate of population increase, surface area and density,” pp. 1–13, [Online]. Available: https://unstats.un.org/unsd/demographic/products/dyb/dyb2005.htm.

[16] R. of Kenya and I. C. Government, “Isiolo County Integrated Development Plan, CIDP, 2018-2022,” 2018.

[17] “Kenya: Administrative Division (Provinces and Counties) - Population Statistics, Charts and Map.” https://www.citypopulation.de/en/kenya/admin/.

[18] LVIA, “WASH NEEDS ASSESSMENT FINAL REPORT - ‘Improve access to clean water, sanitation facilities and quality primary healthcare in Isiolo County, Sub-Counties

of Merti, Isiolo and Garbatulla (M.A.P.S.),'" 2014.
[19] Kenya Meteorological Department, "Isiolo County Climate Information Services Plan," 2018. doi: 10.1016/b978-008044109-2/50026-4.
[20] B. Mati, J. Muchiri, K. Njenga, F. P. de Vries, and D. J. Merrey, "Assessing water availability under pastoral livestock systems in drought-prone Isiolo District, Kenya," in *Water Management*, 2006, p. 13.
[21] National Drought Management Authority, "Isiolo County Drought Early Warning Bulletin for March 2020," 2020.
[22] K. Ministry of Environment and Mineral Resources, "Kenya Wetlands Atlas," 2012.
[23] P. B. Mati, "Water pans and ponds," 2007.
[24] J. Drew, "How Are Excellent Development's Sand Dams Saving Lives In Rural Africa?," 2018. .
[25] *The Sphere Handbook*. 2018.
[26] N. among other partners Ministry of Health, Agriculture, Water, Livestock, "Isiolo County SMART Survey Report," 2019.
[27] K. F. S. S. G. (KFSSG) and I. C. S. G. (CSG), "Isiolo County 2019 Short Rains Food and Nutrition Security Assessment Report," 2020.
[28] C. King-Okumu, O. V. Wasonga, I. Jarso, and Y. M. S. Salah, "Direct use values of climate-dependent ecosystem services in Isiolo County, Kenya," 2016. [Online]. Available: http://pubs.iied.org/10142IIED.
[29] National Drought Management Authority, "Isiolo County Drought Early Warning Bulletin for July 2019," 2019.
[30] T. Finance, "Water Supply and Sanitation in Kenya," no. November 2012. pp. 1–12, 2015.
[31] N. Elvis, B. Orlendo, and E. B. Orlendo, "Behind the tap : An Analysis of Kenya ' s Water Act 2016," 2017.
[32] World Bank Group, "Understanding the Kenya 2016 Water Act," 2016.
[33] Government Printer, *Water Act, 2016*, vol. 3, no. 1. 2016, p. 75.
[34] E. Gachenga, "Chapter 20: Kenya's Water Act (2016): real devolution or simply the 'same script, different cast,'" in *Law | Environment | Africa*, 2019, pp. 429–452.
[35] Republic of Kenya, "Ministry of Water and Sanitation Strategic Plan 2018-2022," 2018. [Online]. Available: https://africacheck.org/wp-content/uploads/2019/04/Ministry-of-Water-Kenya-Strategic-Plan-2018-2022-Final-Version-Dec2018.pdf.
[36] Kenya Meteorological Department, "KMD OND 2019 Seasonal Forecast Report," 2019.
[37] National Drought Management Authority, "Isiolo Flood Risk Assessment Report Dec 2019," 2019.
[38] Kenya Red Cross Society, "Sitrep Report Nov 2019," 2019.
[39] Global Solar and Water Initiative, "Solar Water Pumping Miniguide," 2018. [Online]. Available: http://www.rural-water-supply.net/fr/ressources/details/810.
[40] R. Van Pelt and R. Waskom, "Solar-Powered Groundwater Pumping Systems," 2008.
[41] HiSoUR, "Pompa ad energia solare." https://www.hisour.com/it/solar-powered-pump-39785/#.
[42] TNE, *Guide Blu*, no. 15. 2008.
[43] ENEA, *Tetti fotovoltaici*. .
[44] USDA and NRCS, "Design of small photovoltaic (PV) solar-powered water pump systems," 2010.
[45] O. Coddington, J. L. Lean, P. Pilewskie, M. Snow, and D. Lindholm, "A solar irradiance climate data record," 2016. doi: 10.1175/BAMS-D-14-00265.1.
[46] M. Z. Jacobson and V. Jadhav, "World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels," 2018. doi: 10.1016/j.solener.2018.04.030.
[47] Duilio Citrini and G. Noseda, *Idraulica*. Milano, 1987.

Appendix A

Guidelines for Questions and Household Questionnaire

“Rehabilitation of Boji Village Water Supply System”

INTRODUCTION

I am assisting LVIA to collect information on “Rehabilitation of Boji Village Water Supply System”. All the information you provide will be kept confidential and will not be linked to you without your approval. If you feel uncomfortable you are free to stop the discussion at any time. I will take notes during the discussion for purposes of documentation and the session may take about 30 minutes or less. I am also ready to answer any questions that you may have. With your permission, I hope I can now start the discussion.

SECTION 100: GENERAL INFORMATION

101: Date of interview
…………………………………………………………………………………….

102: Name of interviewee………………………………………………………………………………
Contact…………………………………………………

103: Interview duration………………………Start: ………………………End: ....
Duration: …………………………………..……

104: Study Area/Sub county: (Circle appropriate one)
1. Isiolo **2.** Merti **3.** Garbatulla

SECTION 200: DEMOGRAPHIC INFORMATION

201: Sex of respondent (Circle where appropriate)
1. Male **2.** Female

202. Livelihood:
1. Pastoralist **2.** Agro-pastoralist

202a: Category:
1. Urban **2.** Rural

203: Age of respondent (Circle where appropriate)

1. 15 -19 years
2. 20-24 years
3. 25-29 years
4. 30-34 years
5. 35-39 years
6. 40-44 years
7. 45 years and above

203b: Marital status (Circle where appropriate)

8. Single (Never married)
9. Widow
10. Widower
11. Divorced
12. Married with children
13. Married with no children

204: What is the highest level of education that you have attained? (Circle where applicable)

1. Primary
2. Secondary
3. College
4. University
5. None (Never went to school)

205: Size of household: How many children do you have? (Circle all responses that apply)

S/N	Own children	Circle here
205	0-1	**1**
205	2-4	**2**
205	5-7	**3**
205	Above 7	**4**

206. Family status: How many dependants do you have? (Circle all responses that apply)

S/N	Dependant(s)	Circle here
206a	0-1	**1**
206b	2-4	**2**
206c	5-7	**3**
206d	Above 7	**4**

207. Housing/shelter: What kind of housing/shelter do you live in with your family? (One answer only)

S/N	Housing/Shelter	Circle here
207a	Traditional houses	**1**
207b	Grass roof/mud walled	**2**
207c	Iron roof/mud walled	**3**
207d	Permanent/public house	**4**
207e	Iron roof/iron walled	**5**
207f	Other (specify)	**6**

SECTION 300: SOCIAL ECONOMIC INDICATORS

301. Employment status (Circle responses that apply)

S/N	Type of employment	Circle here
301a	Employed in informal sector	**1**
301b	Informal sector and self-employed	**2**
301c	Employed in formal sector	**3**
301d	Unemployed	**5**

302. Sector of employment/engagement (Circle responses that apply)

S/N	Sector	Circle here
302a	Commercial/Trade	**1**
302b	Livestock	**2**
302c	Agriculture	**3**
302d	Environment	**4**
302e	Other	**5**
302f	Not applicable	**7**

303. What is your main source of livelihood/income? (Circle responses that apply)

S/N	Source of livelihood/income	Circle here
303a	Farming	**1**
303b	Petty trade	**2**
303c	Charcoal burning	**3**
303d	Livestock	**4**
303e	Other (specify)	**7**

304. What is your monthly income? (One answer only)

S/N	Income	Circle here
304a	1000 – 5000 ksh	**1**
304b	5000 – 10000 ksh	**2**
304c	10000 – 20000 ksh	**3**
304d	Above 20000 ksh	**4**

305. What are your monthly expenses? (One answer only)

S/N	Expenses	Circle here
305a	1000 – 5000 ksh	1
305b	5000 – 10000 ksh	2
305c	10000 – 20000 ksh	3
305d	Above 20000 ksh	4

306. In which areas are you most vulnerable? (Circle responses that apply)

S/N	Constraints	Circle here
306a	Health	**1**
306b	Food insecurity	**2**
306c	Education	**3**
306d	Employment	**4**
306e	Security	**5**
306f	Other (specify)	**6**

SECTION 400: WASH (WATER)

401. What are the main sources of water? (Circle responses that apply)

S/N	Water sources	Circle here
401a	Piped water	**1**
401b	Shallow well/spring	**2**
401c	Borehole	**3**
401d	Dam (earth dam/sand dam)	**4**
401h	Rainwater harvesting	**5**

401i. Is water available at all times?

1. Yes

2. No

Explain:
………………………

402. What do you use water for? (Circle responses that apply)

S/N	Water uses	Circle here
402a	Domestic	1
402b	Livestock	2
402c	Farming	3
402d	Other	4

403. What is the distance covered to the nearest water point?

S/N	Distance	Circle here
403a	0-1 km	1
403b	1-2 km	2
403c	2-3 km	3
403d	3-4 km	4
403e	4-5 km	5
403f	Over 5 km	6

404. How do you transport water from water points?

S/N	Transportation of water	Circle here
404a	Jerry cans	1
404b	Donkey carts	2
404c	Other specify	3

405. How long does it take to collect water (including travel to and from, waiting)?

S/N	Time taken to collect water	Circle here
405a	Less than 30 minutes	1
405b	1 hour	2
405c	2 hours	3
405d	3 hours	4
405e	4 hours	5
405f	More than 4 hours	6

406. How much water do you consume per day?

S/N	Water consumption	Circle here
406a	0-5 litres	**1**
406b	5-10 litres	**2**
406c	10-20 litres	**3**
406d	20-30 litres	**4**
406e	Over 30 litres	**5**

407. How do you store water in the house?

S/N	Water consumption	Circle here
407a	Jerry can	**1**
407b	Container without lid	**2**
407c	Container with lid	**3**
407d	Other (specify)	**4**

408. Is the water treated?

1. Yes
2. No

409. Do you boil water for drinking?

1. Yes
2. No

SECTION 500: HYGIENE AND SANITATION

501. What type of toilet do you use? (Multiple answers apply)

S/N	Type of toilets	Circle here
501a	Uncovered pit	**1**
501b	Covered pit	**2**
501c	VIP latrine	**3**
501d	Open air (bush)	**4**
501e	Other (specify)	**5**

502. Do you wash hands before and after eating/visiting toilet?

3. Yes
4. No

Give reason:
…………………………………………………
…………………………

503. How do you wash your hands?

S/N	Hand washing	Circle here
503a	Using soap	**1**
503b	Using ash	**2**
503c	Other (specify)	**3**

504. How do you dispose of garbage?

S/N	Garbage disposal	Circle here
504a	Garbage pit/Burning	**1**
504b	Throw in the garden	**2**
504c	Other (specify)	**3**

505. Which common water borne diseases exist in the village?

S/N	Water borne diseases	Circle here
505a		**1**
505b		**2**
505c		**3**

508. What other challenges do you face in the household?
…………………………………………………………………………………………….

508a. How have you managed the challenges?
…………………………………………………………………………………………….

509. Is there anything you would want to tell me in relation to what I have been asking you on WASH?
………………………………………………………………………………………………
…………………………

THANK YOU.

Appendix B

Boji Water Sources Test Pumping Reports

Test Pumping Results

Boji Borehole 1-Main (Drilled by National Water-used for Livestock)

Location

Boji Village
Garbatula Sub-County
Garbatula Ward
GPS Coordinate: N38.338451, E0.5144773, 615m
Date of test pumping: 16-04-2019

SUMMARY

Client Name	L.V.I.A
Test Conducted by	Jatim Engineering & Hardware
Method of Discharge Measurement	Stop Watch and 20liter Container
Pump used	SP8A25
Water Rest Level (WRL)	26.3m
Safe Yield	$18m^3$/hr.
Method of Monitoring Drawdown	Electric Dipper
Measured Depth of Source	56m
Depth of Pump Intake	50m
Size and Type of Drawdown Pipes	2"dia GI Pipes reduced at outlet to 1 ¼"
Pump Currently Operational	SP3A25
Current Motor size	1.5kW

DRAWDOWN MEASUREMENTS

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
00	**8.00**	**26.30**	**13**	
01	**8.01**	**26.30**		
02	**8.02**	**26.35**		
03	**8.03**	**26.40**		
04	**8.04**	**26.43**		
05	**8.05**	**26.43**	**13**	
06	**8.06**	**26.43**		
07	**8.07**	**26.43**		
08	**8.08**	**26.44**		
09	**8.09**	**26.44**		
10	**8.10**	**26.45**	**13**	

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
12	**8.12**	**26.45**		
14	**8.14**	**26.45**		
16	**8.16**	**26.45**		
18	**8.18**	**26.46**		
20	**8.20**	**26.46**		
25	**8.25**	**26.46**		
30	**8.30**	**26.45**		
35	**8.35**	**26.45**		
40	**8.40**	**26.45**		
45	**8.45**	**26.46**		
50	**8.50**	**26.46**		
55	**8.55**	**26.45**		
60	**9.00**	**26.45**		
70	**9.10**	**26.45**		
80	**9.20**	**26.45**		
90	**9.30**	**26.45**		
100	**9.40**	**26.46**		
110	**9.50**	**26.47**		
120(2 HRS)	**10.00**	**26.46**		
150	**10.30**	**26.45**		
180	**11.00**	**26.44**		
210	**11.30**	**26.51**		
240	**12.00**	**26.50**		
270	**12.30**	**26.50**		
300(5 HRS)	**13.00**	**26.50**		
360(6 HRS)	**14.00**	**26.50**		
420(7 HRS)	**15.00**	**26.54**		
480(8 HRS)	**16.00**	**26.54**		
540	**17.00**	**26.70**		
600	**18.00**	**26.54**		
660	**29.00**	**26.55**	**13**	
720	**20.00**	**26.57**		
780	**21.00**	**26.56**		
840	**22.00**	**26.56**		
900	**23.00**	**26.56**		
960	**00.00**	**26.55**		
1020	**1.00**	**26.55**		
1080	**2.00**	**26.55**		
1140	**3.00**	**26.55**		
1200	**4.00**	**26.55**		
1320	**6.00**	**26.55**		
1440	**8.00**	**26.55**	**13**	

RECOVERY MEASUREMENTS

TIME SINCE PUMPING STOPPED	CLOCK TIME Hrs.	DEPTH TO WATER LEVELS(M)	REMARKS
00	**8.00**	**26.55**	
02	**8.02**	**26.55**	
04	**8.04**	**26.55**	
06	**8.06**	**26.54**	
08	**8.08**	**26.54**	
10	**8.10**	**26.52**	
15	**8.15**	**26.52**	
20	**8.20**	**26.51**	
25	**8.25**	**26.51**	
30	**8.30**	**26.50**	
40	**8.40**	**26.46**	
50	**8.50**	**26.42**	
60	**9.00**	**26.38**	

OBSERVATIONS

- The borehole is installed with $4m^3$/hr. submersible pump;
- The drawdown pipes are 2" dia GI reduced to 1 ¼" at the outlet;
- Pump is driven by a generator 18.5kva and a stand-by one 15kva which is defective;
- Water is used for livestock watering only, pumped to a 5m elevated $10m^3$ plastic tank;
- Safe yield of the borehole is $18m^3$/hr.

CONCLUSION

- The current pump should be changed to a more economical one with a safe yield of $18m^3$/hour against a head of 50m.
- The defective genset to be repaired to act as stand by generator.
- Recommended pumping depth 50m.
- Recommended Pump (SP14-13) or equivalent;

Boji Borehole 2 (Current with Solar)

Location

GPS: N38.338815, E0.5676278, 614m
16-04-2019

SUMMARY

Client Name	L.V.I.A
Test Conducted by	Jatim Engineering & Hardware
Method of Discharge Measurement	Stop Watch and 20liter Container
Pump used	SP3A-25
Water Rest Level (WRL)	23.6m
Safe Yield	12m^3/hr.
Method of Monitoring Drawdown	Electric Dipper
Measured Depth of BH	46m
Depth of Pump Intake	42m
Size and Type of Drawdown Pipes	40mm HDPE
Pump Currently Operational	SQ2-85
Current size of motor	SQ using DC

DRAWDOWN MEASUREMENTS

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
00	**5.30**	**23.60**	**12.6sec 5.7m^3/hr**	
01	**5.31**	**23.60**		
02	**5.32**	**23.72**		
03	**5.33**			**Dipper stuck**
04	**5.34**			**
05	**5.35**			**
06	**5.36**	**24.25**		
07	**5.37**	**24.25**		
08	**5.38**	**24.25**		
09	**5.39**			
10	**5.40**	**24.33**		
12	**5.42**	**24.33**		
14	**5.44**	**24.33**		
16	**5.46**	**24.34**		
18	**5.48**	**24.34**		
20	**5.50**	**24.35**		
25	**5.55**	**24.41**		

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
30	**6.00**	**24.41**		
35	**6.05**	**24.43**		
40	**6.10**	**24.44**		
45	**6.15**	**24.46**		
50	**6.20**	**24.46**	**12.6m**	
55	**6.25**	**24.46**		
60	**6.30**	**24.46**		
70	**6.40**	**24.46**		
80	**6.50**	**24.47**		
90	**7.00**	**24.52**		
100	**7.10**	**24.53**		
110	**7.20**	**24.54**		
120(2 HRS)	**7.30**	**24.55**		
150	**8.00**	**24.58**		
180	**8.30**	**24.60**		
210	**9.00**	**24.60**		
240	**9.30**	**24.65**		
270	**10.00**	**24.65**	**12.6**	
300 (5 HRS)	**10.30**	**24.67**		
360(6 HRS)	**11.30**	**24.70**		
420(7 HRS)	**12.30**	**24.70**		
480(8 HRS)	**13.30**	**24.72**		
540	**14.30**	**24.76**		
600	**15.30**	**24.79**		
660	**16.30**	**24.81**		
720	**17.30**	**24.83**		
780	**18.30**	**24.85**		
840	**19.30**	**24.85**		
900	**20.30**	**24.85**		
960	**21.30**	**24.85**		
1020	**22.30**	**24.85**		
1080	**23.30**	**24.85**		
1140	**00.30**	**24.85**		
1200	**1.30**	**24.87**		
1320	**3.30**	**24.88**		
1440	**5.30**	**24.88**		

RECOVERY MEASUREMENTS

TIME SINCE PUMPING STOPPED	CLOCK TIME Hrs	DEPTH TO WATER LEVELS(M)	REMARKS
00	**17.30**	**24.88**	
02	**17.32**	**24.50**	
04	**17.34**	**24.40**	
06	**17.36**	**24.20**	
08	**17.38**	**23.90**	
10	**17.40**	**23.80**	
15	**17.45**	**23.75**	
20	**17.50**	**23.70**	
25	**17.55**	**23.70**	
30	**18.00**	**23.65**	
40	**18.10**	**23.60**	
50	**18.20**	**23.60**	
60	**18.30**	**23.60**	

OBSERVATIONS:

- This borehole was drilled to replace the old one (BH3) of 9m next to it
- Safe yield is $12m^3$/hr.
- There exist no storage tank and water pours into a nearby trough;
- The existing pump is driven by solar pump $2.5m^3$/hr.;
- The existing solar panels are 6 with a wattage of 100w per panel;

CONCLUSION;

- The borehole pump should be changed to a bigger pump of $7m^3$/hour against a head of 30m with equivalent solar panels and other accessories.
- Recommended pumping depth 42m
- Recommended pump SP5A-12
- Need for a new motor in case of change of the existing pump;
- Additional solar panels required to about 1.1kW;
- Existing gensets can be repaired and used;

Boji Borehole 3 (Old)

Location

GPS: N38.338815, E0.5676278, 614m
16-04-2019

SUMMARY

Client Name	L.V.I.A
Test Conducted by	Jatim Engineering & Hardware
Method of Discharge Measurement	Stop Watch and 20liter Container
Pump used	SP3A25
Water Rest Level (WRL)	23.38m
Safe Yield	2.5m^3/hr.
Method of Monitoring Drawdown	Electric Dipper
Measured Depth of Source	29.5m
Depth of Pump Intake	28.5
Size and Type of Drawdown Pipes	1 ¼ and 2"above
Pump Currently Operational	SP3A-91.5Single phase submersible
Current Motor size	0.55kW

DRAWDOWN MEASUREMENTS

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
00	**9.00**	**23.38**	**5.5**	
01	**9.01**	**24.20**		
02	**9.02**	**24.35**		
03	**9.03**	**24.46**		
04	**9.04**	**24.50**		
05	**9.05**	**24.50**		
06	**9.06**	**24.50**		
07	**9.07**	**24.50**		
08	**9.08**	**24.55**		
09	**9.09**	**24.65**		
10	**9.10**	**24.94**		
12	**9.12**	**25.92**		
14	**9.14**	**26.23**		
16	**9.16**	**26.82**		
18	**9.18**	**27.53**		
20	**9.20**	**28.20**	**4**	**Adj G/Valve**
25	**9.25**	**28.30**		
30	**9.30**	**28.40**	**3.9**	

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
35	**9.35**	**28.40**		
40	**9.40**	**28.40**	**3.6**	
45	**9.45**	**28.40**		
50	**9.50**	**28.40**	**3.3**	
55	**9.55**	**28.40**		
60	**10.00**	**28.40**	**3.3**	
70	**10.10**	**28.50**	**3.3**	
80	**10.20**	**28.50**		
90	**10.30**	**28.50**		
100	**10.40**	**28.50**		
110	**10.50**	**28.50**		
120(2 HRS)	**11.00**	**28.50**	**2.9**	
150	**11.30**	**28.50**		
180	**12.00**	**28.50**		
210	**12.30**	**28.50**		
240	**00.00**	**28.50**		
270	**00.30**	**28.50**		
300 (5 HRS)	**13.00**	**28.50**	**2.8**	
360(6 HRS)	**14.00**	**28.50**		
420(7 HRS)	**15.00**	**28.50**		
480(8 HRS)	**16.00**	**28.50**		
540	**17.00**	**28.50**		
600	**18.00**	**28.50**	**2.8**	
660	**19.00**	**28.50**	‘’	
720	**20.00**	‘’	‘’	
780	**21.00**	‘’	‘’	
840	**22.00**	‘’	‘’	
900	**23.00**	‘’	‘’	
960	**00.00**	‘’	‘’	
1020	**1.00**	‘’	‘’	
1080	**2.00**	‘’	‘’	
1140	**3.00**	‘’	‘’	
1200	**4.00**	‘’	‘’	
1320	**6.00**	‘’	‘’	
1440	**8.00**	‘’	‘’	

RECOVERY MEASUREMENTS

TIME SINCE PUMPING STOPPED	CLOCK TIME Hrs.	DEPTH TO WATER LEVELS(M)	REMARKS
00	**20.00**	**28.50**	
02	**20.02**	**27.90**	
04	**20.04**	**27.50**	
06	**20.06**	**27.00**	
08	**20.08**	**26.85**	
10	**20.10**	**26.20**	
15	**20.15**	**25.95**	
20	**20.20**	**25.55**	
25	**20.25**	**25.05**	
30	**20.30**	**24.70**	
40	**20.40**	**24.45**	
50	**20.50**	**24.25**	
60	**20.00**	**24.65**	

OBSERVATIONS:

- The Borehole is 29.0m deep
- Pump installed $2m^3$/hr. with 40mm PVC pipes
- Gensets on site 10kva lister and single phase 7kva
- Safe yield is $2.5m^3$/hr.
- The borehole has not been in use for the last 3 years
- The borehole is located 10m from another borehole that is currently operational;

CONCLUSION:

The 7kva Genset was repaired and can be used as a stand-by borehole.

- Existing pump can continue to be used;
- Existing genset can still be used;
- The pump can be used as stand by pump;

Boji Spring Wells

Location

GPS: N38.338815, E0.5676278, 618m
16-04-2019

SUMMARY

Client Name	L.V.I.A
Test Conducted by	Jatim Engineering & Hardware
Method of Discharge Measurement	Stop Watch and 200liter open Container
Pump used	Dewatering Pump 1hp
Water Rest Level (WRL)	3.45m
Safe Yield	1.2m^3/hr.
Method of Monitoring Drawdown	Electric Dipper
Measured Depth of Source	4m
Depth of Pump Intake	4m
Pump Currently Operational	None

DRAWDOWN MEASUREMENTS

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
00	**19.00**	**3.45**	**5m^3/hr.**	
01	**19.01**	**3.45**		
02	**19.02**	**3.45**		
03	**19.03**	**3.45**		
04	**19.04**	**3.47**		
05	**19.05**	**3.47**		
06	**19.06**	**3.47**		
07	**19.07**	**3.47**		
08	**19.08**	**3.47**		
09	**19.09**	**3.49**		
10	**19.10**	**3.49**	**2.4**	**Adjust G/V**
12	**19.12**	**3.49**		
14	**19.14**	**3.49**		
16	**19.16**	**3.50**		
18	**19.18**	**3.50**		
20	**19.20**	**3.52**		
25	**19.25**	**3.52**		
30	**19.30**	**3.53**		
35	**19.35**	**3.54**		

TIME SINCE PUMP STARTED (MIN)	CLOCK TIME (HRS)	WATER LEVELS(m)	DISCHARGE (M^3/HR)	REMARKS
40	**19.40**	**3.54**		
45	**19.45**	**3.55**	**2.4**	**G/V adj.**
50	**19.50**	**3.56**		
55	**19.55**	**3.58**		
60	**20.00**	**3.60**		
70	**20.10**	**3.60**		
80	**20.20**	**3.60**		
90	**20.30**	**3.61**		
100	**20.40**	**3.61**		
110	**20.50**	**3.62**		
120(2 HRS)	**21.00**	**3.62**	**2.4**	
150	**21.30**	**3.65**		
180	**22.00**	**3.69**		
210	**22.30**	**3.69**	**1.8**	**G/V adj.**
240	**23.00**	**3.69**		
270	**23.30**	**3.70**		
300 (5 HRS)	**00.00**	**3.73**		
360(6 HRS)	**1.00**	**3.76**		
420(7 HRS)	**2.00**	**3.77**		
480(8 HRS)	**3.00**	**3.78**	**1.6**	
540	**4.00**	**3.79**		
600	**5.00**	**3.80**		
660	**6.00**	**3.80**		
720	**7.00**	**3.80**		
780	**8.00**			
840	**9.00**			
900	**10.00**			
960	**11.00**			
1020	**12.00**			
1080	**13.00**			
	14.00			
	15.00			
	17.00			
	19.00			

RECOVERY MEASUREMENTS

TIME SINCE PUMPING STOPPED	CLOCK TIME (Hrs)	DEPTH TO WATER LEVELS(M)	REMARKS
00	**7.00**	**3.80**	
02	**7.02**	**3.60**	
04	**7.04**	**3.60**	
06	**7.06**	**3.55**	
08	**7.08**	**3.55**	
10	**7.10**	**3.50**	
15	**7.15**	**3.45**	
20	**7.20**		
25	**7.25**		
30	**7.30**		
40	**7.40**		
50	**7.50**		
60	**8.00**		

OBSERVATIONS:

1. The spring well has only 0.5m column of water and it is interconnected to another spring well at the base through a perforated GI pipe;
2. The determined Safe yield is 1.2m^3/hr.
3. The spring well is open, where the community fetch water using a rope and an open bucket.

CONCLUSION

- Protect the spring well to avoid contamination;
- Replace the broken hand pump for use by the community

Reports Compiled by:
T.G Mureithi
Jatim Engineering & Hardware

Appendix C

Water Kiosks Bill of Quantities

	DESCRIPTION	UNIT	QTY	MERTI G HARDWARE	
3	**WATER KIOSKS (See detailed drawing provided)**				
1	**Sub Structure & Pavement**				
1.1	**Fillings**				
1.1.1	Provide and use Hardcore	Ton	4	1,300	5,200
1.1.2	Provide and use Quarry dust/murram	Ton	4	1,300	5,200
1.1.3	Provide and use Damp proof membrane (1000 gauge)	SM	12	317	3,804
1.2	**Concrete & Mortar**				-
1.2.1	Provide and use Ballast	Ton	7	1,500	10,500
1.2.2	Provide and use Building sand	Ton	5	1,500	7,500
1.2.3	Provide and use Ordinary Portland cement (50kg bags)	No.	15	750	11,250
1.3	**Reinforcement Steel (12m lengths)**				-
1.3.1	Provide and use Y12 (in columns)	No.	3	1,850	5,550
1.3.2	Provide and use Y10 (in strip footing)	No.	11	1,550	17,050
1.3.3	Provide and use R8 (in columns)	No.	2	1,250	2,500
1.3.4	Provide and use BRC A142 (in floor slab)	SM	7	3,500	24,500
1.3.5	Provide and use 50 x 50 x 3 mm thick angle sections (per 6 m)	No.	2	550	1,100
1.3.6	Provide and use Binding wire	Rolls	1	750	750
1.4	**Sawn Formwork**				-
1.4.1	Provide and use 150x25mm (in columns & floor slab edges)	LM	20	50	1,000
1.4.2	Provide and use 50mm diameter props (in columns) (3 m)	No.	10	450	4,500
1.5	**Sub - wall**				
1.5.1	Provide and use 9inch hard stone	SM	11	245	2,695
1.6	**Super Wall**				
1.6.1	Provide and use 200mm wide under wall D.P.C	LM	10	250	2,500
1.6.2	Provide and use 200mm thick masonry or equivalent	SM	10	245	2,450
1.6.3	Provide and use Hoop iron	Kg	10	280	2,800

	DESCRIPTION	UNIT	QTY	MERTI G HARDWARE	
1.7	**Reinforcement Steel (Columns, Beams & Roof Slab)**				-
1.7.1	Provide and use Y12	No.	14	1,850	25,900
1.7.2	Provide and use Y10	No.	20	1,550	31,000
1.7.3	Provide and use R8	No.	9	1,250	11,250
1.7.4	Provide and use Binding wire	Rolls	1	750	750
1.8	**Sawn Formwork (Columns, Beams & Slab)**				-
1.8.1	Provide and use 150 x 25mm (in columns & floor slab edges)	LM	200	50	10,000
1.8.2	Provide and use 50mm diameter props (in columns) (3 metres)	No.	10	450	4,500
1.9	**Concrete (Columns, Beams & Slab) Mix 1:2:4**				-
1.9.1	Provide and use Ordinary Portland cement	No.	12	750	9,000
1.9.2	Provide and use Building sand	Ton	4	1,500	6,000
1.9.3	Provide and use Ballast	Ton	5	1,500	7,500
2	**Door, Window & Shelves**				-
2.1.1	Provide and fix 1800mm x 900mm steel door and frame to detail	No.	1	8,333	8,333
2.1.2	Provide and fix 1100mm x 800mm double leaf window to detail	No.	1	6,500	6,500
2.1.3	Provide and fix Shelves to detail	No.	3	10,000	30,000
3	**Plaster, screed & keying**				-
3.1	Provide and use Ordinary Portland cement	No.	15	750	11,250
3.1	Provide and use Building Sand	Ton	7	1,500	10,500
4	**Painting (inside walls, doors, windows etc.)**				-
4.1	Provide and use Assorted materials to prepare surface & brushes	Sum	1	1,000	1,000
4.1	Provide and use Undercoat paint	Lit	5	150	750
4.1	Provide and use Emulsion paint	Lit	5	500	2,500
5	**Plumbing (all GI)**				
	Provide Reducing Bush 1" to 3/4" dia		1	60	60

	DESCRIPTION	UNIT	QTY	MERTI G HARDWARE	
5.1	Provide Pipe 25mm diameter class B (6m lengths)	No.	3	1,500	4,500
5.1	Provide Gate valve 25mm diameter (peglar)	No.	2	650	1,300
5.1	Provide Water meter 25mm diameter	No.	1	2,300	2,300
5.1	Provide Heavy duty taps 25mm diameter	No.	3	1,200	3,600
5.1	Provide Non-return valve 25mm diameter	No.	1	3,500	3,500
5.1	Provide Union 25mm diameter	No.	3	95	285
5.1	Provide Nipple 25mm diameter	No.	11	95	1,045
5.1	Provide Equal tee 25 mm diameter	No.	5	95	475
5.1	Provide Elbows 25 mm diameter	No.	3	95	285
5.1	Provide Bend 25 mm diameter	No.	4	95	380
5.1	Provide Long threaded nipple 25 mm diameter	No.	2	95	190
5.1	Provide Back nut 25 mm diameter	No.	4	60	240
5.1	Provide jute hemp thread	LM	2	100	200
	Total Superstructure				
6	**Storage tanks**				-
6.1	Provide and fix Metal grill to detail	No.	1	25,000	25,000
6.2	Provide and fix Metal platform to receive the tank to detail	No.	1	50,000	50,000
	Sub - Total				
7	**Soak Pit**				-
7.1	Provide and fix Heavy gauge PVC waste pipe 100mm diameter	No.	1	500	500
7.1	Provide and fix Precast concrete cover	No.	1	5,000	5,000
7.1	Provide and use Ordinary Portland cement	No.	2	750	1,500
7.1	Provide and use Building sand	Ton	0.5	1,500	750
7.1	Provide and use Ballast	Ton	0.25	1,500	375

	DESCRIPTION	UNIT	QTY	MERTI G HARDWARE	
7.1	Provide and use Hardcore	Ton	0.5	1,300	650
7.1	Provide and use masonry stone 150mm thick or equivalent	SM	4	245	980
	Sub-Total for 1 Kiosk			**386,647**	**390,697**
	Total 4 No. water kiosk			1,546,588	**1,562,788**

Appendix D

Grundfos Tool Result

Application	Installation type	Installation	Flow	Head
Groundwater supply	Borehole	Borehole installation, open tank	13.5 m^3/h	55 m

Product name	List price [EUR]	Life cycle cost [EUR/10 years]	Brand motor	U [V]	P2 [kW]	Con size outlet	Q [m^3/h]	Q-dev [%]	H [m]	H-dev [%]	Eta pump [%]
SP 17-6	3.138,00	11.776,00	MS4000	380-400-415	4	RP2 1/2	14,12	5	55	0	73,3
SP 17-7	3.295,00	12.147,00	MS4000	380-400-415	4	RP2 1/2	16,94	26	55	0	71,8
SP 14-13	2.777,00	12.310,00	MS4000	380-400-415	3	RP2	13,66	1	55	0	69,5
SP 11-15	-	12.941,00	MS4000	380-400-415	3	RP2	13,40	-1	55	0	68,9

Product name	Eta pump+motor [%]	Valve	Phase	f [Hz]	Start. method	Motor diameter [inch]	Motor version	Temp. transmit.	Shaft seal	Motor No
SP 17-6	57,9	YES	3	50	direct-on-line	4	T40	no	HM/CER	79194510
SP 17-7	56,5	YES	3	50	direct-on-line	4	T40	no	HM/CER	79194510
SP 14-13	52,5	YES	3	50	direct-on-line	4	T40	no	HM/CER	79194508
SP 11-15	52,0	YES	3	50	direct-on-line	4	T40	no	HM/CER	79194508

Appendix E

Solar Pumping System

Economic Assessment

Cost of generator (KSh)	900,000											
Cost of 1 L of fuel (KSh)	110.0											
Year	Capital Cost	Generator Working time (hours/year)	Cumulative hours for overhaul	Cumulative hours for replacement	Minor Service	Major Service	Fuel Consumption (l/hr)	Cost of fuel	Overhaul	Replacement		Generator
					16 KSh every 250h	160 KSh every 1000h			30% genset cost every 10,000h	New genset every 35,000h	Change pump every 15 yrs	
1	Ksh 0	3,285	3,285	3,285	Ksh 210	Ksh 526	4.0	Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
2		3,285	6,570	6,570	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
3		3,285	9,855	9,855	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
4		3,285	3,140	13,140	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 270,000	Ksh 0	Ksh 0	Ksh 1,716,136
5		3,285	6,425	16,425	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
6		3,285	9,710	19,710	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
7		3,285	2,995	22,995	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 270,000	Ksh 0	Ksh 0	Ksh 1,716,136
8		3,285	6,280	26,280	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
9		3,285	9,565	29,565	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
10		3,285	2,850	32,850	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 270,000	Ksh 0	Ksh 0	Ksh 1,716,136
11		3,285	1,135	1,135	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 900,000	Ksh 0	Ksh 2,346,136
12		3,285	4,420	4,420	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
13		3,285	7,705	7,705	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
14		3,285	990	10,990	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 270,000	Ksh 0	Ksh 0	Ksh 1,716,136
15		3,285	4,275	14,275	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 2,000	Ksh 1,446,136
16		3,285	7,560	17,560	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
17		3,285	845	20,845	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 270,000	Ksh 0	Ksh 0	Ksh 1,716,136
18		3,285	4,130	24,130	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
19		3,285	7,415	27,415	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
20		3,285	700	30,700	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 270,000	Ksh 0	Ksh 0	Ksh 1,716,136
21		3,285	3,985	33,985	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
22		3,285	2,270	2,270	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 900,000	Ksh 0	Ksh 2,346,136
23		3,285	5,555	5,555	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
24		3,285	8,840	8,840	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 0	Ksh 0	Ksh 0	Ksh 1,446,136
25		3,285	2,125	12,125	Ksh 210	Ksh 526		Ksh 1,445,400	Ksh 270,000	Ksh 0	Ksh 0	Ksh 1,716,136
											TOTAL COST	**Ksh 39,843,396**

Cost of solar (KSh)	0								
Cost of Invertor (KSh)	110000								
Year	Capital Cost	Preventive and Minor Service and	Major Service	Fuel Consumption (l/h)	Cost of fuel	Overhaul	Replacement		Solar
		Cleaning	_			_	Change pump every 15 yrs	Change invertor every 10 yrs	
1	Ksh 0	Ksh 80	Ksh 0	0	Ksh 0		Ksh 0	Ksh 0	Ksh 80
2		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
3		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
4		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
5		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
6		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
7		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
8		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
9		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
10		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 110,000	Ksh 110,080
11		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
12		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
13		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
14		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
15		Ksh 80	Ksh 0		Ksh 0		Ksh 250,000	Ksh 0	Ksh 250,080
16		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
17		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
18		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
19		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
20		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 110,000	Ksh 110,080
21		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
22		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
23		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
24		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
25		Ksh 80	Ksh 0		Ksh 0		Ksh 0	Ksh 0	Ksh 80
								TOTAL COST	**Ksh 472,000**

Cost of generator (KSh)	900,000												
Cost of 1 L of fuel (KSh)	110.0												
Year	Capital Cost	Generator Working time (hours/year)	Cumulative hours for overhaul	Cumulative hours for replacement	Minor Service	Major Service	Fuel Consumption (l/h)	Cost of fuel	Overhaul	Replacement	**Generator**	**Solar**	**Generator +Solar**
					16 KSh every 250h	160 KSh every 1000h			30% genset cost every 10,000h	New genset every 35,000h			
1	Ksh 0	540	540	540	Ksh 35	Ksh 86	4.0	Ksh 237,600			Ksh 238,261	Ksh 80	Ksh 238,341
2		540	1,080	1,080	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
3		540	1,620	1,620	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
4		540	2,160	2,160	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
5		540	2,700	2,700	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
6		540	3,240	3,240	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
7		540	3,780	3,780	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
8		540	4,320	4,320	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
9		540	4,860	4,860	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
10		540	5,400	5,400	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 110,080	Ksh 347,801
11		540	5,940	5,940	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
12		540	6,480	6,480	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
13		540	7,020	7,020	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
14		540	7,560	7,560	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
15		540	8,100	8,100	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 250,080	Ksh 487,801
16		540	8,640	8,640	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
17		540	9,180	9,180	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
18		540	9,720	9,720	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
19		540	260	10,260	Ksh 35	Ksh 86		Ksh 237,600	Ksh 270,000	Ksh 0	Ksh 507,721	Ksh 80	Ksh 507,801
20		540	800	10,800	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 110,080	Ksh 347,801
21		540	1,340	11,340	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
22		540	1,880	11,880	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
23		540	2,420	12,420	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
24		540	2,960	12,960	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
25		540	3,500	13,500	Ksh 35	Ksh 86		Ksh 237,600	Ksh 0	Ksh 0	Ksh 237,721	Ksh 80	Ksh 237,801
										TOTAL COST	**Ksh 6,213,564**	**Ksh 472,000**	**Ksh 6,685,564**

Year	Generator	Solar	Hybrid
0	Ksh 0	Ksh 0	Ksh 0
1	Ksh 1,446,136	Ksh 80	Ksh 238,341
2	Ksh 2,892,272	Ksh 160	Ksh 476,142
3	Ksh 4,338,408	Ksh 240	Ksh 713,943
4	Ksh 6,054,543	Ksh 320	Ksh 951,744
5	Ksh 7,500,679	Ksh 400	Ksh 1,189,545
6	Ksh 8,946,815	Ksh 480	Ksh 1,427,346
7	Ksh 10,662,951	Ksh 560	Ksh 1,665,147
8	Ksh 12,109,087	Ksh 640	Ksh 1,902,948
9	Ksh 13,555,223	Ksh 720	Ksh 2,140,749
10	Ksh 15,271,358	Ksh 110,800	Ksh 2,488,550
11	Ksh 17,617,494	Ksh 110,880	Ksh 2,726,351
12	Ksh 19,063,630	Ksh 110,960	Ksh 2,964,152
13	Ksh 20,509,766	Ksh 111,040	Ksh 3,201,952
14	Ksh 22,225,902	Ksh 111,120	Ksh 3,439,753
15	Ksh 23,672,038	Ksh 361,200	Ksh 3,927,554
16	Ksh 25,118,173	Ksh 361,280	Ksh 4,165,355
17	Ksh 26,834,309	Ksh 361,360	Ksh 4,403,156
18	Ksh 28,280,445	Ksh 361,440	Ksh 4,640,957
19	Ksh 29,726,581	Ksh 361,520	Ksh 5,148,758
20	Ksh 31,442,717	Ksh 471,600	Ksh 5,496,559
21	Ksh 32,888,853	Ksh 471,680	Ksh 5,734,360
22	Ksh 35,234,988	Ksh 471,760	Ksh 5,972,161
23	Ksh 36,681,124	Ksh 471,840	Ksh 6,209,962
24	Ksh 38,127,260	Ksh 471,920	Ksh 6,447,763
25	Ksh 39,843,396	Ksh 472,000	Ksh 6,685,564

Appendix F

Interviews

Service for peace LVIA

Small community water supplies in the Isiolo County, Kenya

INTERVIEW TO GATHER INFORMATION FOR THE MASTER'S THESIS IN HYDRAULIC CIVIL ENGINEERING.

to *MERTI GENERAL CONTRACTORS*

1. Briefly introduce me your company and your role and experiences in it.

   The company Merti General Contractors was started in 2004, I am the director with my father, the company specific deals with civil works like Road, Water and Buildings constructions, the water works include drilling and Dam Construction.

2. Which are the difficulties in carrying out civil works for water infrastructures in rural areas?

   Poor road network- Some rural areas have poor road networks and therefore affects movement of construction materials, especially during the wet seasons some roads are completely impassible.
   High transport cost- The cost of transporting materials to rural areas is always high compared to transporting within urban areas. This is due to poor state of roads and lack of emergency services in case the vehicle providing transport breaks down.
   Siting of water infrastructure- Some communities take long to agree on the right place to site the water infrastructure like public stand pipes, even after they had agreed during the planning session with the project engineer they still disagree some feeling that the service is not closer to them as they may wish.
   Lack of skilled labor-Some communities insist that they don't want the contractors to bring people (skilled and unskilled) to do the work since they can do the work themselves. This leads to poor workmanship and some contractors are forced to re-do the works by the project engineer.
   Difficulty in accessing materials- In very remote areas where they are completely no vehicle movements, the contractors usually encounter high cost in accessing any supplies that was not purchased. They fuel their vehicles for hundreds of kilometers to get a few supplies or hire bodabodas that charge high prices to bring them the needed supplies.

3. According to stakeholder's analysis, funds availability is a limitation in water infrastructures and pumping systems design and donor put a strong emphasis on procurement only. Constructing companies also confirmed that sometime do not design water infrastructures and pumping systems based on need and technical assessments but only according to the available budget. Have you ever faced this issue? If yes, which kind of solutions have you found?

   Yes. We have been faced by this issue on several occasions. When there is limited budget, we look for partners with similar mind as us and partner in implementing the project, we do so by designing the whole project in the required standards and dividing the various components amongst the partners to implement. For example, one partner can drill and equip a borehole while the other partner installs the pipeline and storage tanks. In some occasions, the county governments have come in as partners and implemented a component of the water system.

Small community water supplies in the Isiolo County, Kenya

4. Social aspects before technology choice. Do you think social issues are more important than technological aspects in rural areas? Why?

   Yes. Before selecting any technology it's mandatory to consult the community so that you can know how they feel about various technologies. The risk of not consulting the community is that you might build a project that they might like and therefore some may not use it and the ones who do, use it just use it for the sake of eliminating their needs and as a result that project will not be sustainable since they will not feel that it's their project and they will not properly manage it.

5. How sustainable management of water infrastructures can be guaranteed in rural areas of Kenya?

   The best way to ensure sustainable management of water infrastructure is adopting the WASH systems strengthening approach which put emphasis on water infrastructure construction as well as sustainable management of the projects. It entails building of strong WASH systems (system means all factors and actors involved in WASH service delivery) for sustainable management of WASH systems. WASH system in this case consist of nine building blocks (policy and legislation, Institutions, Planning, Monitoring, regulation and accountability, infrastructure, finance, water resources management, learning and adaptation) that are believed that if each of them work on a minimum there will be sustainable management of WASH systems.

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Small community water supplies in the Isiolo County, Kenya

INTERVIEW TO GATHER INFORMATION FOR THE MASTER'S THESIS IN HYDRAULIC CIVIL ENGINEERING.

to <u>*DAVIS & SHIRTLIFF*</u>

1. Briefly introduce me your company and your role and experiences in it.

   The Davis & Shirtliff Group is the leading supplier of water and energy related equipment in the East African region. Established over 70 years ago and still owned by one of the founding families, business activities are focused on six principal product sectors - water pumps, boreholes, swimming pools, water treatment, generators and solar equipment. The Group is Kenya based and operates through a network of Kenyan branches as well as regional subsidiaries in Uganda, Tanzania, Zambia, Rwanda, South Sudan and most recently in DRC and also an associate company in Ethiopia. Davis & Shirtliff regionally distributes high quality equipment sourced from a number of industry leading companies from around the world as well as carrying out manufacture and assembly of various water related products. With a total complement of over 650 highly trained and professional staff, particular emphasis has been placed on infrastructure investment and the company is extremely well resourced with modern office facilities, a fully integrated ICT network and large product and spare parts stocks. The Nairobi headquarters cover an area of 10,000m^2 with extensive warehousing, manufacturing, training and administrative facilities from where products are efficiently distributed by the company's own fleet of trucks. The company is also ISO 9001:2015 certified to demonstrate the quality focus. Recognising that the provision of efficient water and energy supplies are essential for the region's economic development, Davis & Shirtliff is committed to playing a major role in this vital industry by offering a comprehensive and competitive product range with regional availability and unrivalled technical and service support.

2. Please, describe advantages and disadvantages of solar energy for water pumping and any differences between rural and urban areas in Kenya? Please, try to compare solar power generations systems and diesel genset for water pumping. How a genset can be integrated in a solar pumping system?

   <u>*Advantages of solar energy for water pumping*</u>

   i. *No running cost from solar energy generator unlike the diesel generator that require diesel engine servicing.*
   ii. *Clean energy for the environment, unlike exhaust fumes from diesel engine*
   iii. *Assured power availability especially for the remote places. Reliable energy. Difficult and expensive to get diesel in remote areas.*
   iv. *In hot regions solar systems are not adversely affected by heat as diesel engine generators while running during the day.*
   v. *Easily installed in the remote areas with prefabricated solar structure or weld on site structures. Diesel generator units are quite heavy. Overhauling diesel engine is more difficult and requires skill and equipment unlike replacing a broken/faulty solar panel.*

Small community water supplies in the Isiolo County, Kenya

vi. *Solar systems are becoming cheaper and more affordable every year. Diesel engines and fuel becomes more expensive to run every year.*
vii. *Solar generator system has a longer lifetime 30years unlike Diesel generator whose average lifetime is less than 10 years due to the sensitive engine maintenance required.*

Disadvantages of solar energy for water pumping

i. *High investment cost compared to diesel generators.*
ii. *Unlike diesel generators, for solar generators a large area required that is open to the sky. (not a big problem for most remote areas)*
iii. *Unlike Diesel generators, there's no solar power at night and the solar irradiation varies from morning to evening with its maximum at noon.*
iv. *Cloudy and rainy days have little or no water*
v. *Solar panel can be easily vandalized as they are fragile and must be left open to the sky,*
vi. *Large water storage is required because pumping is only available when the sun is up. Unlike diesel generators where water can be pumped on demand.*

How a genset can be integrated in a solar pumping system?

Genset/Mainspower/Solar power can all be integrated into a pumping system using hybrid solar pump controllers such as Dayliff Sunverter2 or Grundfos RSI. These controllers take AC and DC power and feed it to AC motors. They act as pump controllers, variable speed drives and as inverters for pump motors.

3. When solar pumping should be discouraged?

- *When pumping is required at night.*
- *When there is no space open to the sky for installation of solar panels*
- *When theft and vandalisms of solar panels are rampant in the area.*

4. Please, describe which are your approaches on ordinary and extraordinary maintenance of your solar water pumping systems (e.g. Service & Maintenance Contract, times in the year to conduct regular maintenance checks, costs).

Unlike diesel engine generators, solar generators do not require a lot of service and maintenance. For the regions prone to dusty winds, or other forms of dirt that can stain the solar panels(eg birds droppings, leaves) it is recommended that the system operator generates a regular cleaning schedule for the panels which should be done in the mornings or evenings when the glass is not hot to prevent it from shattering. In such regions, we normally design a permanent sprinkler system on top of the solar structure that can be switched in the morning or evening to assist in cleaning.

For the borehole pump and control system normal preventive maintenance procedures are carried out, and where service contract is signed, in addition to ensuring that the control panel is clean and functioning properly, a routine test on the equipment is carried out every three (3) months and a report submitted on:

i. *the sustained yield of the borehole;*

Small community water supplies in the Isiolo County, Kenya

ii. *the current consumed by the pump;*

iii. *the closed head of the pump;*

iv. *the operational status of any protective devices;*

v. *the resistance of the drop cable between the phases and between the phases and neutral, and*

vi. *the continuity of the drop cable.*

5. Analysis of component breakdown. What are easily damaged components in a solar pumping system and what are the behaviors to be adopted by both the manufacturer (system type, installation care, etc.) and the community/water management committee to avoid damages?

   Though the solar panels have the longest lifetime, they are easily damaged components to damage as they are fragile. Therefore, children praying around and throwing stone can cause the system to fail. To prevent this, most of community projects have solar structures that are at least 4m above the ground and a fence around the system. For the electronic gadgets such as the pump controller, unless there is an electrical fault such as short circuits due to tampering with cables or damages caused by lightening, water ingress, dust accumulation etc, the system can serve for long without breakdown. The common components for a solar pumping system to break down is the pump and motor, definitely due to ware and tire with time.

6. Maintenance measures that can be adopted to enhance lifespan and improve functionality of the solar panels.

   Keeping the panels clean at all times

   Avoid shading by pruning nearby trees

7. Which are the best technical design and maintenance procedures to minimize wastage of solar energy in a water pumping system?

   Sizing the system accordingly

   Keeping the panels clean at all times

   Avoid shading by pruning nearby trees

8. Which are the typical sizes of solar water schemes in the rural areas in Kenya?

   The most common solar systems are for borehole pumps of 3kw to 7.5kw

Small community water supplies in the Isiolo County, Kenya

9. Key points in the solar pump systems design. Briefly describe the steps to follow when you need to size and design a solar pumping system.

   Step 1 – Pump selection. For a new borehole, the first step is selecting an appropriate pump for the borehole to be equipped. This is done by taking into consideration the borehole yield (with max pump out rate being 70% of the yield), total required head and water demand/requirements of the end user.

   Step 2 – Sizing of the solar system. Once the pump is selected (or for an existing borehole) the motor power requirement is noted. A common practice is to mark up this requirement by at least 30% in order to determine the solar system required. This markup is to cater for power loses and intermittent irradiation from the sun due to cloud cover to attain at least 6 full sunshine hours for the pump operation in a day. Sometimes the markup can be up to 80% in effort of increasing daily water output from the system.

   Step 3 – Equipment selection. Once the solar system size is determined the solar panels size to be used and pump controller are selected. The size and number of solar panels to be used is based on critically checking the best match of configuration to give the required power and have controller's operation requirements met. Mostly requirements of a solar controller will be:

   - *MPP Voltage VDC- this is determined by the total peak voltage of the panels connected in series of each string. It must be within the range provided for the controller eg 500-700VDC*
   - *Max DC input Voltage – this is the maximum open circuit voltage a string can have.*

   All strings in a system must have equal number of panels of similar size.

   Step 4 – sizing of cable size required. This is done in consideration of distance and current.

   Step 5 – sizing/design of solar support structure

10. When multiple panels are required, they must be wired in series, parallel, or a combination of series-parallel to meet both the voltage, amperage and power requirements of the pump. Considering the different range of solar panels currently available in the market, engineers should try to achieve economic efficiency in their selection of solar panels and arrangement of modules.
    In your opinion, which is the best solutions?

    The best way to have the most economic efficient system is to check the possible combinations using either of the panels available and do a cost analysis to determine the best. The common sizes of panels being 150w, 195/200w, 265/270w, 315/320/330w.

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11. Cost and economic assessment of Solar PV Water Pumping Schemes. What is the typical cost of a system? What are the most and least expensive components? Which items have higher and lower maintenance costs?

    Costing of a system varies widely from one borehole to another depending on the depth and yield of a borehole. For shallow boreholes with average output(5m^3/h), the list from most to least expensive component will be: - Solar panels – controller – pump - installation cables and pipes

12. Which types of submersible pumps are most used in Kenya and why? Which is the typical depth of pump installation?

    Dayliff – quality and affordable, 80m

13. Typical borehole yield in Kenya (especially in the Isiolo County) and what tests to do on the aquifer to establish performance and technical specification of the borehole.

    8m^3/hr. 24hr borehole test pumping.

14. Water purification methods. Briefly describe the most widely used technologies in rural areas of Kenya.

15. Social aspects before technology choice. Do you think social issues are more important than technological aspects in rural areas? Why?

    Yes. In some cases the community do not value technology and some will prefer their normal way of life such as walking several km to get water from a river than having a borehole. At times the community do not attach the monetary value of a donor project simply because they don't feel the pinch. It is important to involve community contribution for them to own up a project.

16. An excessive focus on the technology itself might put at risk the sustainability of a water system that depends on system design, Operation & Maintenance mechanisms and financial management. What do you think? do you agree or not?

    Excessive focus on technology might bring up system sustainability challenges as the community operators might not be able to diagnose/resolve simple failures especially where there are no or few trained/learned personnel in the community.

17. How sustainable management of water infrastructures can be guaranteed in rural areas of Kenya?

    By having community members contribute some fees which should be saved in bank accounts using easily available mobile banking platforms. This will enable the community cater for some repairs when need arises. Nothing is free.

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18. According to stakeholder's analysis, funds availability is a limitation in water infrastructures and pumping systems design and donor put a strong emphasis on procurement only. Constructing companies also confirmed that sometime do not design water infrastructures and pumping systems based on need and technical assessments but only according to the available budget. Have you ever faced this issue? If yes, which kind of solutions have you found?

    Yes. In some instances where the donor funding is not sufficient. The system is scaled down to fit the available funding. For instance when a community requirement and borehole yield demand a 10m^3/h system, but the funding is only enough for 3m^3/h.

19. Which are key regulations on water in Kenya and in the counties? According to them, how should be protected the water resource? and how should it be managed and exploited? Which are specific technical regulations to design a water infrastructure? Are these technical regulations also used in the water infrastructures design in rural areas of Kenya? How Is it possible to apply them in rural areas, as for instance in the Isiolo County?

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Small community water supplies in the Isiolo County, Kenya

INTERVIEW TO GATHER INFORMATION FOR THE MASTER'S THESIS IN HYDRAULIC CIVIL ENGINEERING.

to *DAVID KAMAU (LVIA WASH Officer)*

1. Briefly introduce me your company and your role and experiences in it.

   LVIA is an INGO working in Kenya and other African Countries. The organization works to eliminate poverty and improve livelihoods of communities in various programs ranging from WASH, livelihood enhancement, humanitarian and development projects and programmes.

   As a WASH Programme officer my Roles include

- *Project management Support: Developing work plans and budgets for WASH activities, Planning and field activities, organizing and participating in meetings at community, County and Sub-Counties level and development of funding proposals.*
- *Technical Assignments:* *Undertaking water resources assessments, WASH needs assessments, Emergency WASH needs assessments, identification of community projects, design and development of technical specifications for WASH infrastructures, tender preparations, and contract management and construction supervision.*
- *Monitoring, Evaluation and Learning: Conducting regular onsite monitoring of field activities, evaluation of project performance, outputs and impacts, documentation of feedback, lessons learnt, preparation of monitoring reports, offering recommendation for improvement on project implementation and performance.*
- *Training and Capacity Building: planning, organizing and undertaking capacity building activities of community water management, water resources users associations, water operators technical staff and community health workers where WASH project activities are undertaken. I also undertake hygiene promotion activities using participatory approaches such as CLTS, PHAST and CHAST.*

   My experiences have mainly been on emergency and development programmes/projects mainly in WASH. Most of the projects are community based mostly in rural and peri-urban areas and of late in ASAL areas.

2. Which are the main water sources in rural areas in Isiolo County? Have you any info about water sources in other ASALs or/and rural Counties in Kenya?

   Main water sources- Boreholes and Surface water
   Info about other ASAL areas/rural counties- Mainly boreholes, and surface water mainly rivers in highland areas

Small community water supplies in the Isiolo County, Kenya

3. Typical borehole yield in Kenya (especially in the Isiolo County) and what tests to do on the aquifer to establish performance and technical specification of the borehole.

   BH Yield- Ranges between 3-20$m^{3/}hr$
   Tests- Hydrogeological studies and ground water potential assessment.

4. Average water supply in rural communities in the Isiolo County (How many liters daily per capita). Do you think it's enough? Which should be next goals? And the ways to achieve them?

   Average water supply- 5 to 15m3/p/l. Not adequate during dry seasons. Need to explore more sources, reduction of non-revenue water, proper management of water schemes.

5. Which types of submersible pumps are most used in Kenya and why? Which is the typical depth of pump installation?

   Centrifugal pumps, typical depth depends on water rest levels each BH is unique

6. Key points in the solar pump systems design. Briefly describe the steps to follow when you need to size and design a solar pumping system.

   Establish BH Yield
   Establish permitted abstraction amount 60% of yield
   Establish total dynamic head
   Design a pump size from pump curves
   Establish pump power requirements and size the motor
   Establish pump control requirements
   Design solar sizes and their alignments

7. Water purification methods. Briefly describe manual and the most widely used technologies in rural areas of Kenya.

   Point of Use treatment methods -chlorine
   Boiling

8. Key and strategic water points/sources in water supply networks in rural areas. Why are these places chosen?

   Settlement with populations
   Aquifers/sources with fresh water

9. Who is in charge of managing the water resource in a village? How does he comply with his tasks?

Management committees. Mostly do not comply since they work on voluntary basis with no proper regulations.

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10. Which is the average cost of water in Kenya (especially in the Isiolo County)? Cost per family or people and livestock. How many times are fee paid? Who collects water fees? Which are the differences in costs and fees collection between urban and rural areas?

Average cost of water Ksh 5 per 20-liter jerrican
Average costs 1000kes per month
Daily for water kiosks and monthly for flat rate piped systems
Water fees collected by management committees
Rural areas about 50% Urban areas up to 80%

11. How water fees collection can be guaranteed in rural areas of Kenya? And why is it important?

Can be guaranteed through regulation. It is important for sustainability

12. Which are the difficulties in carrying out civil works in rural areas?

Accessibility and availability of construction materials
Poor road networks,

13. Field visit. Why is it important? Which are the main issues usually you have to face during a site visit?

Important in order to understand beneficiaries needs and monitoring. Main Issues- poor road networks, harsh weather conditions

14. Which are the main challenges for rural communities in water supply? (e.g. community, technical, etc.)

lack of technical supports, illiteracy, lack of skills, low income levels

15. Social aspects before technology choice. Do you think social issues are more important than technological aspects in rural areas? Why?

I think social issues are important and plays a big role to the success of a project. You require to address social need in order to design systems that are in line with the social needs.

16. How sustainable management of water infrastructures can be guaranteed in rural areas of Kenya?

Through proper regulation, skills transfer and training.

Small community water supplies in the Isiolo County, Kenya

17. Flood and drought issues. Climate change also affects Kenya. Severe droughts are followed by strong floods. How does it affect the Kenyan environment and water availability? Which new problems water authorities and stakeholders have faced in the last years because of climate change? Which are main mitigation interventions?

    Climate change is a big challenge in Kenya as it makes the human environments unbearable to live and must adapt. It affects water availability through by depleting the sources and destruction of catchments and infrastructures.
    New problems include excessive floods and droughts, lack of early warnings and unpredictable climate patterns. Mitigation measures include Climate smart adaptations

18. Which are key regulations on water in Kenya and in the counties? According to them, how should be protected the water resource? and how should it be managed and exploited? Which are specific technical regulations to design a water infrastructure? Are these technical regulations also used in the water infrastructures design in rural areas of Kenya? How Is it possible to apply them in rural areas, as for instance in the Isiolo County?

    Key regulations. Kenya Water law 2016, and County water laws Regulation of urban water through Water Service Providers. Water sources are state resources and protected through IWRM. Managed through IWM approach and equitably and sustainably exploited. Technical regulations, Water Design Manual by MoW, Technical specifications cut across all areas, Application need to be guided and enforced by County Government and other National regulating and enforcement agencies.

19. Which are key policies in the water sector at international, national and county levels? How do these interact with each other? Which are the main challenges and objectives?

    International waters are guided by existing treaties eg Nile treaty, National waters are guided by transboundary laws and National and Counties are guided by Water Act 2016.

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INTERVIEW TO GATHER INFORMATION FOR THE MASTER'S THESIS IN HYDRAULIC CIVIL ENGINEERING.

to *EMILIANO CESARETTI (LVIA Country Rep. and Project coordinator)*

1. Briefly introduce me your company and your role and experiences in it.

   LVIA is an international NGO based in Italy and active in 11 different countries (Burundi, Burkina Faso, Ethiopia, Guinea Bissau, Guinea Conakry, Kenya, Mali, Mozambique, Senegal, Tanzania, and Italy).
   In general, LVIA aims to promote responsible citizenship based on the principles of solidarity, to act effectively to promote change, to sustain dialogue and mutual understanding among peoples for building a more just and united world.
   In Kenya, LVIA has been present since 1967. In more than 50 years it has implemented different projects focused on: WASH, health, emergency response, livelihood, livestock, agriculture and rural development. The areas of action during those years are Meru, Isiolo and Samburu Counties. In particular, LVIA moved from Meru to Isiolo County in 2012, implementing a project funded by OCHA, to reduce water borne diseases in pastoral communities living in rural areas of the County. In the framework of this and of other projects developed by LVIA in Isiolo County, we rehabilitated/built several water (boreholes, pipelines, RWHS, etc.) and sanitation (latrines) infrastructures. LVIA have worked with beneficiary communities and key local institutions in order to guarantee sustainable management of WASH infrastructures built/rehabilitated. According to LVIA strategy, project implemented in Isiolo County were focused also on rural development, supporting establishment and development of groups of beekeepers and gums and resins producers in order to promote economic diversification and development of Isiolo County rural areas.
   I am the Country Representative of LVIA in Kenya. My role is related to the overall management of project activities of the organization in Kenya. I work, together with local and international LVIA team writing and developing project proposal. I am also involved in administrative issues and networking activities. Finally, as Country Representative, I represent the organization in public meeting or events.

2. How does an NGO such as LVIA work in rural water infrastructure? Which are your goals? Which are main issues you faced? How is it possible to improve way of work in water infrastructure construction and rehabilitation? Which are future challenges in this sector?

   Our way of work is to start from the needs of our beneficiaries. Together with key authorities, we start our projects assessing real needs of the people. Once we have all the key information about people needs, LVIA team carries on a technical analysis of the situation to provide to the people the best technical solution available. Therefore, we write our project according to these two analyses (needs and technical assessments). In general, we prefer to work on underground water sources because of their reliability and low contamination level. In order to guarantee the sustainability of water infrastructures rehabilitated/built, we work with local water management committees and key authorities supporting them with specific training on water infrastructures

Small community water supplies in the Isiolo County, Kenya

technical and economic management. Our main goal is to provide enough water for all the people in Isiolo County, especially the ones living in rural and remote areas. "Enough water" means to comply with international standards on water availability (according to the main international standards for WASH sector, as for instance the standards sphere), but also to guarantee that water fees are affordable for poor or disadvantages people. The availability of water is strictly related to technical issues (yields, distances, distribution systems, etc.). Affordability is dependent by management and sustainability of water schemes.

Main issues we have to face are related to water infrastructure management. In fact, technical issue can be easily managed by LVIA technical team. For the majority of the villages in which we have implemented our project, water is enough to guarantee the compliance with LVIA targets and international standards. Management is the real problem: local water management committees, usually, do not have proper skills to manage water infrastructures and, additionally, they use to do not care about management because they know that, in case of problems, they can ask funds or interventions to NGOs or County Government. This way of management can affect people and reduce reliability of water provision. According to the above, main improvements to be achieved and key future challenges are related to water management and not to construction or rehabilitation of water infrastructures. About hard activities (construction/rehabilitation) is critical to focus on:

- *Energy: renewable energies as part of a multi-source system. Solar panels are not enough but is important to consider backup systems (diesel genset, etc.) and other source of renewable energies. The real challenge is to find systems that can be easily managed, from a technical point of view, by water management committees*
- *Water sources: rehabilitation of boreholes should be preferred to other water source*
- *Storage: it is important to consider people needs and to include in any project a storage component that can guarantee water availability also in case of lack of energy or pumping systems breaks*

3. According to your opinion, which is the best solution, both technical and managing, for the water supply systems in a rural village of Kenya (especially in the Isiolo County) and why?

Technical solutions:

- *Water sources: boreholes (availability more reliable, low degree of pollution)*
- *Storage: steel elevated tanks (pressure of the distribution system is higher and pipeline system can be extended, less accidentally or intentionally damages, increase of tank lifetime)*
- *Distribution: water kiosks in strategic places (CAPEX reduced if compared con direct connection to the house, more manageable)*
- *Energy: integrated systems, primary source of energy should be solar or other renewable energies, it is mandatory to include a backup system based on fossil energy*

Managing solutions:

- *Water committees paid with revenues from water fees recollection and not by an NGO (welfarism) or the County government (not reliable)*
- *Water committees should find an easy way to report revenues, costs and activities to the communities*
- *People should pay an affordable fee for the water, but they have to pay. Without payment there is no sustainability*

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- *Every water committee should develop its own business plan in order to foresee investments, replacement of equipment, etc.*

4. Except for emergency situations, how do you choose water sources to be used through water infrastructure? How important communities are in the selection of water resources to be exploited?

Communities involvement in water source selection is critical for several reasons:

- *Communities know better than us where it is possible to find water in the area*
- *Communities know challenges related to water sources in the area (pollution, salinity, accessibility, etc.)*
- *Intra-communities' conflicts on specific water resources can stop or derail the project. Involving communities in the selection of water sources can help project team to understand and avoid/solve these kind of conflicts*
- *Without communities support there is no project can works*

When LVIA team has to choose water sources in an area, the procedure we follow is the following:

- *Involvement of local authorities at County, sub-County, Ward and villages level to get info about water sources in the area*
- *Field visit with people from the local Water Management Committee/local leaders/local government institutions*
- *Technical analysis on water availability and quality of water sources identified during the site visit*
- *Field visit to present to the communities the results of the technical analysis and final decision about water sources LVIA will rehabilitate*

5. Which are the main challenges for rural communities in water supply? (e.g. community, technical, etc.)

   a. *Economic management:*
      i. *water management committee have no economic management skills. For instance, they do not know how to calculate equipment depreciation or establish a replacement plan.*
      ii. *Lack of interest about proper economic management of the water infrastructures: people in Isiolo rural areas used to think that, in case they have water related problems, they have just to contact an NGO or the government and ask to them to find a solution. Furthermore, during rehabilitation/construction activities they can receive money for training or jobs.*
      iii. *Some water committees are not transparent. Fraud and corruption can be part of the problems related to economic management of water infrastructures*
   b. *Technical management*
      i. *Water management committees' technical staffs, usually, do not have right skills to guarantee a proper technical management of local water infrastructures. Usually, people with high skills level look for jobs in Isiolo town or in other*

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Kenyan cities. Sometimes, also people trained by NGO's projects leave the area to look for a better job using skills provided by the NGOs themselves

ii. Lack of economic management affects technical management because technical staff cannot be paid enough (or can not be paid at all) and spare parts for maintenance services cannot be bought in time

c. *Conflicts intra and inter communities*

i. Conflicts between people in the communities expose water infrastructures to different risks (damages, alterations, etc.). Water sources selection and water infrastructures constructions can generate new conflicts in the communities, dialogue and involvement of people is mandatory to avoid them

ii. Conflicts with people coming from other communities (especially pastoralists) are common. When a rumor about a new water sources spreads in the area, pastoralists from neighboring communities can arrive to the village to get water for their livestock. To avoid this situation is mandatory to involve local authorities, especially County government officers, that are in charge to the management of such conflicts

d. *Natural disasters*

i. Floods can damage or destroy water resources. Technical assessment should consider this risk

ii. Drought can bring to overuse water pumps. Technical assessment should consider this risk

6. Field visit. Why is it important? Which are the main issues usually you have to face during a site visit?

There are different kind of site visits and, consequently, different issues we have to face.
During assessment field visits (that we carry on before the beginning of a project), the biggest challenges are to find a way to involve beneficiaries into the project idea and recollect reliable info. In fact, several time people in rural areas do not believe in NGOs or they think that the proposed project idea is useful only to get money from the NGO. Furthermore, people sometimes do not have info about something that we need to know to write a project so they can give you wrong info on which you have to "build" a project. Anyway, this kind of site visit is critical to have info to write a project and to receive feedback from the beneficiaries that can be aware about the project proposal (without the approval from the beneficiaries it is useless to proceed with a project idea)
At the beginning of the project we have to visit the beneficiaries to present them the contractors and to discuss with them about technical issues. In this case the biggest challenge is related to the conflict can be generated by external contractors in the beneficiary community. If they do not know the contractor and reason for which it is working in their village or if they cannot provide to the contractors technical info (for example where it is better to install a water kiosk or when it is possible to install a pipeline), the project can fail because of the opposition of the community to some of the works that we are going to implement or can generate conflicts into the community itself. This kind of site visit is critical to avoid conflicts with and into the communities and to allow to the contractor to work I the best way.

Small community water supplies in the Isiolo County, Kenya

During the works implementation it is important to visit frequently the site in order to checkif the contractor is doing properly its job and if problems rised into the community or between the contractor and the community.
After the completion of the job, it is mandatory to visit the site to check if the jobs have been completed properly and to receive feedback from the beneficiaries. Without this site visit is not possible to complete the payment of the works to the contractor. Furthermore, through the feedback from the beneficiaries we can understand which mistakes we have done and how we can improve in future projects.

7. How water fees collection can be guaranteed in rural areas of Kenya? And why is it important?

Without water fees payment there is no sustainability for water infrastructure. Recollect fees for water in rural areas is very complicated because:
- *People are not used to pay for water because they have ever received water for free through funds of NGOs and National/County government*
- *People do not want to pay for water because they tell you that they are poor and water fees are not affordable for them*
- *People do not trust in who has to manage the water resources, so they do not want pay because they think that they are not paying for water infrastructures maintenance*

In order to guarantee the payment of the water fees in our project areas there are no 100% guaranteed solutions. What it should be done is:
- *Find a way to convince people that is better/cheaper to pay small fees to have reliable water schemes (for health, economic activities, etc.) than to pay nothing and stay for months without water waiting for another NGO intervention*
- *Rehabilitate/build not only a part of the water scheme but consider all of it in order to enhance reliability of the entire system*
- *Improve transparency of local water management committees, also through smart metering and digital monitoring systems*
- *Reduce as much as possible the fee in order to allow to everyone to pay it*

8. How sustainable management of water infrastructures can be guaranteed in rural areas of Kenya?

Key points to enhance (guarantee is not possible) the sustainability of the management of water infrastructures in rural areas of Isiolo County are:
- *Provide technical and business skills to the local water management committees*
- *Improve transparency of local water management committees, also through smart metering and digital monitoring systems*
- *Reduce as much as possible the fee in order to allow to everyone to pay it*
- *Find a way to convince people that is better/cheaper to pay small fees to have reliable water schemes (for health, economic activities, etc.) than to pay nothing and stay for months without water waiting for another NGO intervention*
- *Involve key Department of the local County government on water management Committees supervision, taking care to control also the same County government and intervene in case of issues between County Government officer and Water Management Committee members*

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9. How can you assess water infrastructures long term sustainability? And how to help communities to achieve long term it?

   Long term sustainability is related to:
   - *water infrastructures management (please see the answers to question 8)*
   - *intervention on all the water scheme and not on just a part of it. In fact, if you repair a pump but you do not consider the storage or the distribution, you cannot guarantee that beneficiaries will receive water in the long term because of breaks of the water scheme component that you have not considered. In this sense, communities can help you to understand the condition of the water infrastructures that they have and to identify better the main challenges related to them*

10. Social aspects before technology choice. Do you think social issues are more important than technological aspects in rural areas? Why?

    Both the aspects are critical and connected each other. The best water scheme, from a technical point of view, cannot be managed by local committees or, at the same time, a traditional technical water scheme can be not efficient or can be useless especially considering climate change or logistics issues. It is important to consider social and technical issues together. For instance, install a solar pumping system in a rural area of Isiolo County can be the best technical solution because the availability of solar energy and because of the difficulties in fuel supply. On the other hand, people are convinced that a solar pumping system has no costs so they can refuse to pay water fees, affecting long term sustainability of the water scheme. When you choose to use this kind of the technologies you have to consider also to implement activities to explain in detail their operative costs.

11. How are contractors chosen to build/to rehabilitate water works? Which are main requirements in procurement process in LVIA?

    We have different steps of procurement. Apart for procurement with a value of more than 100,000 €, all the contractors should be included in our prequalification list. All the companies included in this list have been already evaluated from LVIA team in order to administrative and financial issues.
    When we start a procurement, we sent to the companies included in the pre-qualification list for the specific sector (civil works, pumping systems, etc.) request for quotations (approved by LVIA headquarter in Cuneo) with a deadline to receive an answer.
    When we receive all the quotations, we start the evaluation process using a matrix developed by LVIA team. The matrix does not give you info on the final score of every bidder up to the end of the evaluation so it is not possible to modify the score of a bidder to increase the possibility that this bidder will win.
    The matrix starts with the analysis of the administrative criteria (30/100 points), then analyze technical criteria (50/100 points) and finally take into consideration the economic offer (20/100 points). The contractor with the highest score wins the procurement.
    After the evaluation, we send an email to every bidder to inform them about the final decision and we proceed with the contract signature process.

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12. How should funds for the construction of a water infrastructure be used in the best way? Do you used your funds only water infrastructures construction/rehabilitation or for long term water availability programs including management training, etc.?

    In development project, it is mandatory to use part of the funds also to new/rehabilitated infrastructures water management and to use part of the funds available for sensitization activities and local institutions involvement. Only in case of emergency project it is possible to use 100% of the funds for water infrastructures rehabilitation/construction.

13. Is it more important to base the financing decisions on equipment life cycle costs or on capital costs of installations? Why?

    Equipment life cycle costs. If you build the best water scheme but, because of the equipment you decided to use, the cost for replacement or maintenance is not affordable for the management committees, in the medium-long term, the water scheme will be useless. Furthermore, a water scheme with a long life cycle can allow the water management committee that has to manage it to recollect enough funds for maintenance and repairs and to test sustainability of the business model they decided to choose.

14. Which is keys challenge in relationships with stakeholders in water sector in Isiolo County?

    - *Local institution (County Government, WRMA, NDMA, etc.): these stakeholders are critical for project implementation and sustainability. For instance, Isiolo County Government Water Department is the institution in charge of overall management of water infrastructures in the County. The main challenge with these kinds of stakeholders is related to economic issues. They are not able to plan activities according to their budget, so they are continuously looking for additional funds, especially to pay their employees. It is important to have a transparent relation with them and negotiate before of any activity, payment to employees or DSA that is possible to provide to their officers*
    - *Local NGOs/CBOs (CARITAS, WordlVision, CRS, Kenya red cross, etc.): these are "our colleagues" on the field. The key challenge with them is related to the coordination of the activities in the different areas of the County. It is important to participate in coordination meeting to avoid duplication of activities and to develop synergies that can leverage results and impact of our projects. In Isiolo County there are several coordination meetings and LVIA is involved in the most critical*
    - *Private sector (Davis&Shirtliff, Merti general constructors, etc.): mainly, these are contractors that can implement rehabilitation/construction of water infrastructures on the ground. The main challenge with them is related to transparency and reliability. In fact, is relevant to establish procedures to guarantee that all the reliable companies can participate in our procurement without discrimination or corruption and, at the same time, it is important that the contractors know we check works quality and respect of the deadline. The golden rule is that 100% of the payment for a job can be done only after the test of the infrastructure built/rehabilitated*
    - *Local communities: these are our beneficiaries. You can find key challenges in previous answers*

Small community water supplies in the Isiolo County, Kenya

15. Flood and drought issues. Climate change also affects Kenya. Severe droughts are followed by strong floods. How does it affect the Kenyan environment and water availability? Which new problems water authorities and stakeholders have faced in the last years because of climate change? Which are main mitigation interventions?

    The alternation of severe floods and drought can affect environment because of the increased of soil erosion and the decreased of soil fertility. Due to this situation, Isiolo County is changing from a semi-desertic to a desertic area. 80% of people in Isiolo are pastoralists so, less grazing areas means that the pressure on the remaining grazing areas increase. Also, water availability is strongly affected by this alternation of floods and droughts because several water infrastructures are damaged or destroyed during floods and are overused during droughts, reducing lifetime and increasing maintenance costs. Unfortunately, efficient solutions in order to strongly mitigate the impact of climate change on environment and water availability have not been found yet. Local institutions and stakeholders try to promote awareness and provide support to local communities to reduce environment exploitation and introduce renewable energies to increase water infrastructures economic sustainability. Another important mitigation intervention is the development of the traditional value chains and the improvement of the economic diversification. In fact, more income means also an increase of water fee affordability for the people and, consequently, the improvement of long term sustainability of these infrastructures. From a technical point of view, all the stakeholders are turning to rehabilitation/construction of boreholes instead of traditional water pans or sand dams because they are more reliable in this specific situation. Finally, Isiolo County Government promotes reforestation of rural areas but, because lack of planning and funds, the results achieved by this government programme are not relevant.

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