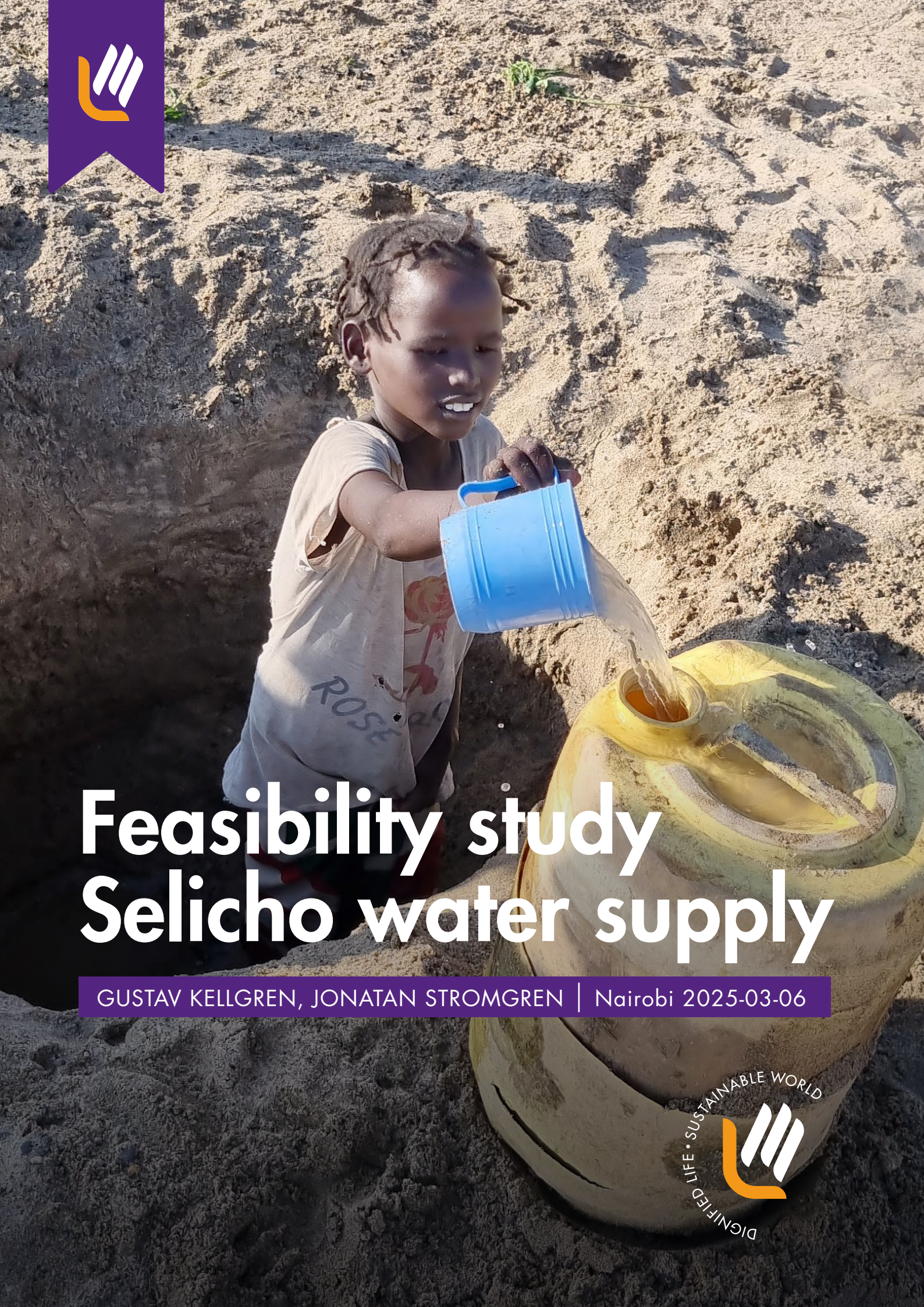


Feasibility study Selicho water supply

GUSTAV KELLGREN, JONATAN STROMGREN | Nairobi 2025-03-06

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BACKGROUND

The main purpose of the study was fact-finding to assess the feasibility of a pilot with the Swedish company Ingeson water and their new innovation for desalination, but also to assess the water situation in the area and help develop feasible ideas for water supply and irrigation to help support the local community and Full Gospel Church of Kenya (FGCK) and their initiative in Selicho settlement.

Participants were Jonatan Stromgren (Sr Water Advisor) and Gustav Kellgren (WASH intern) from LM International, Hussein Dima from Water4World, Meshak Gayere (community health worker from Loglogo with previous working experience from Selicho) and Elias Kithinji Ikiugu who recently has moved to Selicho to work with FGCK.

FIELD STUDY

Selicho was visited for four days between the 6th and 9th of December 2024.

Itinerary and actors met

Table 1 Itinerary of fieldtrip in Selicho

Day	Activities	Actor
6 Dec	Flight to Ileret with MAF Met by Elias Kithinji Ikiugu from Selicho FGCK	
6 Dec	Visit at Turkana Basin institute and their desalination plants + hydroponics	Turkana Basin Institute
6 Dec	Meeting with CIFA (NGO active in the borderlands). Good introduction to the area and context	CIFA Kenya
6 Dec	Water sampling between Ileret and Selicho	
7 Dec	Discussion with Mr Moniki, head of Selicho health post	Ministry of Health, Selicho Dispensary
7 Dec	Meeting with Selicho chief	Local authorities Selicho
7 Dec	Water sampling area between Selicho and border w Ethiopia	
7 Dec	Discussion with Elias Kithinji Ikiugu on needs and visions for Selicho	
7 Dec	Discussions with Benedicter monks serving in Ileret on local context and needs	
8 Dec	Visit to church service, Full Gospel Church of Kenya in Ilegele settlement	
8 Dec	Water sampling scoop holes + dug well Ilegele	
8 Dec	Water sampling Lake Turkana, visit of the plot donated to FGCK by Selicho community	
9 Dec	Visit Ileret area chief	Ileret area local authorities

AREA DESCRIPTION

Location

The project area is in one of Kenya's most remote areas, on the eastern shores of Lake Turkana in Marsabit County, North Horr Sub-County, and Illeret Ward. The feasibility study targeted Selicho Village, located approximately 10 km north of Illeret and about 6 km south of the Ethiopian border, see Figure 1. The area around Illeret and the northeastern parts of Lake Turkana is inhabited by the nomadic and pastoralist Daasanach tribe.

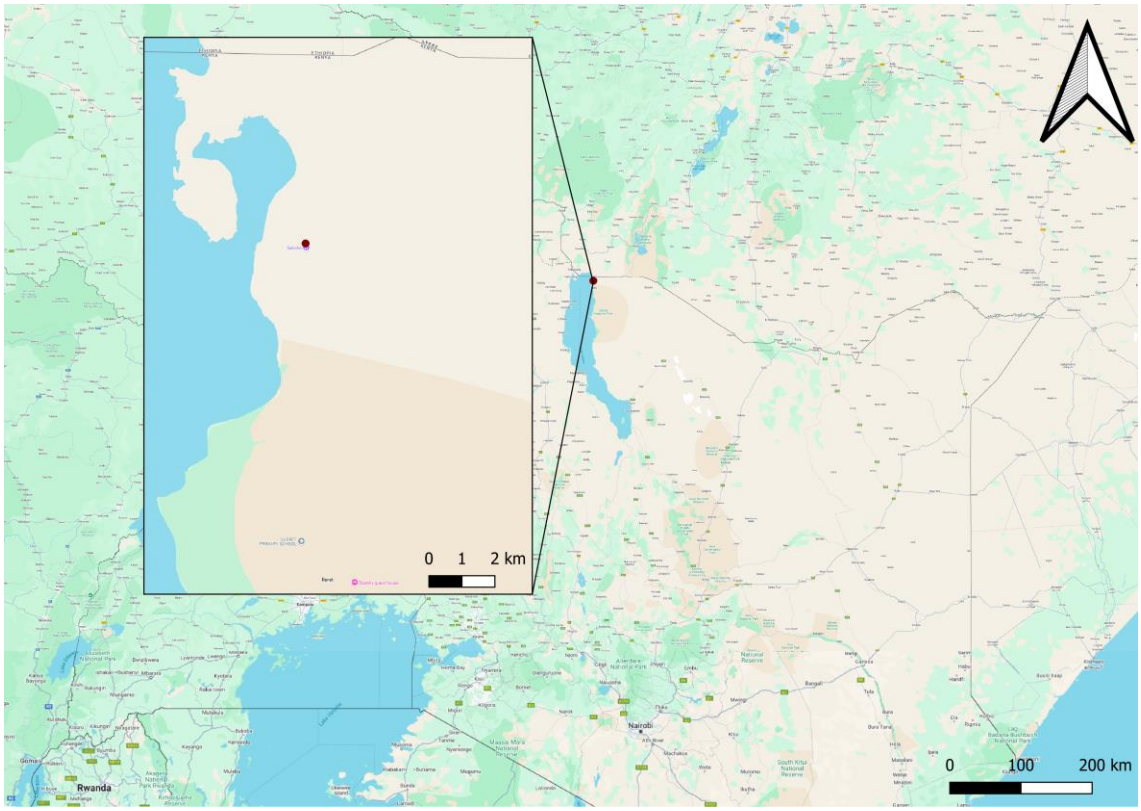


Figure 1 Regional and Local Overview of Selicho

Land use and land cover, derived from a 10m resolution dataset by the European Space Agency, around Selicho and the upstream catchment area, comprises lake, shrubland, grassland, and sparse vegetation, with negligible cultivated areas (ESA, 2021). Based on high-resolution satellite imagery, most of the built areas are concentrated within a few hundred meters of Selicho centre, though scattered settlements extend up to a few km from the village centre. Approximately 1 km east of the main village, in Telesgaye , where FGCK is currently operating a church in an old school building. This area comprises around 20 households.

In the village centre, a government-run dispensary serves approximately 9,090 people from Selicho and surrounding areas. The health clinic provides basic medical services and distributes specialised nutrition foods. Additional public facilities include a preschool.

The FGCK church has been allocated one plot of land spanning over 14 hectares by the community. The plot is located just south of the village along the road to Ileret. Currently, the plot extends from the road to the lake's edge. Given the involvement of FGCK in the feasibility study and the required area, the plot would be an ideal location for a water treatment facility. See Figure 2 for key points and areas in Selicho.

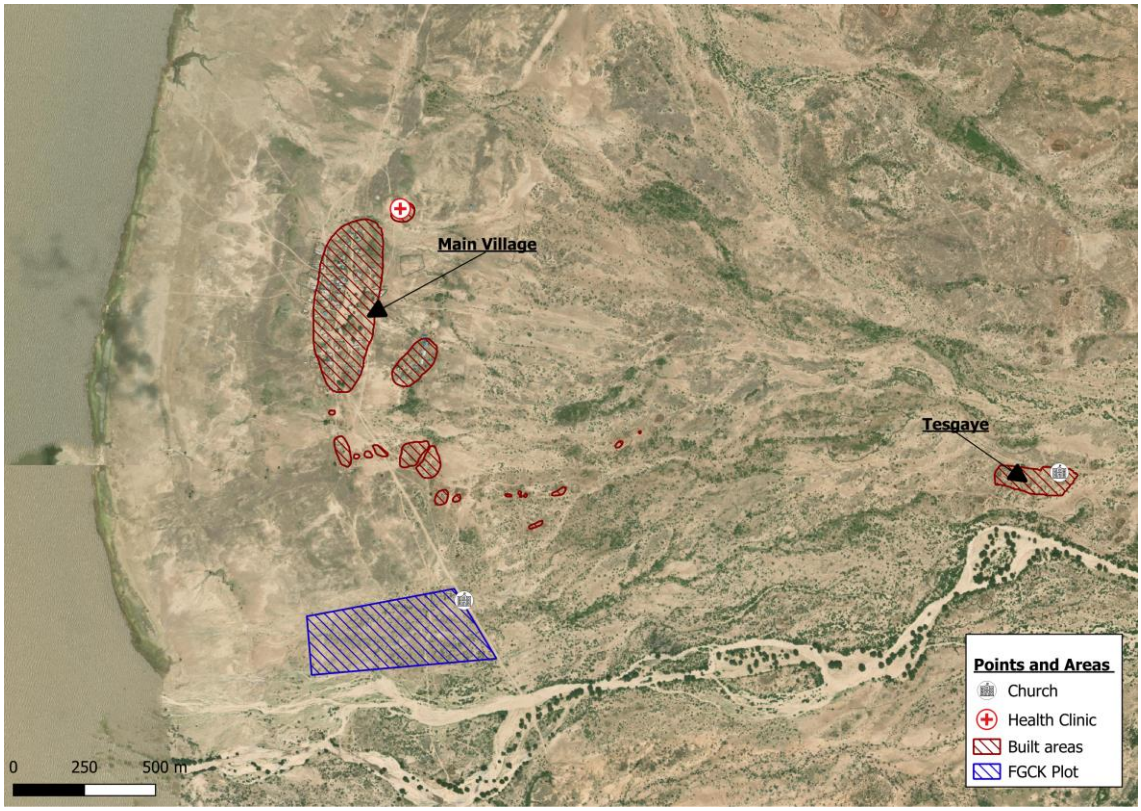


Figure 2 Built areas in Selicho including local overview of key points and area

Socio-economic setting

The current population of Illeret Ward is 18,233 people, with an average household size of nine. The population density is estimated to be 9 persons/km^2, and poverty rates in the sub-county range from 76% to 90%. As of 2019, 35% of households in North Horr had access to safe drinking water. Meanwhile, 60% relied on unprotected wells where only 16% used protected wells, and 11% public taps (KNBS, 2019). In Selicho, the number of households is estimated to be around 220, with a population of approximately 2,000 to 2,200 people.

The primary livelihood in the area comes from fishing, see Figure 3, with fish either consumed locally or sold to purchase other food such as cereals. However, fish stocks are reported to have declined in response to the recent rise in lake levels. Additional sources of income include small businesses. Agriculture practices in the area remain limited, due to saline water and limited tradition and experience. Thus, the scarcity of clean water is affecting food security, as well as a high prevalence of water-borne diseases, with the area having the highest malnutrition rates in Kenya where 80% of the children under 5 suffer from malnutrition according to the head of Selicho dispensary and clinic.



Figure 3 Fishing on the shores of Lake Turkana.

Climate

North Horr is classified as an arid region. Rainfall in the catchment follows a bimodal pattern, with most rainfall occurring between March and May, peaking in April with an average of 90 mm. A less intense rainy period occurs between October and December, peaking in November with an average of 75 mm (see Figure 4). However, these rainfall patterns have become increasingly unreliable and erratic in recent years.

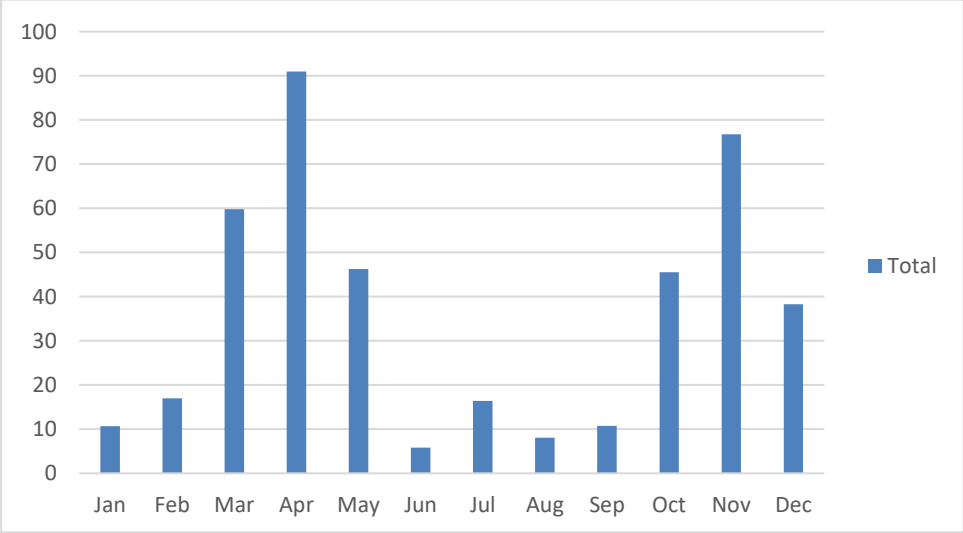


Figure 4 Average monthly rainfall from 2004-2024 (CHIRPS)

Annual rainfall over the past 20 years has averaged 475 mm per year, based on the 5 km resolution CHIRPS precipitation data, see Figure 5. Actual evaporation (AET) rates derived from the FAO WaPor portal (100 m resolution) averaged 240 mm per year across the catchment. Potential evapotranspiration (PET) is approximate 2,200 mm per year (acacia, 2017a).

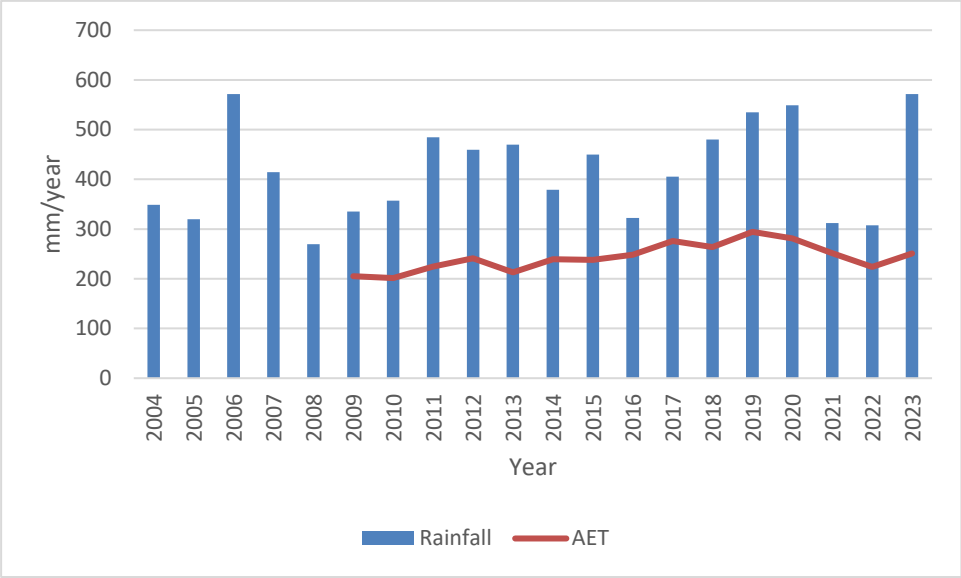


Figure 5 Annual rainfall from 2004-2023 (CHIRPS) and AET from 2009-2023 (WaPor)

Hydrology

The catchment area and stream network, as shown in Figure 6, were delineated using Copernicus DEM data with a spatial resolution of 30 meters. The catchment area was calculated to be 63 km^2. The area surrounding the village is predominantly flat with gentle slopes. There are no perennial rivers, only seasonal streams locally referred to as Laga. The water flow is normally only for a few days after rainfall. The lagas provide the only source of fresh water, accessible through shallow dug scoop holes accessing groundwater in the alluvial sediments.

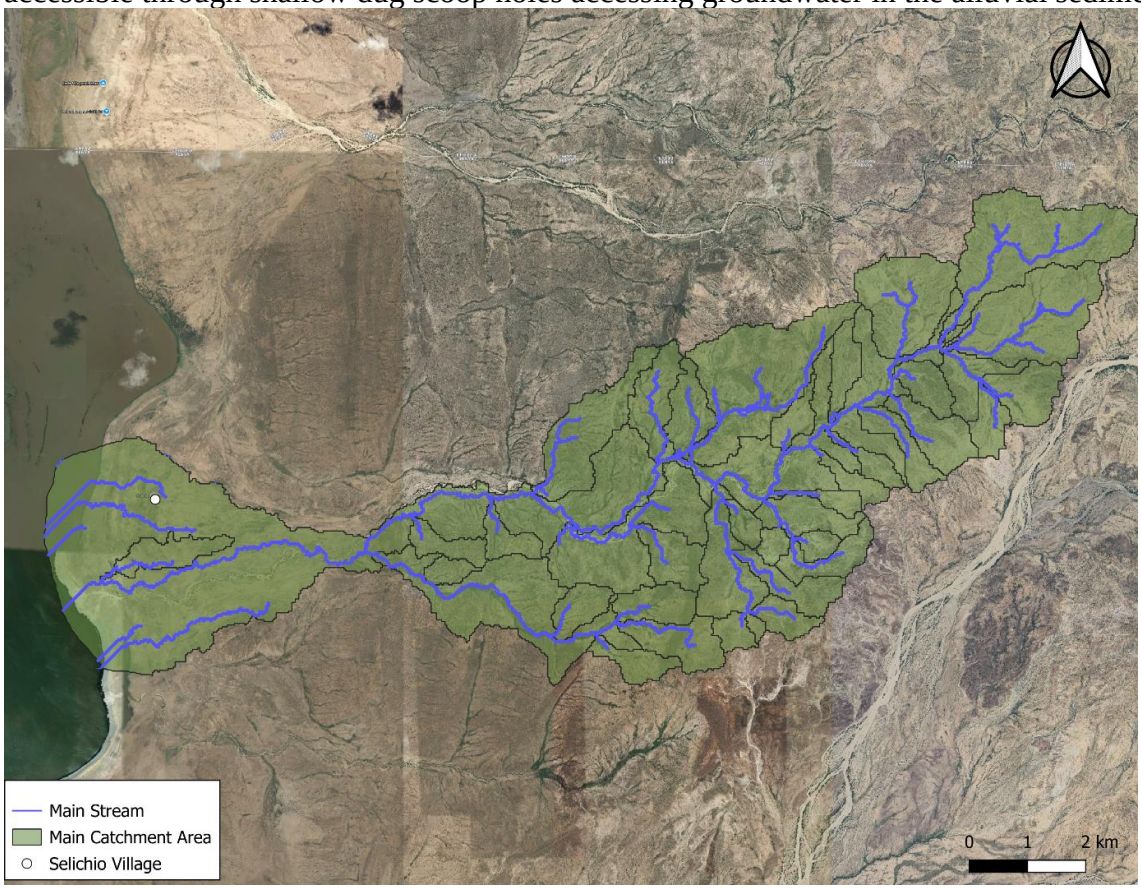


Figure 6 Delineated Catchment and Stream Network.

Geology and Hydrogeology

The area around Selichio comprises lake/shore deposits underlain by Tertiary/Quaternary unconsolidated alluvial sedimentary formations, see Figure 6. The area has been recognized as a high-potential zone for groundwater exploration. The primary known aquifer lies beneath the riverbed of the old Chalbi Lake, now part of the Chalbi Desert. While several high-yielding boreholes have been identified in the aquifer around North Horr, the overall groundwater potential remains unknown (Acacia, 2017a). However, the old lakebed is predominantly covered by alkaline and saline materials, indicating high salinity in the groundwater.

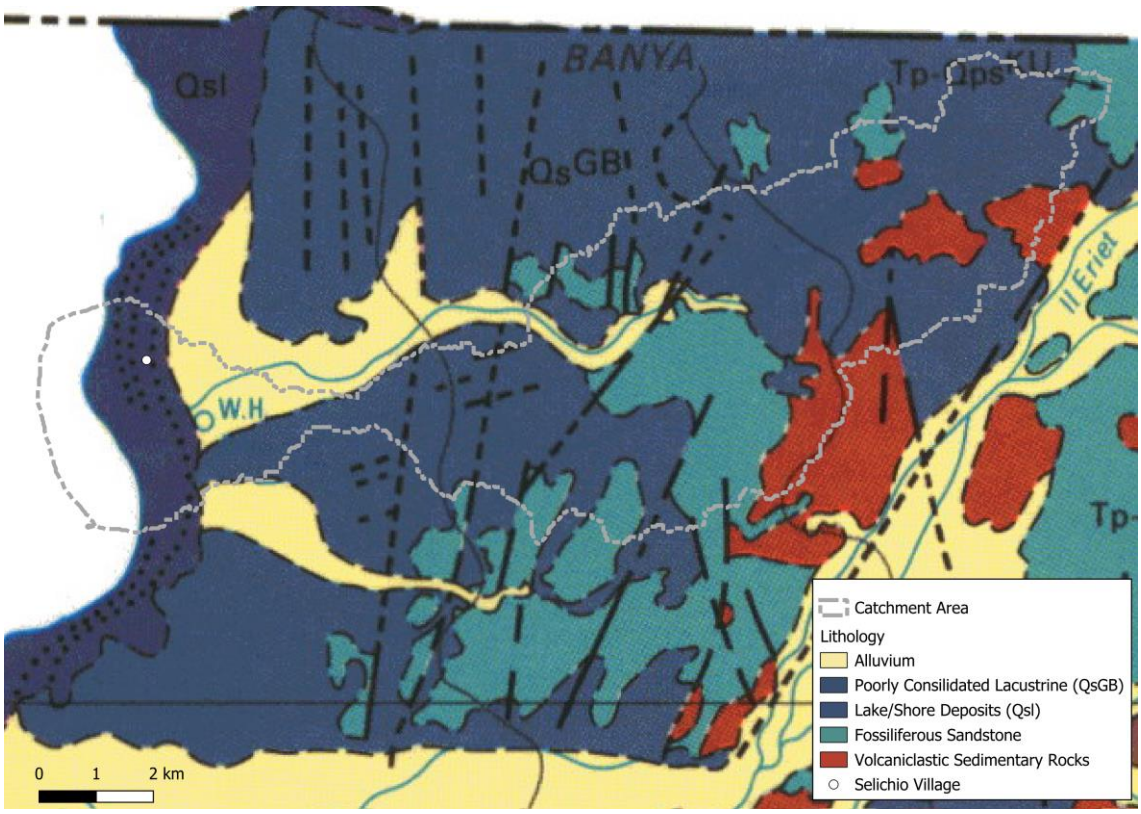


Figure 7 Lithology around Selicho

Geological formations and data from MacDonald indicate that the area has medium to high storage capacity and high groundwater productivity (Acacia, 2017b). Long-term average (LTA) recharge can be empirically estimated using various methods. MacDonald et al. (2021) proposed an equation for estimating LTA recharge based on 134 field-based measurements across Africa, as expressed in Equation 1

Equation 1

$$\text{Log}_e\,[\text{LTA recharge}] = \beta_0 + \beta_1 \text{Log}_e\,[\text{LTA Rainfall}]$$

LTA recharge = Long-term average recharge (mm/year)
B_0 = -5
B_1 = 1.388
LTA Rainfall = Long-term average rainfall (mm/year)

MacDonald et al. (2021) developed four different maps for Africa, covering LTA recharge, depth to groundwater, storage capacity, and productivity. The output data for the area, along with the results from the equation, are presented in Table 2.

Table 2 Output data from MacDonald et al. on groundwater characteristics in the study area.

LTA Recharge (Equation)	LTA Recharge (map)	Depth to groundwater	Groundwater productivity	Storage Capacity
45 mm/year	13.7 mm/year	Medium (50-100m)	High 5-20 l/s	Low/medium

The methods above provide rough estimates of groundwater recharge, productivity and storage. For a more precise estimation, detailed local studies comprising assessments of borehole and test pumping data as well as analysis of chloride mass balance or isotopes are required. This is outside the scope of this feasibility study.

Selicho water supply - current situation

The current domestic water supply is sourced from unsafe water from shallow scoop holes in the dry riverbed and brackish water from Lake Turkana. Although several boreholes have been drilled in the area, the groundwater is too saline for any drinking or household use. The shallow dug wells in the Laga, also known as Scoop holes, are located 1.3 to 2 km from the main village centre and only provide water for about three months a year during the rainy seasons. During the dry season, these scoop holes dry out, leaving the community reliant on either brackish lake water or highly saline groundwater, neither of which is suitable for consumption. Other sources of drinking water include water sold by vendors, which is fetched from the scoop holes in the laga or from a borehole in Ileret. The water is sold to the community for between 70 and 200 kes/jerrycan (20 l). See Figure 8 for the identified water supply in Selicho and Figure 9 for typical scoop hole and dugwell.

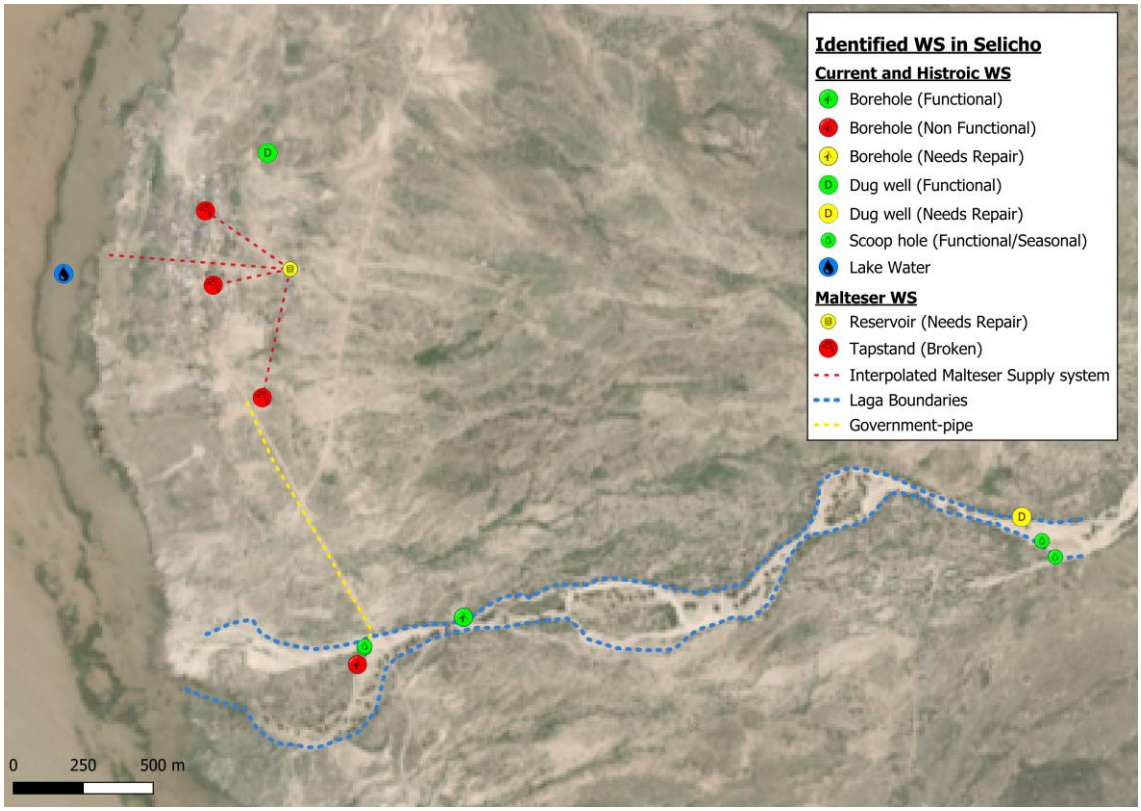


Figure 8 Identified water supply in Selicho



Figure 10 Left: Scoop hole, Right: Measuring groundwater level in a dug well



Figure 11 Lake Turkana shore in Selicho, the main water body is behind the vegetation band

Between 2010 and 2014, a water supply system operated in the area, sourcing water from Lake Turkana and distributing it to three tap stands via a reservoir without any treatment (see Figure 8). This system was implemented by Malteser International. However, as lake levels rose, the pump was relocated to Illeret by the local authorities. After the pump's removal, the system was partly vandalized, leaving only the foundation of the tapstands intact, see Figure 12. The reservoir stand, which includes two 5 m³ tanks, remains in place, and the pipelines are still buried underground. However, in some areas, the pipes have been damaged, indicating that the system is currently nonfunctional and would need rehabilitation. Additionally in 2021 (?), the Kenyan government drilled a borehole 1.8 km from the main village with the aim of connecting

it to the reservoir of the old Malteser system. The borehole proved to be highly saline, but in spite of this a pipeline was installed between the borehole and the village – most likely an effect of unwise contracting allowing the contractor to complete the system even though the water quality was unfit for human consumption. The pipe is likely buried under or runs parallel to the road, crossing the plot owned by FGCK, however, this needs to be confirmed. This pipe could potentially be used in a new system.



Figure 12 Foundation of former tapstand in Selicho center

Groundwater availability and quality

Water quality samples were collected from five groundwater locations and analysed for physio-chemical parameters, see Figure 13.

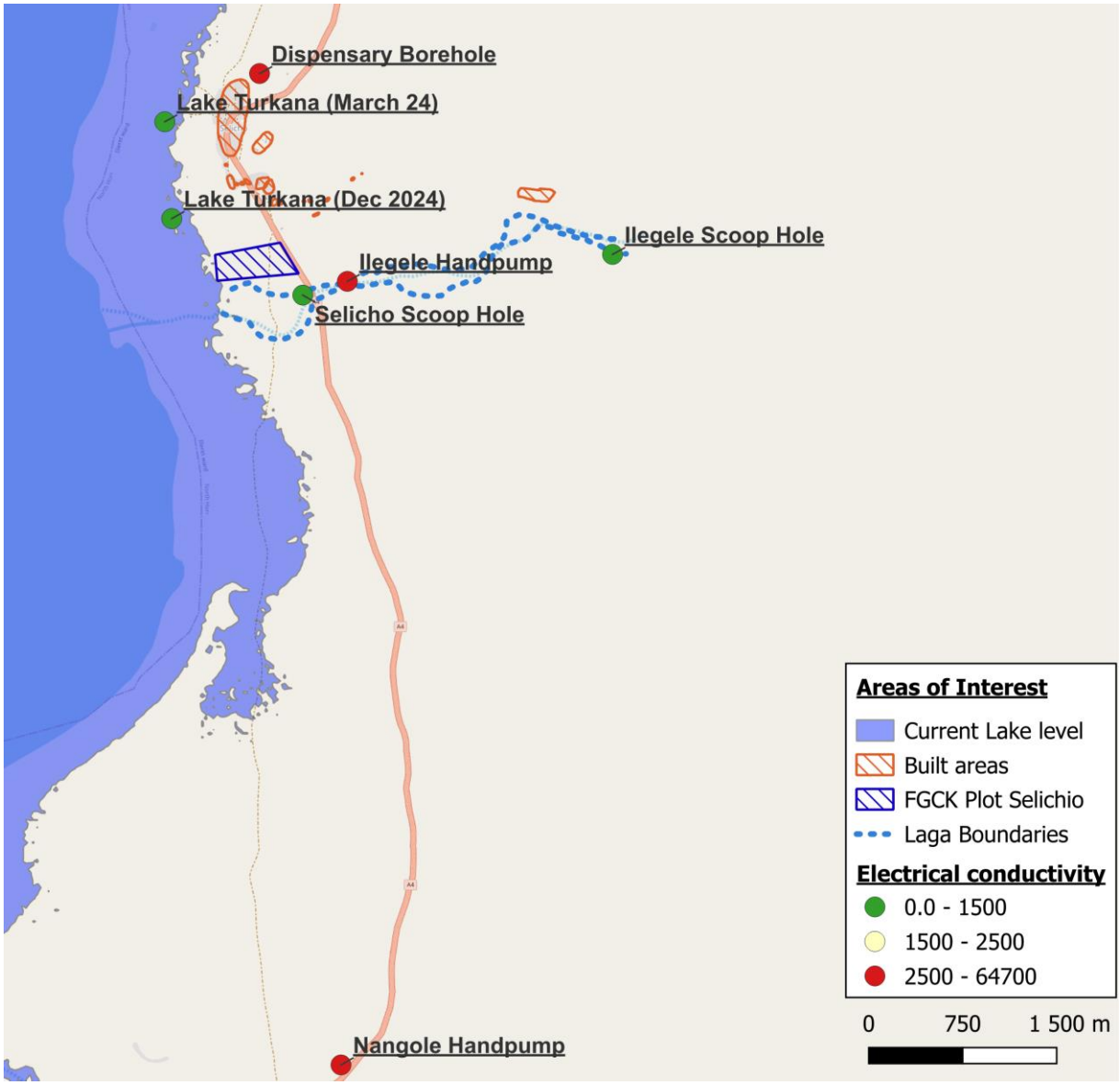


Figure 13 Location of sampled water points and Electrical Conductivity

Boreholes and dug wells

Table 3 Physical-chemical laboratory results of borehole and dug well samples (dispemsary well is dug with a depth of 13 m)

Parameter	Unit	Dispensary	Nangole	Ilgele	Standards
pH	pH	9	7,7	7,6	5.5-9.5 (6.5-8.5)**
Colour	mgPt/l	40	125	150	15**
Turbidity	N.T.U	2,6	143	33	25 (5)**
Conductivity (25°C)	µS/cm	39000	44800	64700	2500 (1500)**
Iron	mg/l	0,4	0,8	1,1	0.3
Manganese	mg/l	ND	0,4	0,2	0.1
Calcium	mg/l	2,4	200	440	150
Magnesium	mg/l	ND	219	49	100
Sodium	mg/l	8957	9641	14274	200
Potassium	mg/l	18	22	12	50
Total Hardness	mg $CaCO_3$/l	6	1400	1300	600 (300)**
Total Alkalinity	mg $CaCO_3$/l	4670	552	2694	500**
Chloride	mg/l	2750	13700	27100	250
Fluoride	mg/l	15	3,5	1,2	1.5
Nitrate	mg/l	ND	2,6	13	45
Nitrite	mg/l	<0,01	0,12	0,01	3
Sulphate	mg/l	10428	140	32	400
Free Carbon Dioxide	mg/l	ND	10	20	Not Applicable
Total Dissolved Solids	mg/l	24180	27776	40114	1500 (1000)**
Arsenic	µg/l	ND	ND	ND	10

None of the boreholes or dug wells in the area provide potable drinking water due to the highly mineralized water and extreme salinity levels, with conductivity values ranging from 39,000 to 64,700 µS/cm compared to Kenya standard of 2,500 µS/cm. Additionally, the water fails to meet the required thresholds for several critical parameters, including total dissolved solids (TDS), chloride, fluoride, sulphate, and alkalinity. The fluoride levels in the dug well (13 m deep) at the dispensary show extremely high levels of fluoride – 15 mg/l, ten times above the WHO guidelines. Desalination is required before the water can be safely used for domestic purposes.

Lagas – shallow groundwater in riverbeds

Table 4 Physical-Chemical Laboratory Results of Laga samples

Parameter	Selicho Scoop Hole	Ilgele Scoop Hole	Standards
pH	8,1	8,3	5.5-9.5 (6.5-8.5)**
Colour	70	10	15**
Turbidity	249	2,5	25 (5)**
Conductivity (25°C)	428	437	2500 (1500)**
Iron	1	0,2	0.3
Manganese	0,3	ND	0.1
Calcium	11	20	150
Magnesium	1,5	4,4	100
Sodium	82	67	200
Potassium	2,2	2,9	50
Total Hardness	34	68	600 (300)**
Total Alkalinity	86	118	500**
Chloride	32	28	250
Fluoride	0,4	0,7	1.5
Nitrate	8,1	3,3	45
Nitrite	0,01	0,01	3
Sulphate	51	46	400
Free Carbon Dioxide	4	ND	Not Applicable
Total Dissolved Solids	265	271	1500 (1000)**
Arsenic	ND	ND	10

Both scoop holes sampled in the laga south of Selicho generally meet Kenyan national standards for most chemical parameters, with conductivity values ranging from 428 to 437 µS/cm, well within the acceptable limits. TDS, chloride, fluoride, nitrate, sulphate, and alkalinity levels also comply with the standards, indicating the water is not mineralized or saline. Iron, color and turbidity levels are elevated in Selicho scoop hole. This could be an effect of mineral particles in the sample, and part of the high iron concentration is probably associated with particulate iron and would be significantly lower in a proper well.

Most probably the scoop holes are contaminated by bacteria as people stand in the water while scooping. The time from sampling to assessment in lab exceeded the recommended 24 h and microbiological parameters were therefore not analyzed.

The groundwater in the laga has the best water quality in the area, and if proper wells are constructed, most probably the elevated levels of iron and manganese in Selicho scoop hole would not be a problem. Also, a proper well would also decrease the risk of bacteriological contamination.

Surface water availability and quality

Quality

Lake Turkana is the world's largest permanent desert lake and alkaline water body, with the Omo River contributing approximately 90% of the lake's inflow. (Ojwang, et al., 2016) The lake's water budget is balanced between river inflows, groundwater exchanges, and evaporation losses. However, water is retained in the lake for only 13 years, leaving behind minerals with saline water and high electrical conductivity (EC). (Avery, 2010).

One water sample was taken from the lake during the field visit, and an additional sample, collected in the same area on 31st March 2024 and provided by FGCK, was used for comparison. The results for the physical-chemical analysis are presented in Table 5. It is not known exactly where the sample from (Abiy et al, 2024) was taken, but most probably on the Ethiopian side of the lake.
The two samples show quite different characteristics, with the sample from December 2024 being considerably more saline, while at the same time having lower hardness, Fe and Mn. Also Fluoride is 2.5 times higher in December than in March 2024. Turbidity is high in both samples, and can be a result of the samples being taken relatively close to the beach in a 100-200 m wide "channel" with shallow water formed between land and a vegetation zone (see Figure 11. In this channel it can be expected that both organic content and turbidity due to dissolved particles are higher than in the main water body.

The cause of these elevated fluoride levels remains unclear and could be due to measurement errors. Abiy et al. (2024) found a fluoride level of 2.03 mg/l in the northern parts of the lake, aligning with the FGCK sample range. Moreover, the local health clinic has not identified fluorosis as a concern, suggesting that fluoride levels are generally acceptable. However, in order to use lake water for domestic water supply, additional sampling at various locations and times is recommended. The recent sample was also tested for heavy metals (chromium, cadmium, aluminum, and lead), all of which were below 0.01 mg/l and are not considered a concern.

However, given the current situation where people drink untreated lake water, a first step could be reducing Fe, Mn, turbidity and organic content in sand filter using slow filtration technology- If further sampling confirms that fluoride levels are around 2 mg/l this might not be ideal, but ok from a health perspective. As a comparison US drinking water standards (EPA) have a level of 4.0 mg/l Fluoride as their limit to prevent skeletal fluorosis. With this perspective, a Fluoride concentration of 2 or even 3.6 mg/l do not pose any acute threat to public health. The expected bacteriological load in the lake poses a much greater risk to public health and priority should be reduction of organic content and desinfection.

Ideally to comply with Kenyan water standards the water should be treated for removal of organic substance in combination with desalination to reduce fluoride to 1.5 mg/l

Table 5 Physical-Chemical Laboratory Results of Lake Water

Parameter	Unit	December Sample	March Sample	Abiy et al. (2024)s	Standards
pH	pH Scale	9.0	8,4	8.8	5.5-9.5 (6.5-8.5)**
Colour	mgPt/l	375	250	-	15**
Turbidity	N.T.U	140	664	162.4	25 (5)**
Conductivity (25°C)	µS/cm	1332	773	9842	2500 (1500)**
Iron	mg/l	0.7	2,8		0.3
Manganese	mg/l	0.3	4,6		0.1
Calcium	mg/l	5.6	14	11.44	150
Magnesium	mg/l	ND	4,4	10.7	100
Sodium	mg/l	296	148		200
Potassium	mg/l	7.2	9,2		50
Total Hardness	mg $CaCO_3$/l	14	52	65	600 (300)**
Total Alkalinity	mg $CaCO_3$/l	212	248	904.8	500**
Chloride	mg/l	310	94	220.1	250
Fluoride	mg/l	4.6	1,8	2.03	1.5 (4)***
Nitrate	mg/l	ND	ND	17.8	45
Nitrite	mg/l	<0.01	<0,01	0.54	3
Sulphate	mg/l	<0.3	ND		400
Free Carbon Dioxide	mg/l	ND	ND		Not Applicable
Total Dissolved Solids	mg/l	826	479	519.6	1500 (1000)**
Arsenic	µg/l	ND	-		10
Chromium	mg/l	<0.01	-		0.05
Cadmium	mg/l	<0.01	-		0.003
Aluminium	mg/l	<0.01	-		0.2
Lead	mg/l	<0.01	-		0.01
Total Organic carbon	mg/l	12.8	-		Not Applicable
Total Suspended Solids	mg/l	17	-		Not Applicable

Lake Levels

Satellite images from Landsat 5, 7, and 8 (L5-L8) with a spatial resolution of 30m were used to map areal fluctuations in lake levels from 1984 to the present. Additionally, Sentinel-2 (S2) imagery, with a higher resolution of 10m, was used from 2019 to the present. For each RGB image, a Normalized Difference Water Index (NDWI) was calculated to distinguish pixels covered by water. Otsu thresholding was applied, which automatically divides the NDWI into a bimodal pixel distribution, distinguishing water from non-water areas by minimizing intra-class variance. Based on this, water occurrence was calculated in Google Earth Engine, defined as the percentage of time a pixel is covered by water. The water occurrence maps are displayed in Figure 14

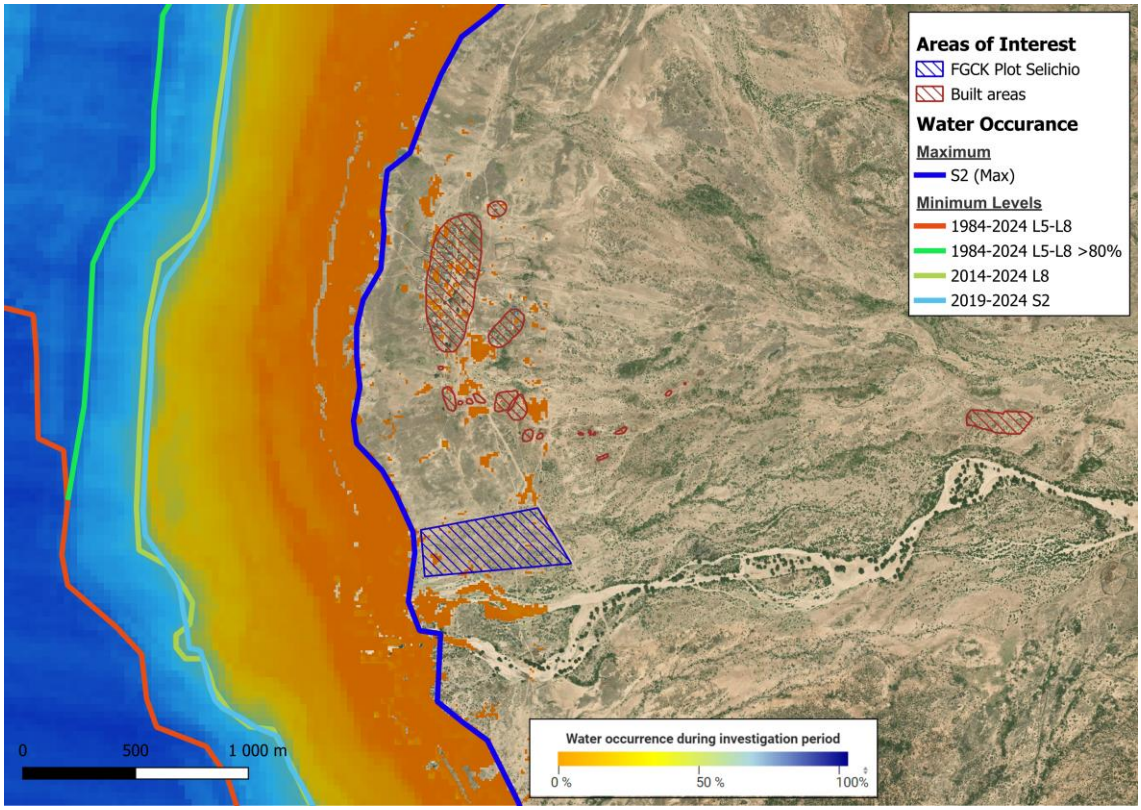


Figure 14 Surface Water Occurrence from 1984-2024

Between 1984 and November 2024, fluctuations in water levels varied by a maximum of approximately 1.3 km horizontally and around 9 meters AMSL. The lowest levels were recorded in the 1990s, while the lake is currently experiencing its highest levels to date. Since 2018, lake levels have steadily risen, accelerating over the past four years, with an annual increase of approximately one meter/year, see Figure 15. Research suggests that extreme rainfall over the catchment areas, increased soil runoff from deforestation, and tectonic activity are contributing factors (Africanews, n.d.).

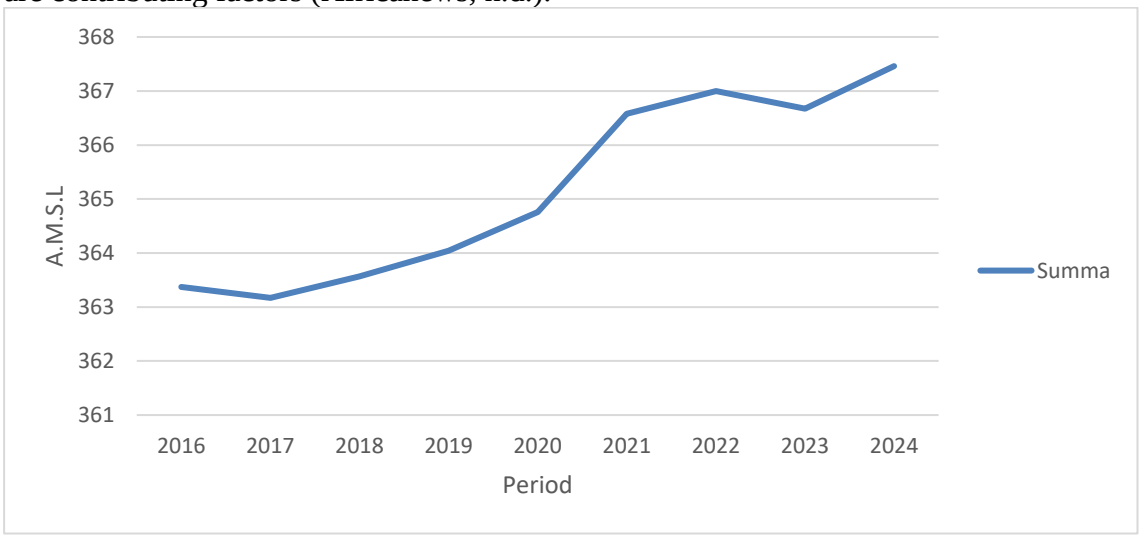


Figure 15 Lake levels in Turkana from 2019-2024 (USDA, 2025)

Willingness to pay

No comprehensive willingness to pay (WTP) assessment was conducted during the field study. Instead, information on current and historical water pricing was gathered through discussions with key local stakeholders. When the Malteser system was operational in the area, the old water committee charged 5 KSH per jerrycan. Given that the water was untreated, the village chief now believed that the WTP could increase to 10-20 KSH per jerrycan if clean water were provided. Currently, for those purchasing scoop hole water from vendors, prices range from 70 to 200 KSH per jerrycan. However, the 200 KSH price is believed to be uncommon, as it is far above what is affordable. Table 6 summarises the current and historical pricing, as well as the potential WTP for clean water.

Table 6 Willingness to Pay

Scenario	Price KSH/ 20 l	Price USD/ 20 l
Malteser system	5	0.04
WTP Clean Water	10-20	0.08-0.15
Vendors	70-200	0.54-1.55

Water demand assessment

According to the Sphere standards, a minimum reference value for water supply is 15 litres per capita per day (l/cap/day), with 20 l/cap/day also commonly used as a benchmark for drinking, cooking, food hygiene, handwashing, and face washing, but excluding other hygiene practices. The WHO recommends 4.6 l/cap/day specifically for drinking water. Based on Selicho population of 2000-2200 people and the reference water demand, the daily water needs are outlined in Table 7.

Table 7 Domestic Water Demand

Water demand	L/Cap/day	m^3/day
Standard benchmark	20	40-44
Sphere	15	30-33
Drinking	4.6	9-10

Other observations

The team had several discussions with Elias Kithinji Ikiugu on the context and opportunities in Selicho. At the moment, several NGOs are active in Ileret, but few reach Selicho. Elias has a solid experience from development and livelihood activities connected to clean water from his 10+ years in Loglogo where a new borehole created opportunities for a school, kitchen gardens, women groups, muringa production et c. For Selicho he has a vision to engage in safe water provision in the community and start agriculture projects with community kitchen gardens and moringa plantations to help decrease the high malnutrition rates.

From our time in Selicho, it is evident that Elias has a good relationship with the local authorities and community leaders, together with his proven ability to develop a water project in Loglogo, it is likely that a water and agriculture project could work also from an O&M perspective.

DISCUSSION OF FINDINGS

Feasible water sources and water supply

Boreholes and deep dug wells

The study shows that although there is groundwater available in boreholes and dug wells, the high salinity and fluoride levels demand desalination before human consumption. The water is also too saline for most agricultural purposes.

Lagas

The groundwater in the laga has a reasonably good chemical water quality although the current scoop holes create high risks of bacteriological contamination. The water availability in the laga is however limited and the groundwater levels drops after the rainy season. The scoop holes are deepened to reach water until approx. 3 m. but 1-2 months after the rains the only available water source is Lake Turkana. Some of the dug wells along the laga were in a bad shape and had not been maintained by the community, in e.g Ilgele the pump was broken and the well was full with debris (note – different hand pump from the Ilgele borehole). The community claimed that the dug well used to dry out. Anyhow, it would provide safer water during rainy season and a few months longerthan the current scoop holes. It is important to strengthen the O&M of the existing WASH infrastructure, and rehabilitation of the well and hand pump would provide a safer water supply during some months of the year.

Potentially, a subsurface dam with a height of 3 m in the laga upstream Selicho could create a storage of 9,000 m^3 that could provide drinking water for Selicho community for the whole year (9 L/person*day for 2500 persons). Detailed surveys of the lithology and the sediments in the laga is needed before design and construction. Test pits for sampling would need to be dug along the laga and to the sides to map the extents and permeability of the sediments. Ideally geophysical surveys such as georadar could be used to measure the sediment depths and extents of impermeable layers or rock that could act as a foundation for the subsurface dam.

Lake Turkana

Lake Turkana has water available year-round and could serve as a source both for drinking water and agricultural purposes. The water is alkaline and slightly brackish, has elevated turbidity and some organic content. The fluoride levels are higher (two samples approx. 2 mg/l, 1 sample 4.6 mg/l) than the WHO and Kenya National standards of 1,5 mg/l. The US EPA drinking water standard is 4 mg/l and the dispensary in Selicho had not observed any sign of fluorosis among the population, if further sampling confirms that the fluoride level is approx. 2 mg/l this would not pose any acute risks to public health.

Ideally the Lake Turkana water should be desalinized before consumption, however given the high capital and operational costs this might not be feasible as a first step. The most acute need would be disinfection of the lake Turkana water as it has high risk of elevated microbiology. For safe chlorination ideally the organic content should be reduced first.

A possible approach could be:

1. Intake of water
    a. Using bank infiltration in the sand sediments where the laga spills into the lake
    b. Surface water intake – ideally outside of the vegetation strip between land and the main water body

Note: Alternative a) is recommended as this probably would decrease turbidity and organic material in the raw water

2. Slow filtration through sand filters at FGCK plot – this would reduce Fe, Mn and organic content and reduce bacteria's with approx. 99%. To reduce cleansing of the schmutzdecke, prefiltration through a contact filter with stones or gravel is recommended. *(Ideally a final decision can be taken after water testing of the bank infiltration water intake- if this works well the prefiltration step might not be needed)*
3. Desinfection with chlorine to improve water quality also at household level (the water from the slow filtration should be free of bacterias, but there is always a risk of contamination when filling jerrycans at tap stands
4. Distribution to tapstands at FGCK plot + three in Selicho village

The intake should be sized so it has capacity of also supplying water for smaller scale kitchen gardens.

Household water treatment

A first step to improve the water situation in Selicho could be introduction of household water treatment, e.g. water filters or solar disinfection (SODIS[1] using empty PET bottles or Solvatten containers [2]. The dispensary is distributing chlorination tablets to households with malnourished children, but distribution and training of household water filters could decrease water-borne diseases in a relatively cost-effective way. There are many examples of household water filtration not being sustainable (or even used) long-term but is recommended as a first relatively non-costly step while raising funds for a more comprehensive water supply solution.

Water for agriculture

Water availability in Lake Turkana offers significant opportunities for irrigation, which could support agriculture projects in Selicho, improving food security, income, and helping to alleviate malnutrition. However, due to the slightly brackish water, only salt-tolerant crops can be grown. Fortunately, the water quality indicate that the salinity in Lake Turkana is below the threshold for most crops, except for highly sensitive crops like beans, carrots, onions, and most fruit trees which should be avoided.

Table 8 summarizes the most salt-tolerant crops and the yield decline with each increase in DS/m. For additional crop options, please refer to the FAO Drainage and Irrigation Paper 61, Annex 1 (Tanji & Neeltje, 2002).

*Table 8 Salt tolerance of common crops (Tanji & Neeltje, 2002) * Samples collected in Selicho*

Crop	Salinity Threshold dS/m	Salinity Lake dS/m	% Yield Decline
Barley	8.0	0.8-1.3	5
Millet	-	0.8-1.3	-
Sorghum	6.8	0.8-1.3	16
Wheat	6.0	0.8-1.3	7.1
Maize	1.7	0.8-1.3	12
Spinach	2.0	0.8-1.3	7.6
Peanuts	3.2	0.8-1.3	29

[1] https://en.wikipedia.org/wiki/Solar_water_disinfection
[2] https://solvatten.org/

Irrigation requirements (IRQ) were estimated using the Kc x ETo approach in FAO Cropwat 8.0, based on the most salt-tolerant crops and agrometeorological data for Selicho. The daily IRQ, presented in Figure 16, reflects the daily average water needed to compensate for the evapotranspiration losses. These estimates do not account for field application efficiency, thus, depending on irrigation methods, the actual IRQ could be 1.11 to 1.66 times higher depending on if surface or drip irrigation is used.

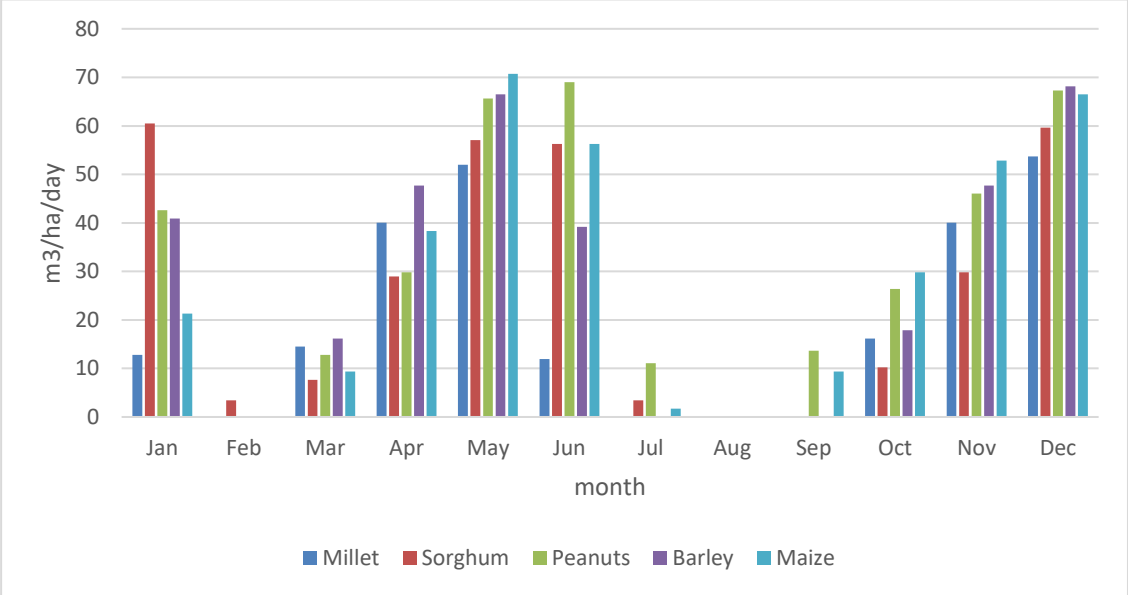


Figure 16 Daily IRQ expressed as m3/ha/day

The highest IRQ occurs in May, reaching around 70 m^3/hectare/day. However, these estimates are based on current climate data for evapotranspiration where actual requirements could be significantly lower if shade houses are used. Combining shade cultivation with drip irrigation can further reduce overall water demand, as it helps control temperature and conserve water. Alternatively, if no shading is applied, gravity-fed irrigation directly from the lake could be considered, as it would reduce the need for pumping and lower operational costs.

The risks of rising water levels do not only affect any WASH infrastructure but if the village of Selicho is flooded in 2027, the population will need to relocate. The need for improved water supply is still there, and a possible intervention should be designed in a way so that it can be moved to a new location, utilizing raw water from lake Turkana.

Lake Turkana rising levels- risks

The fluctuations in Lake Turkana's levels pose a major challenge for both the village and the feasibility of the desalination pilot and other water infrastructure interventions. It is crucial to consider historic low levels to ensure a sufficient distance to the water inlet, while also accounting for potential rises that increase the risk of flooding. The future trends in these fluctuations remain uncertain, with no clear indication of whether the current levels will return to historic lows or continue to rise. If levels continue to rise by 1 meter per year, Selicho is projected to be flooded within the next 2 to 4 years, see Figure 18. In a nearby village rising water levels have already impacted the area, resulting in parts of the village being flooded. (see Figure 17).



Figure 17 Flooded village near Selicho

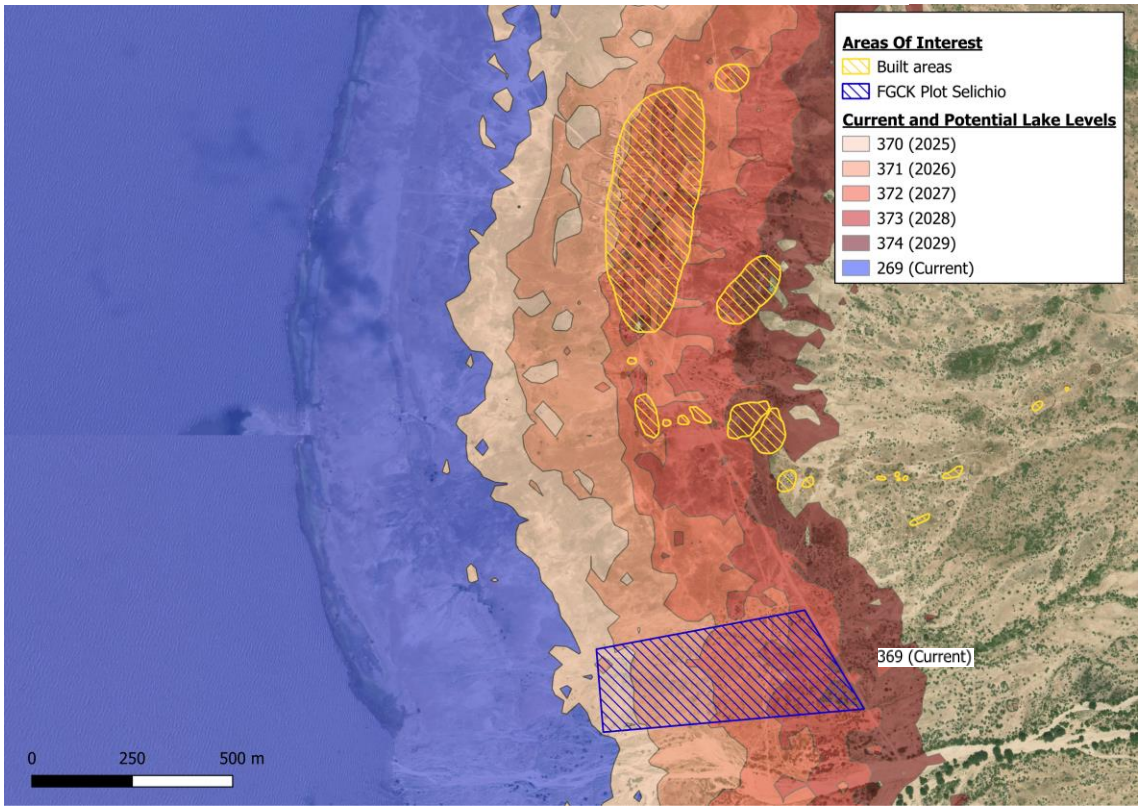


Figure 18 Flood risk map of potential lake level rise, under the assumption that the lake level will increase with the same rate as in 2019-2024

Potential Environmental Impacts

None of the alternatives are expected to have significant environmental impacts. The primary risk associated with piloting a desalination system is the high salinity of the reject water, which may range between 25 and 50 percent of the total water use. The other alternatives that source water directly from Lake Turkana have not been found to pose any risks. One potential risk for constructing a subsurface dam in the laga is a reduced inflow of freshwater into the lake, potentially affecting the local ecosystem. However, because the contribution of the Laga in Selicho is minimal compared to the Omo River and other catchments, any environmental impacts are considered negligible.

IDENTIFICATION OF ALTERNATIVES/OPTIONS/SCENARIOS

Options 1, 2 and 3 present the most feasible options while option 4 and 5 includes desalination. Option 6, The initial recommendation to improve water quality is to proceed with any of alternatives 1-3. Managed aquifer recharge is also a recommended option but needs piloting on a larger scale. More detailed information on technical solutions is found in the following appendices.

- Solutions for lake water intakes in – Appendix A
- Design of pipes and pumps in – Appendix B
- Subsurface dam in the Laga in – Appendix C
- Technical implementation of SSF – Appendix D
- Technical implementation of MAR – Appendix E
- Technical implementation of Collectors Well – Appendix F
- Bill of Quantities – Appendix G

1) Slow Sand Filter Treatment + Irrigation

The first scenario excludes piloting a desalination system but still using the FGCK plot as the inlet for irrigation and an SPWS. This approach offers an initial step for supplying water for kitchen gardening and less advanced treated drinking water. It may be possible to use the existing government-installed pipeline to transport treated water to Selicho with a gravity fed system from a 5m water tower, but the diameter and precise location of that pipeline must first be confirmed. Alternatively, could tapstands be installed at the plot for people to fetch water. Although this option requires a 0.8 to 1.2 km walk, which exceeds the 500 m maximum recommended by the Sphere standards, it is still more accessible than the current situation. Figure 19 provides a local overview of this option.

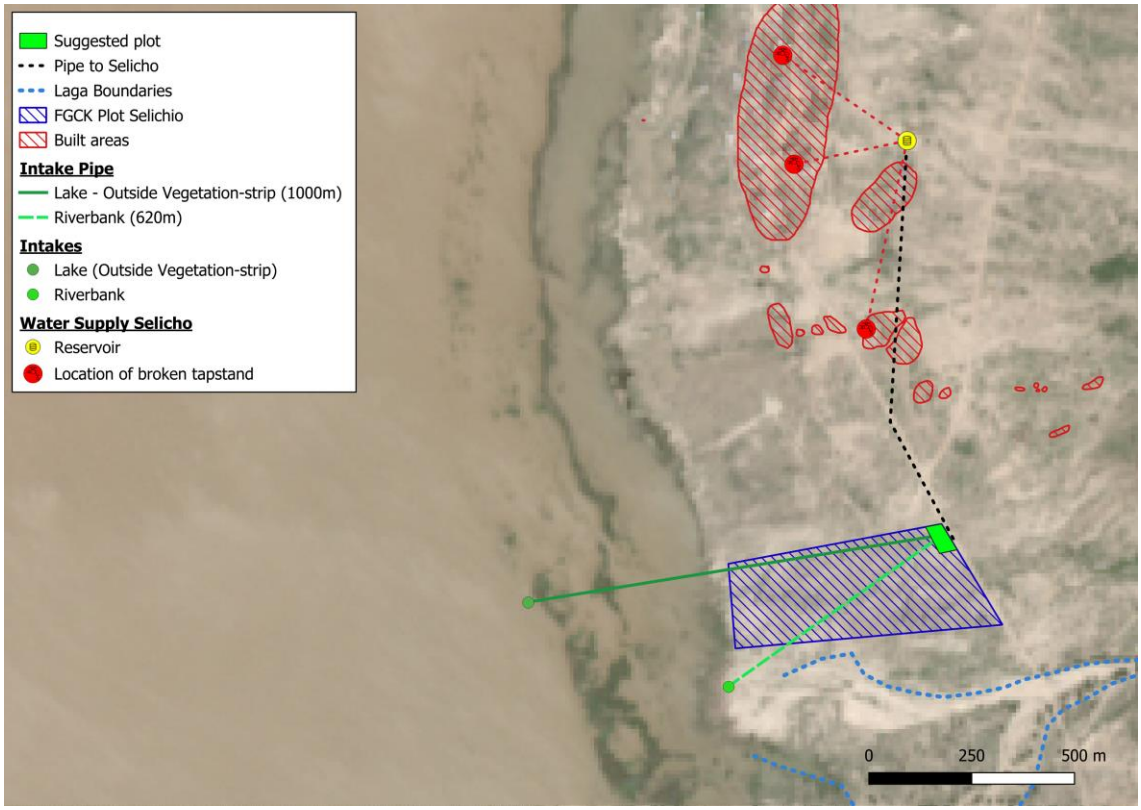


Figure 19 Overview of alternative 1 including intake and required land. Green intakes are the most feasible

Figure 20 presents a simplified schematic overview of the treatment, where solutions on different intakes are found in Appendix A, design of the inlet pump, inlet pipe and pipe to Selicho in Appendix B and technical design of the treatment in Appendix D. Note that the design below is highly conceptual and may not be the most feasible option.

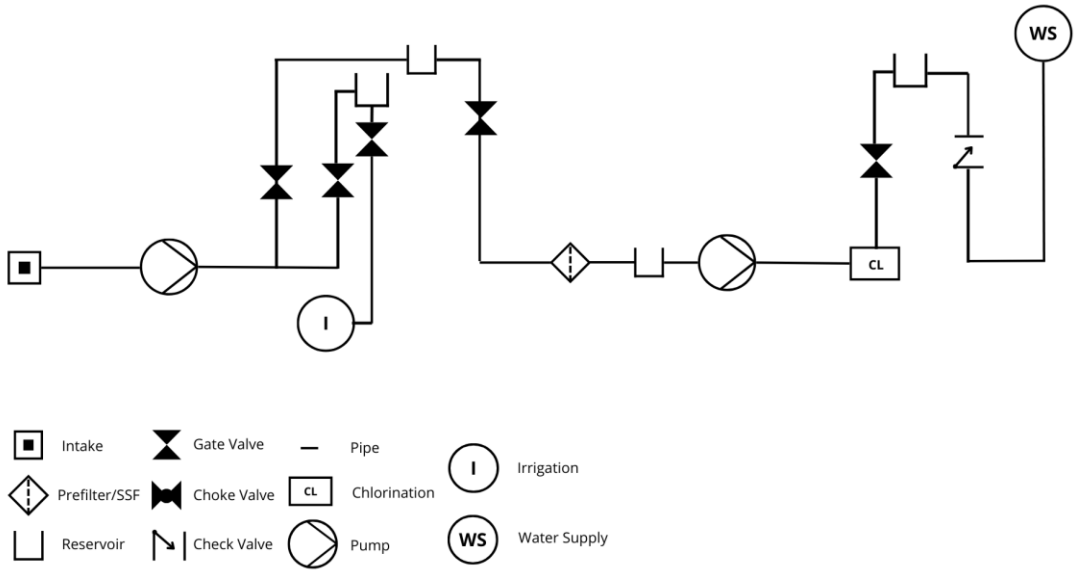


Figure 20 Schematic overview of Alternative 1 - See appendix D for technical detailes.

To use lake water, additional water samples are required. Before water enters the SSF, the incoming water should have an NTU value below 25-30 NTU. If water from any intake option exceeds this threshold, a contact filter is needed to reduce Turbidity. Preferably, a bank-infiltration intake should be used to minimize Turbidity. With this approach, the water is likely to have a sufficiently low NTU, eliminating the need for a contact filter. The design solutions for the prefilter (contact filter) and SSF are detailed in Appendix D.

For a drip irrigation system in Kenya, the recommended height of a water tower is typically around 3 meters to ensure sufficient water pressure for the drip lines to function properly. There are several suppliers in Kenya that provide complete drip irrigation kits designed to connect to a reservoir. It is important to note that pre-filtration is also required to remove solids, as this helps prevent clogging in the small-diameter pipes.

2) Water harvesting in Laga

The samples from the lagas indicated that the water is chemically suitable for domestic purposes. The fourth option involves scaling up the current scoop holes in the lagas into a larger-scale water harvesting system, where shallow groundwater from the lagas is collected into a collector well. Since the scoop holes are open and prone to contamination, this approach would provide protected water, potentially enhancing water security by supplying clean water over an extended seasonal period.

The most suitable locations for water harvesting are just upstream of wider sections of the laga. These areas are ideal because of the presence of coarser material deposited due to the higher velocity of flow in narrower upstream sections. See Figure 21 for the identified areas.

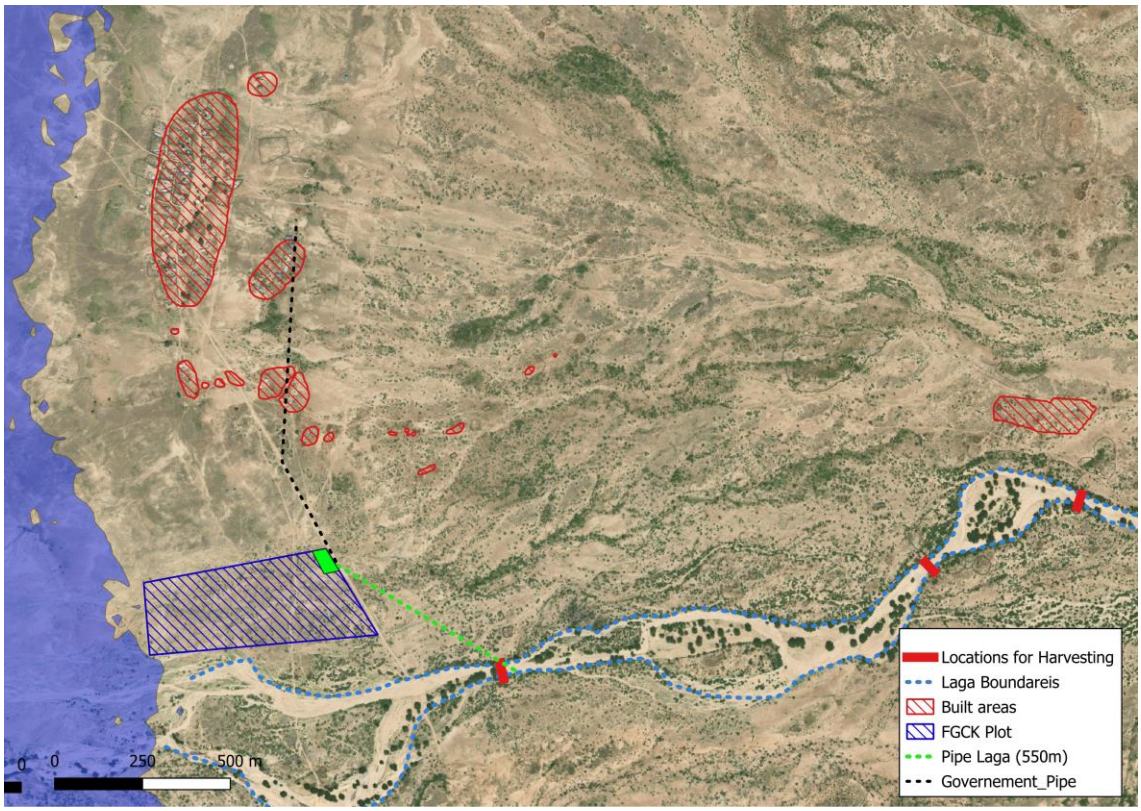


Figure 21 Suitable locations for water harvesting + piping to the plot and distributing with water tower to Selicho

Before implementing this approach, further investigations are needed to determine key parameters such as the optimal depth of the collector well, depth to bedrock and confining layers aquifer thickness, and permeability of the riverbed. Data can be gathered through geophysical measurements, point sampling from digging, or borelogs from nearby boreholes like the Ilegele handpump and the government-implemented borehole. If these parameters are well known, it could be feasible to construct a subsurface dam. This combination would improve water retention in the riverbed by restricting subsurface flow and providing a reservoir covering the annual domestic water demand in Selicho, see Appendix C for storage estimates and Figure 22 for a typical sub-surface dam. However, the field observations did not reveal any outcrops along the riverbanks, which may impact feasibility.

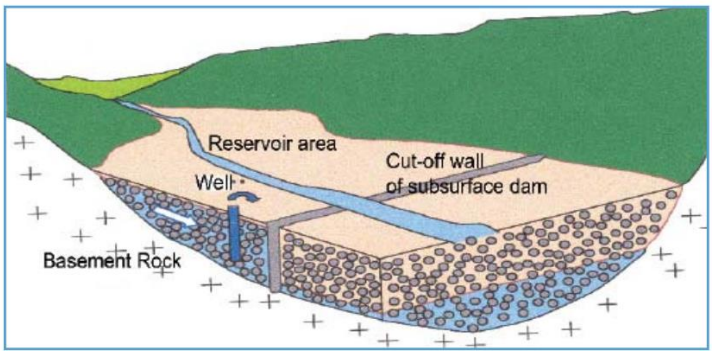


Figure 22. Schematic cross-section of typical sub-surface dam (VSF, 2006)

Should conditions be suitable for creating a subsurface reservoir, this solution could be combined with using the FGCK plot for storage, chlorination, and transporting water to Selicho. The technical requirements would be largely similar to those of Alternative 1, with instead the collector well serving as the intake, thereby removing the need for pre-filtration.

Nevertheless, it is recommended that this alternative is restricted to domestic water supply and should not be used for irrigation. The reservoir's limited capacity may not sustainably meet agricultural demands, and allocating a large portion of the laga to one user could create conflicts, as the laga is currently the only communal source of clean water.

3) Household Water filter

An initial step to improve water quality in Selicho is to distribute household water filters, such as the Village Filter. The Village Water Filter is a bucket system that uses a fibre membrane to effectively remove bacteria and protozoa. It does not remove dissolved solids like chemicals or heavy metals, but based on the water quality reports, this is not a major concern for the lake water. The filter's lifespan depends on water turbidity and maintenance, however, with proper care, it can last for several years.

4) Desalination of Lake Water + Irrigation

The third scenario involves using water from Lake Turkana for the desalination pilot, treating it at the FGCK plot, and piping water to Selicho as well as implementing irrigation using the same inlet. This option is similar as option 1, with the difference that desalination is also used. It should be noted that the salinity levels in Lake Turkana are already within the range suitable for domestic use; however, the water could still benefit from desalination to remove fluoride and other minerals.

Given the overall domestic water demand of around 30 m^3/day and drinking demand of 10 m^3/day, an alternative strategy with desalination of drinking water only could be more feasible e.g. 7-10 m^3/d. This could ideally be combined with a less advanced treatment of the bulk water needs, for example, chlorination, to eliminate bacteria. Figure 23 presents a simplified schematic overview of the treatment, where solutions on different intake solutions are found in Appendix A and design of inlet pump, inlet pipe and pipe to Selicho in Appendix B. In the figure below, two reservoirs are shown. The total volume, which is the number of reservoirs, depends on the maximum daily demand and irrigated area. If only small-scale drip irrigation in the shade house and water supply is required, a single reservoir would suffice.

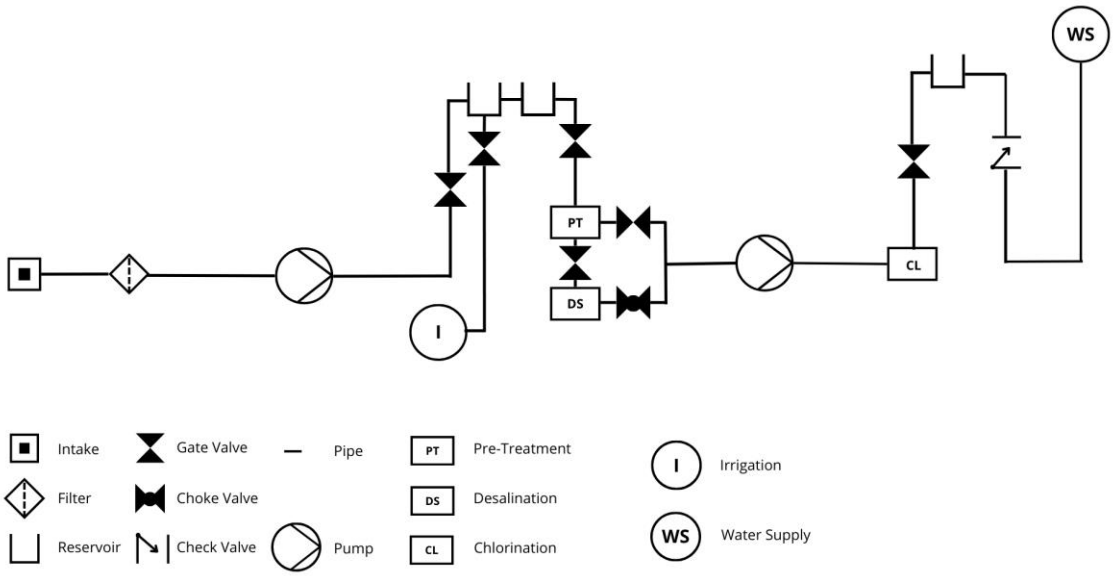


Figure 23 Schematic overview of Lake Turkana desalination.

5) Small scale desalination at health clinic

The third option builds on desalinating groundwater from the dug well at Selicho Health Clinic. This option will produce sufficient clean water to meet the daily needs of the clinic while excess water could be sold for drinking purposes only for the community. A capacity of producing 5-10 m3/day would allow 1-2 jerrycans/day/household, while this volume doesn't cover the full demand it at least provides 2.2-4.5 l/cap /day of drinking water.

The Schematic design of this alternative is presented in Figure 24. Comparing this with alternative 4 offers a simpler approach in terms of capital cost and installation since it's more concentrated and piping over long distances is not required.

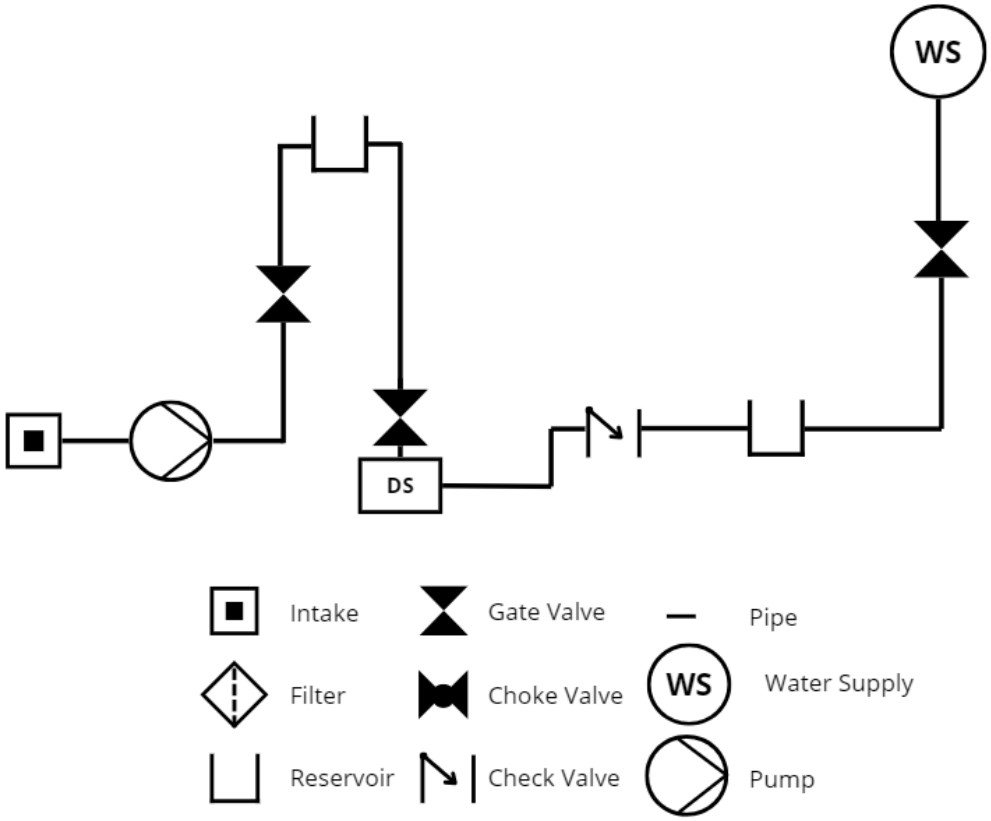


Figure 24 Schematic overview of desalination pilot at Selicho health clinic

The water tower should be at least 3 meters tall to provide sufficient pressure for the desalination process. The well is 12 meters deep (40 ft), and the static water level was measured at 5.7 meters, indicating the pump should be placed at a depth of 8–10 meters. Therefore, it is recommended to select a pump capable of lifting at least 13 meters and sustaining a flow of 1 l/s. The selection of pipes between components should be made in consultation with the desalination unit manufacturer, however, around 20 meters is estimated to be required.

6) Managed Aquifer Recharge (MAR)

Managed Aquifer Recharge (MAR) can be used not only to increase groundwater availability, but also to improve water quality. For Lake Turkana area, MAR could have great potential in areas where the Lake Turkana water is not too saline for human consumption (like the water samples from Selicho). By infiltrating water from Lake Turkana in the sand sediments in the lagas and abstracting the recharged water in wells (or even better a horizontal well screen connected to a collector well) 50-100 m downstream, the natural filtration processes in the alluvial sediments in combination with microbiological processes would greatly reduce the organic content, high turbidity, bacteria's and manganese and iron content. The salinity and fluoride content would not be reduced but given the current situation where the population drink lake water contaminated by bacteria a MAR system would greatly improve the situation. (Chlorination of the lake water with its high content of organic matter is also not very effective and can in chlorinated organic substances that is harmful to health). Figure 25 describes a local overview of MAR. Technical details are found in Appendix E for MAR and Appendix F for the collector well.

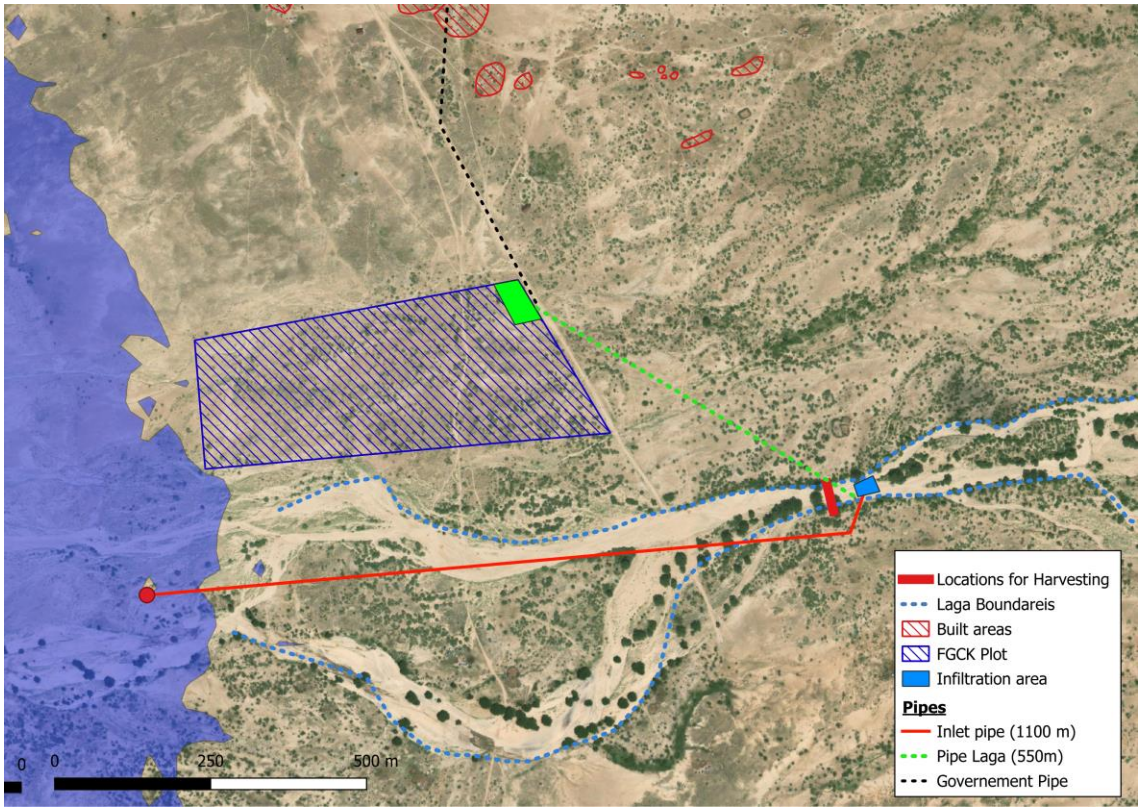


Figure 25 Local overview of MAR in Selicho

This concept of using MAR to improve water quality and availability is widely used in e.g. Sweden. It needs careful siting and piloting but could be a long-term cost-effective method of improving the water quality around Lake Turkana. The main challenge is expected to be to recover the recharged lake water in the laga.

Before considering MAR using water from Lake Turkana, it is recommended to monitor the water quality with regards to salinity and fluoride monthly for 12 months.

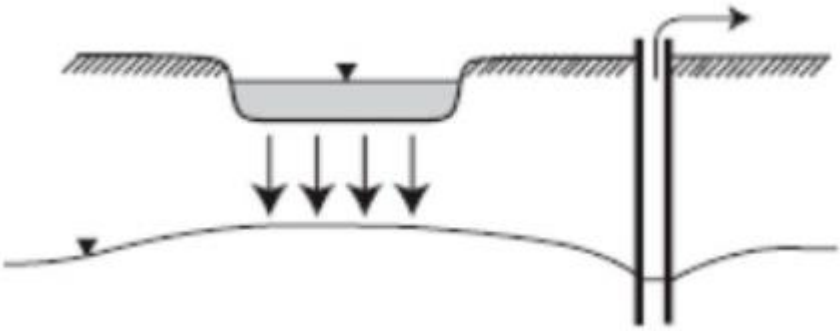


Figure 26 Primciple of MAR basin inflíltration

Cost and Materials

The table below provides a rough cost estimate for the different identified alternatives. It is important to note that these estimates are highly indicative as they build on conceptual designs and should be used for comparison purposes only. Additionally, labor and transportation costs are not included, which can significantly impact the total cost - especially for MAR and water harvesting, as they require extensive excavation work.

Alternative	**Estimated cost (KSH)**
Slow Sand Filter Treatment + Irrigation	6 887 000
Water harvesting in Laga	5 700 000
HH Water Filters	1 500 000
Desalination of Lake Water + Irrigation	14 148 000
Small-scale desalination at health clinic	12 000 000
Managed Aquifer Recharge	7 528 000

Recommendations and Conclusions

Selicho faces several challenges. Water quality in the area is very poor, with highly saline and heavily mineralized groundwater, potentially contaminated lake water; and clean water available from the laga only a few months each year (and this too gets contaminated when people stand in the scoopholes). Coupled with difficulties in practising agriculture and high malnutrition rates, the needs are high. The remoteness of the area further complicates the implementation, maintenance, and monitoring of any WASH project, especially a pilot that requires continuous follow-up.

The primary concern, however, is the uncertainty around lake levels. If they continue to rise, the long-term viability of a pilot desalination system could be compromised, and there may also be a need to relocate the village. Despite these challenges, there are opportunities. If lake levels stabilize, the community could greatly benefit from desalination. Additionally, irrigation could be feasible using several identified salt-tolerant crops.

As an initial step, the recommendation is to distribute household filters and explore the feasibility of constructing either a sub-surface dam system in the laga, or implementing irrigation and SSF-treated lake water at the FGCK plot. Furthermore, could MAR be an effective solution improving water supply in the area. This needs however to be piloted on a large scale to assess the feasibility. See Figure 27 for main challenges, opportunities and recommended actions.



Figure 27 Challenges, Opportunities and Actions

References

Abiy, A. K., Girma, T. Y., Sorsa, S., & Yohannes, S. B. (2024). Evaluating Water Quality of Lower Omo River and the Ethiopian part of Lake Turkana, Southern Ethiopia. *Journal of Applied Sciences and Environmental Management*, 187-194.

Acacia. (2017a). *Marsabit County Water Resources Factsheet.* Retrieved from https://kenyarapid.acaciadata.com/media/cluster3/Marsabit_County_WR_factsheet.pdf

Acacia. (2017b). *Support for water sector plan developent - Marsabit County*. Retrieved from file:///C:/Users/GustavKellgren/OneDrive%20-%20L%C3%A4karmissionen/Turkana/FS/Reports/Water%20resources/Support_for_water_sector_plan_development_-_Marsabit%20Acacia%20Water.pdf

Africanews. (n.d.). *Kenya's Lake Turkana water level rises, cutting off islanders*. Retrieved from africanews: https://www.africanews.com/2022/08/23/kenyas-lake-turkana-water-level-rises-cutting-off-islanders/#:~:text=%2D%20Blessings%20and%20curses%20%2D,all%20cited%20as%20contributing%20causes.&text=Blessings%20and%20curses%20%2D-,The%20phenomenon%20has%20profoun

Akvopedia. (2019). *Water Portal / Rainwater Harvesting / Surface water / Floating intake*. Retrieved from Akvopedia: https://akvopedia.org/wiki/Water_Portal_/_Rainwater_Harvesting_/_Surface_water_/_Floating_intake

Avery, S. (2010). *HYDROLOGICAL IMPACTS OF ETHIOPIA'S.* Retrieved from https://www.afdb.org/fileadmin/uploads/afdb/Documents/Compliance-Review/REPORT_NOV_2010_S_AVERY_TURKANA_Small_file.pdf

Chatterton, K., & Shaw, R. (2025). *Loughborough University.* Retrieved from https://doi.org/10.17028/rd.lboro.8095175.v2

ESA. (2021). Retrieved from https://worldcover2021.esa.int/

KNBS. (2019). *Distribution Of Population by Socio Economic Characteristics.* Nairobi: KNBS.

MacDonald, A., Lark, R. M., Taylor, R. G., Abiye, T., Fallas, H. C., Favreau, G., . . . West, C. (2021). Mapping groundwater recharge in Africa from ground observations and implications for water security. *Environmental Research Letters*, 034012.

Ojwang, W. O., Obiero, K. O., Donde, O. O., Gownaris, N., Pikitch, E. K., Omondi, R., . . . Avery, S. T. (2016). *Lake Turkana: World's Largest Permanent Desert Lake (Kenya9.*

Tanji, K., & Neeltje, K. (2002). *Agricultural Drainage Water Management in Arid and Semi-Arid Areas.* Rome: FAO.

USDA. (2025). *Global Reservoirs and Lakes Monitor (G-REALM).* Retrieved from Lake Turkana: https://ipad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_chart.aspx?regionid=eafrica&reservoir_name=Turkana&lakeid=000093

VSF. (2006). . *SubSurface Dams : a simple, safe and affordable technology for pastoralists - A manual on SubSurface Dams construction based on an experience of Vétérinaires Sans Frontières in Turkana District (Kenya).* Belgium: Vétérinaires Sans Frontières.

Appendices

A. Inlet solutions for alternatives 1 and 3

Lake Intake

For a lake intake, it should be installed on an anchored floating platform to minimize sediment entering the system. Additionally, the technical requirements for the inlet include a screen at the pipe mouth, and the pipe should be flexible to accommodate fluctuations in water levels. The pipe should be submerged between 0.5 and 1m below water level, A principal drawing is solutions is outlined in Figure 28.

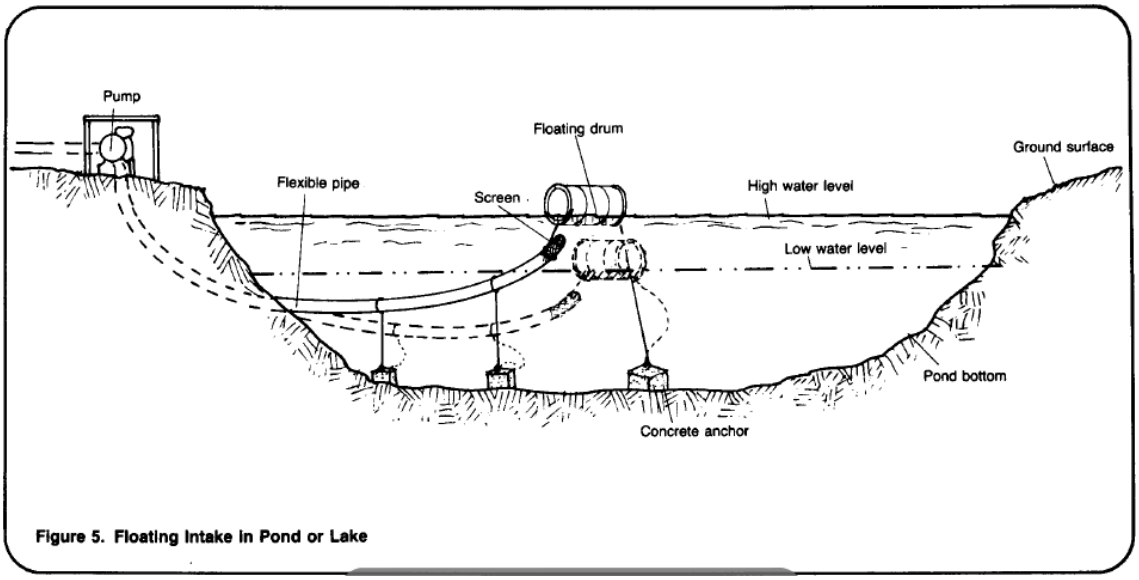


Figure 28 Floating Lake Intake (Akvopedia, 2019)

Bank Filtration

If bank filtration is used, the well screen should be buried at a depth of 1.5 meters to extract infiltrated groundwater while minimizing the intake of native groundwater. The area surrounding the horizontal well screen should be packed with a filter material, consisting of a 30 cm gravel layer (2–4 mm), followed by a sand layer. A protective geotextile layer may also be added to reduce sediment intrusion. Figure 29 illustrates this option.

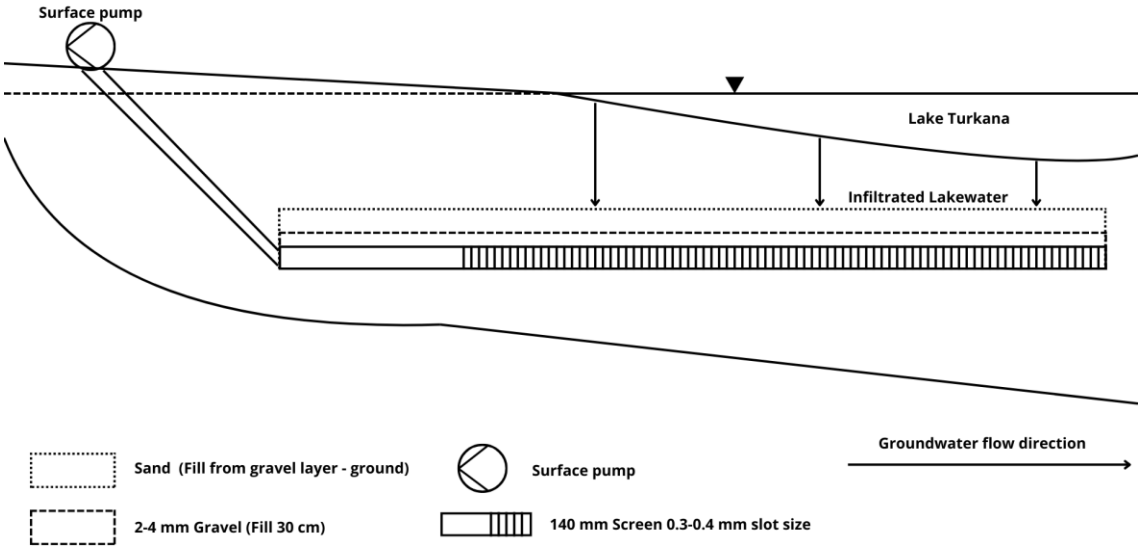


Figure 29 Technical implementation of bank infiltration

The well screen should be made of PVC with slot sizes smaller than 1 mm. For this case, an outer diameter of 140 mm with a slot size of 0.3–0.4 mm could be used, allowing a discharge of 2.4 m³/h per meter while maintaining an entry velocity of 0.03 m/s. Therefore, the potential water demand, based on 8 hours of operation and a 1–3-meter screen, is presented in Table 9.

Table 9 Daily water demand VS Screen length

Meters of screen	Daily Demand (m^3/day)
1	19
2	38
3	58

If lake levels remain stable or continue to rise, 620 meters of piping will be needed, as this is the distance to the current water's edge in the laga. However, if the lake recedes, a longer pipe will be required, and the inlet must be relocated accordingly Therefore, it is recommended to place the inlet at the current water's edge before the rainy season, as this is likely the lowest annual level, while also ensuring the possibility of extending the inlet if water levels drop further.

B. Head losses for pump and pipes

For bank filtration, a surface pump is required, while for lake intake, either a submerged pump at the inlet or a surface pump can be used. A surface pump is generally more cost-effective as it significantly reduces capital costs, given the high expense of pump cables. However, uncertainties in lake fluctuations pose a risk of flooding the pump, as it needs to be located close to the water's edge to minimize suction distance. Therefore, these factors should be carefully evaluated to balance costs and risks.

The required pipe length for both bank infiltration and floating intake is determined by lake levels where if the water levels decrease, longer pipe is required increasing both head losses in pipe and greater static head. If levels increase, no modification of inlets are required.

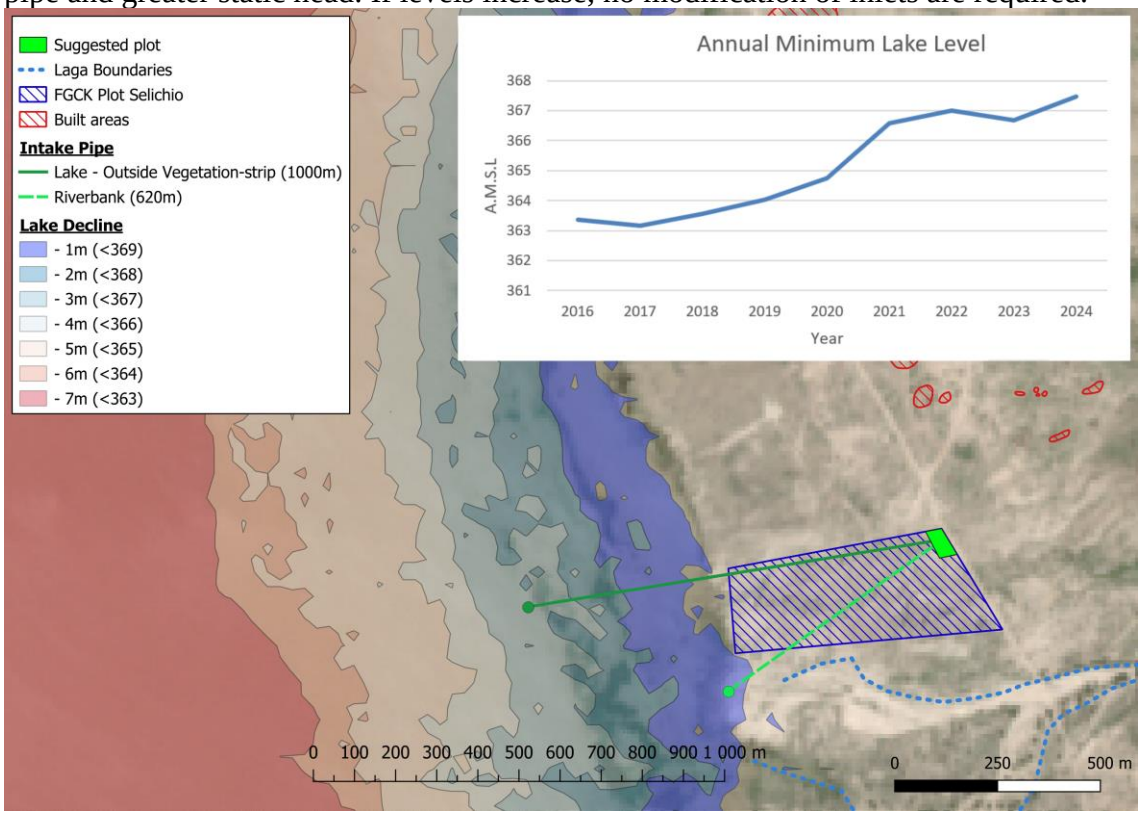


Figure 30 Required pipe length VS Decline in lake levels

Pump and pipe for floating lake intake

To accommodate for potential declines in lake levels, the most cost-effective option would initally be to place the inlet just outside the vegetation-strip, with the possibility of extending the pipe if or simultaneously as the lake levels decline. This approach would lower initial capital and labour costs, requiring only about 1,000 meters of piping.

Given an OD 90 mm pipe is used, the pump should be selected based on Figure 31 if a floating The figure illustrates the pump head as a function of flow rates, pipe length, and potential lake level decreases. If water levels drop below the capacity of the initial 1000-meter pipeline, the pipe must be extended, resulting in a greater static head and increased head losses due to the longer pipeline. Static head was calculated based on elevation differences and a 5-meter reservoir structure.

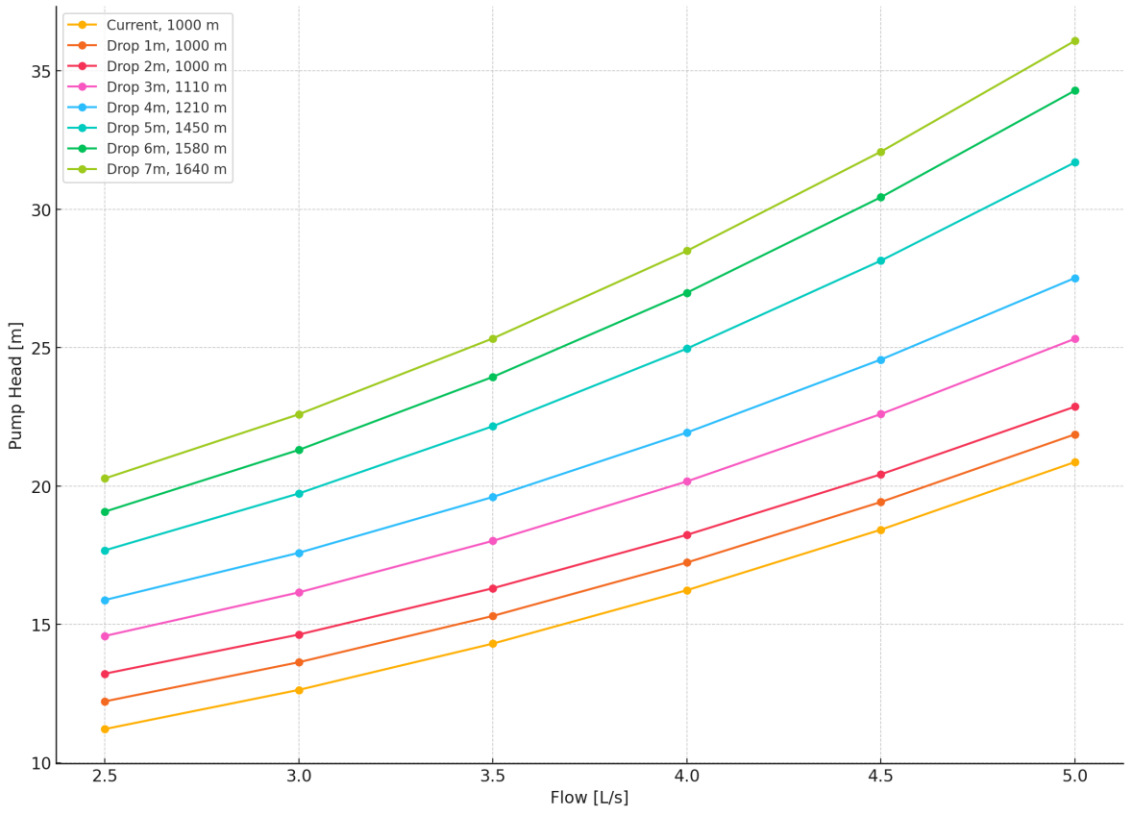


Figure 31 Pump Head for floating lake water intakes based on fluctuations in static head, flow and pipe length

Pump and pipe for bank infiltration

An OD 75 mm pipe would be sufficient if the distance to the water edge remains around 620 meters. However, if lake levels drop below this, it would be better to use an OD 90 pipe. Similarly, as for the lake intake Figure 32, illustrated pump head as a function of flow rates, pipe length, and potential lake level decreases.

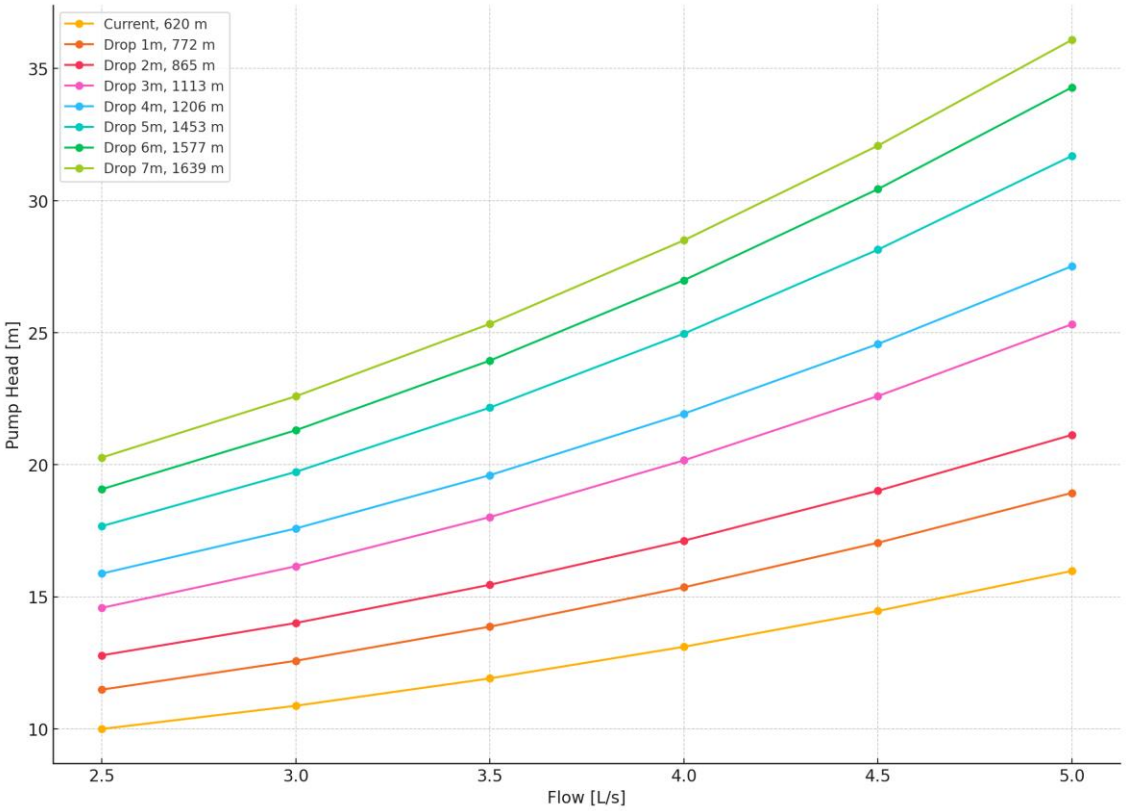


Figure 32 Pump Head for riverbank filtration water intakes based on fluctuations in static head, flow and pipe length

Pipe to Selicho

The head losses for the pipe from the plot to Selicho depend on the desired flow. The baseline value of 1.5 l/s was estimated based on Sphere standards of 7.5 l/min per tap, 3 tap stands and 4 taps per tap stand. If a higher flow is needed (exceeding 7.5 l/min per tap) or if demand increases over time, head losses should not exceed 3 m, which corresponds to around 2.2 l/s, see Figure 33. In such cases, a larger-diameter pipe should be considered to ensure sufficient capacity.

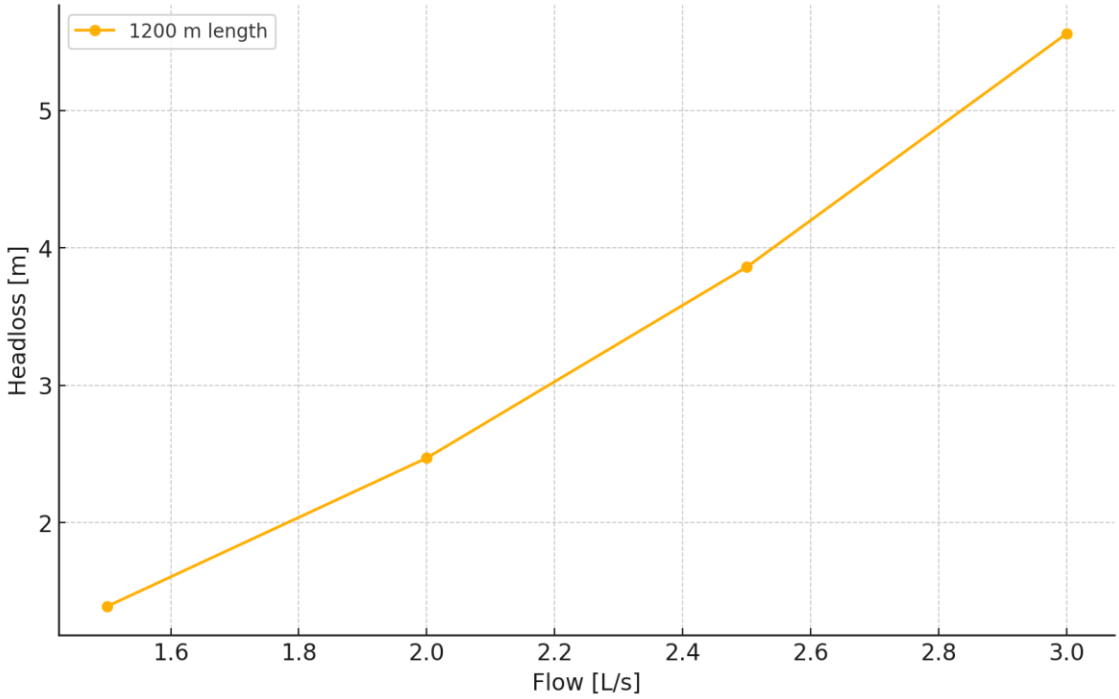


Figure 33 Headlosses for WS-Pipe (OD 90) between Selicho and FGCK-plot

C. Stored volume in laga of subsurface dam

If further investigations confirm the feasibility of constructing a subsurface dam, the potential storage volume can be estimated based on the surface area of the laga, porosity, and the depth of the laga.

A centerline (x) was placed along a 1 km section of the Laga to generate a terrain profile and divide the Laga into perpendicular sections at 30-meter intervals. The accumulated area for each 30-meter increment was calculated to analyze how the area changes along the x-axis. A polynomial regression was applied to the area data, achieving an R^2 value of 0.99, indicating a strong fit and resulting in the area function A(x).

Similarly, a linear regression was performed along the terrain profile under the assumption that the bedrock follows the DEM, giving a depth function D(x) that describes depth variations along the centerline.

The potential storage at different depths to bedrock at the dam wall, was determined by integrating the derivative of A(x) and D(x) along the x-axis, as described in Equation 2. Since an increase in depth affects the corresponding upstream distance, it also influences the accumulated area at that location, leading to greater overall storage capacity. The storage potential as a function of dam wall depth is illustrated in Figure 34.

Equation 2

$$\emptyset * \int_0^{h/k} A'(x) * D(x)dx$$

Ø= Porosity (0.15%)
A(x) = Area along Centreline
D(x) = Depth along Centreline (Kx+h)
h= Damwall Depth

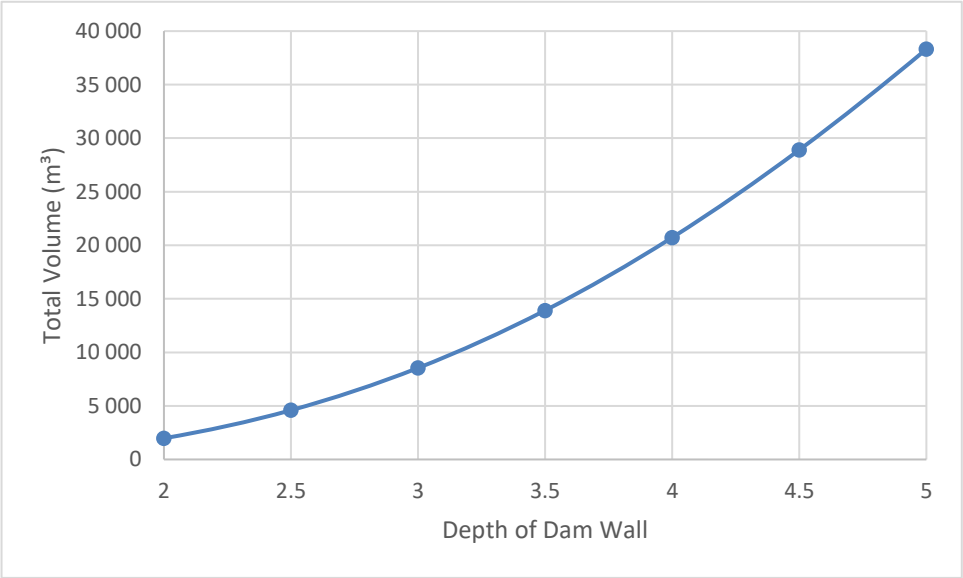


Figure 34 Estimated storage in a subsurface dam in the laga. Note that this is the location closest to the FGCK plot.

D. Treatment options

Figure 35 illustrates the treatment process for Alternative 1. If the incoming lake water has a turbidity level above 25-30 NTU, a contact filter should be used to ensure proper operation of the SSF.

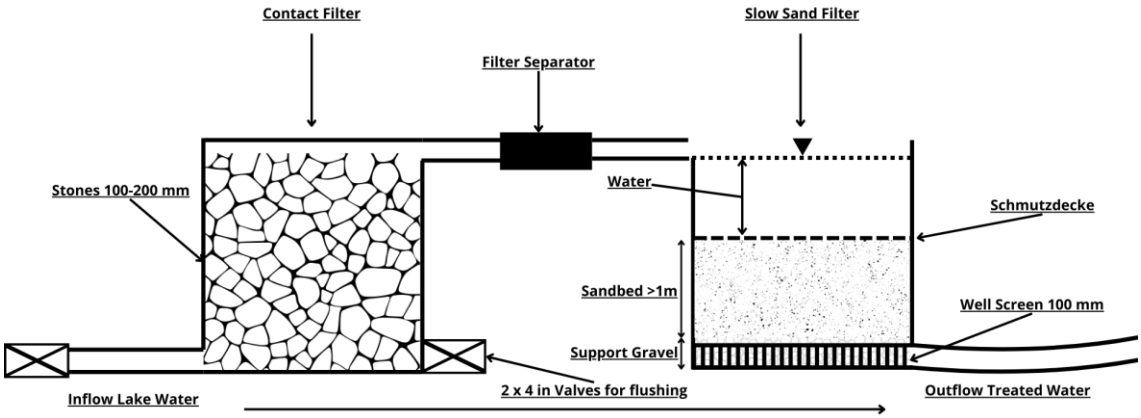


Figure 35 Treatment for Alternative 1 for SSF and reducing Turbidity

Regulating the inflow to the filters

To maintain a constant inflow of 1 m³/hour, different regulation methods can be used depending on budget, energy availability, and operational capacity. The primary solutions are:

1. Variable Speed Drive (VSD) Pump

A VSD pump dynamically adjusts its motor speed to maintain a precise 1 m³/hour flow rate, compensating for variations in reservoir water levels and pressure. This solution provides high accuracy but requires a external power supply, leading to higher initial costs, and demands regular maintenance.

2. Constant Head Reservoir

A constant head reservoir with a float switch could be placed after the main reservoir, ensuring a stable water level and regulating flow using gravity. Water exits through a fixed outlet or flow control device. This method is energy-efficient and ideal for gravity-fed systems, reducing O&M costs while eliminating the need for additional energy

Design of the filters

The contact filter should be filled with 100–200 mm stones, preferably sourced locally to minimize capital costs. The filter should be equipped with two 4-inch valves for flushing and cleaning the system. After passing through a filter separator, approximately 1 meter of water should infiltrate through a 1-meter sand layer, a common guideline is a 1:1 ratio of sand to water depth. The sand should also be locally sourced and needs to be replaced every 4-5 years. At the bottom of the slow sand filter, a layer of support gravel and a 100 mm well screen should be installed before the treated water outflow.

The design and required filtration area depend on the daily demand and key assumptions stated below: The required area for each filter is presented in Table 10

- Filtration rate of contact filter V_C = 1m/h
- Filtration rate of SSF V_{SSF} = 0.1m/h
- 8 hours of operation per day
- Daily demand 10-30 m^3/day
- Inner diameter of manhole rings 1200 mm
- Height of filter = 2 m – 2 manhole rings on top of each other.

Table 10 Required area for various daily demands

Q(m^3/d)	Area Contact filter(m^2)	**No. Parallel filters**	No. Rings	Area SSF(m^2)	**No. Parallel filters**	No. Rings
10	1,3	**2**	4	4,2	**4**	8
13	1,6	**2**	4	5,4	**5**	10
16	2,0	**2**	4	6,7	**6**	12
18	2,3	**2**	4	7,5	**7**	14
21	2,6	**3**	6	8,8	**8**	16
24	3,0	**3**	6	10,0	**9**	18
27	3,4	**3**	6	11,3	**10**	20
29	3,6	**4**	8	12,1	**11**	22
32	4,0	**4**	8	13,3	**12**	24

E. MAR Technical requirements and implementation

When implementing MAR, the volume of lake water pumped should be significantly higher than the amount abstracted from the Laga. A key advantage of MAR is that it provides a simple and cost-effective solution to meet not only the drinking water demand of 10 m^3/day but also the daily per capita requirement of 15–20 liters/day.

To ensure sustainability, the over-abstraction from the lake should be around 50% higher than the discharge from the collector well. With a daily demand of 50 m^3, including an additional 20 m^3beyond Sphere standards to account for population growth, a daily infiltration of 75 m^3 would be sufficient to maintain balance. Even if more than 50% over-abstraction is required, the system will still be able to meet the daily demand. Table 11 outlines the required lake water abstraction rates.

Table 11 Water demand for MAR and over-abstraction

Incoming water(m^3/day)	Over abstraction (%)	Potential water supply (m^3/day)
75	50	50
75	100	37.5
75	150	25

Principal drawing of MAR implantation is presented in Figure 36.

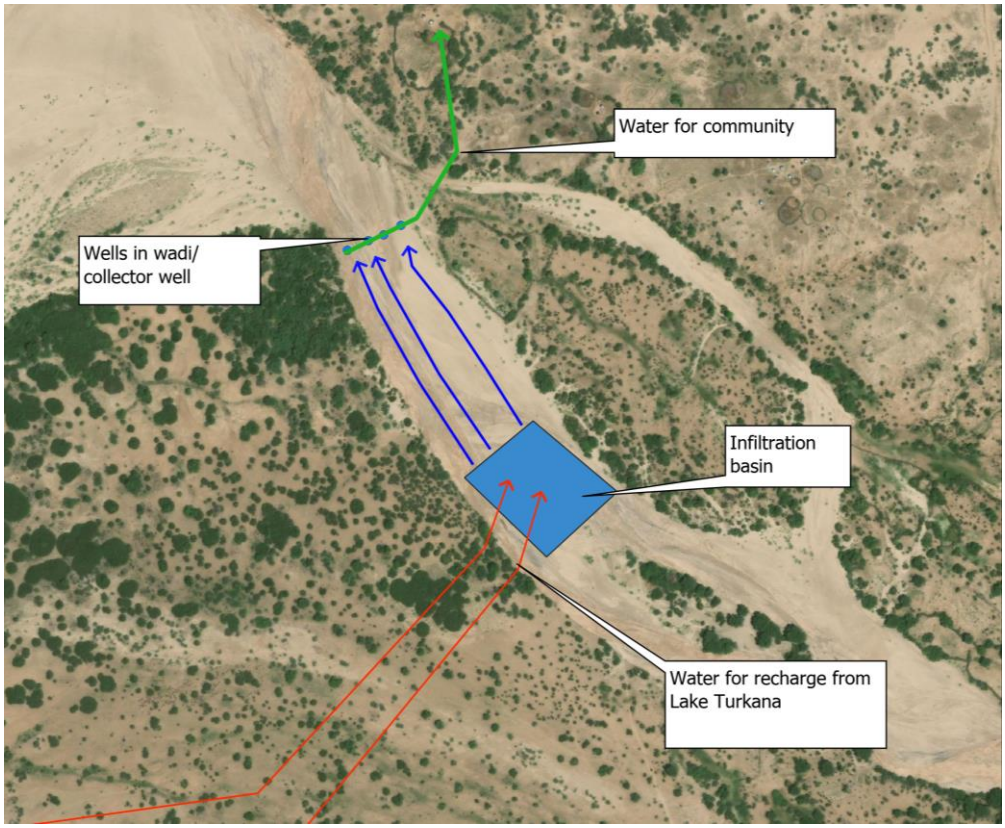


Figure 36 Schematic view of MAR in laga using recharge water from Lake Turkana and recovering through downstream wells

Inlet pipe

The distance from the lake to the infiltration area is approximately 1,100 meters. Ideally, although more expensive, the OD110 pipe should be used to meet the required abstraction and

minimize head losses. While an OD90 pipe would still be sufficient, it would result in significantly higher head losses of around 9 meters.

Given the risk of declining lake levels, the OD110 pipe is the preferred option, as it would accommodate potential increases in distance and static head due to declining water levels. The elevation difference between the lake and the infiltration area is currently 5 meters.

Table 12 presents the head losses for the inlet pipe, including the static head by elevation differences. Note that this does not account for potential lake level declines. However, if water levels drop, leading to longer distances and greater static head, the OD110 pipe would still be sufficient.

Table 12 Head losses for MAR inlet pipe

Pipe diameter	Flow m^3	Length (m)	Static head (m)	Head-losses pipe (m)	Pump head (m)
110	10	1100	5	4.58	9.58

F. Collectors well implementation

The technical approach, according to Figure 37, involves collecting shallow groundwater from riverbeds using well screens surrounded by filter materials such as pebbles or gravel. These pipes transport the water into a concrete-protected collector well adjacent to the laga. While this method requires significant excavation, it remains a cost-effective solution.

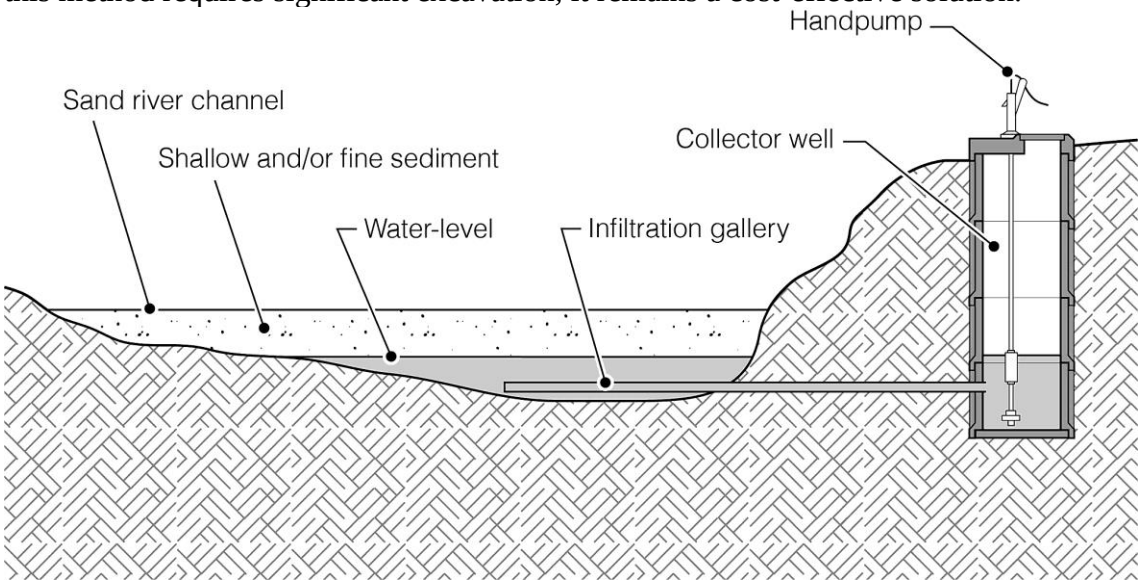


Figure 37 Implementation of water harvesting in Laga (Chatterton & Shaw, 2025)

The width of the Laga at the identified location is approximately 40 meters, which is the most suitable site for both water harvesting and MAR. Given this distance, well screens should be placed horizontally from the collector well extending into the riverbed. The estimated well screen requirements include two layers of 30-meter each using 5 in well screen.

Table 13 Well screen requirements for collector well

Width of Laga (m)	Well screen length (m)
30	2 x 30 m

The exact depth required for the collector well remains unknown, however, it is estimated to be around 6 meters. Based on this depth, approximately six manhole rings will be needed.

Table 14 Manhole requirements for collector well

Depth of Laga (m)	Manhole rings (m)
6 (estimated)	6

G. Bill of Quantities

It is important to note that these estimates are highly indicative as they build on conceptual designs and should be used for comparison purposes only. Additionally, labour and transportation costs are not included, which can significantly impact the total cost - especially for MAR and water harvesting, as they require extensive excavation work.

Slow Sand Filter Treatment + Irrigation

Type	Dimension	Unit	Type	price/unit	Amount	Cost/unit	Tot
Pipes							
Inlet Pipe	90	mm	HDPE SDR11- PN16	meter	650	847	550 550
Pipe to village	90	mm	HDPE SDR11- PN16	meter	1000	847	847 000
Pipe within system	50	mm	HDPE SDR17 - PN10	meter	20	263	5 260
Pipe/ha/Irrigation	-	Kit	1 Acre Irrigation kit	Acre	1	130 000	130 000
Storage and supply							
Water reservoir	10	m3	PVC	pcs	3	95 000	285 000
Water reservoir	1.5	m3	PVC	pcs	1	12 500	12 500
Reservoir Structure	5	m	Welded Steel	meter	2	1 750 000	3 500 000
Tapstand (plot)	-	-	4 taps/stand	pcs	1	25 000	25 000
Tapstand (village)	-	-	4 taps/stand	pcs	3	25 000	75 000
Supply System							
Inlet Pump + Solar panels	-	-	GRUNDFOS CR20-03 4KW 3PH	pcs	1	723 000	723 000
Booster pump + Solar panels	-	-	DAB JETCOM 82M 0.6KW 1PH	pcs	1	194 000	194 000
Valves							
Gate Valves	4	in	Stainless steel	pcs	2	10 000	20 000
Gate Valves	2	in	Stainless steel	pcs	3	10 000	30 000
Check Valve	4	in	Stainless steel	pcs	1	3 450	3 450
Treatment							
Chlorination	-	-	-	pcs	1	295 000	295 000
Contact Filter							
Manhole rings	1,2	m	ID 1.2 mm - H 1m	pcs	4	10 937	43 748
Gate Valves	2	in	Stainless steel	pcs	4	10 000	40 000
Gate Valves	4	in	Stainless steel	pcs	2	10 000	20 000
SSF							
Manhole rings	1,2	m	ID 1.2 mm - H 1m	pcs	8	10 937	87 496
Sum							

6 887 000

LM International

Water harvesting in Laga

Type	Dimension	Unit	Type	price/unit	Amount	Cost/unit	Tot
Pipes							
Inlet Pipe	90	mm	HDPE SDR11- PN16	meter	550	847	465 850
Pipe to plot	90	mm	HDPE SDR11- PN16	meter	600	847	508 200
Pipe to village	90	mm	HDPE SDR11- PN16	meter	1000	847	847 000
Pipe within system	50	mm	HDPE SDR17 - PN10	meter	20	263	5 260
Storage and supply							
Water reservoir	10	m3	PVC	pcs	1	95 000	95 000
Reservoir Structure	5	m	Welded Steel	meter	1	1 750 000	1 750 000
Tapstand (plot)	-	-	4 taps/stand	pcs	1	25 000	25 000
Tapstand (village)	-	-	4 taps/stand	pcs	3	25 000	75 000
Supply System							
Inlet Pump + Solar panels	-	-	GRUNDFOS CR20-03 4KW 3PH	pcs	1	723 000	723 000
Valves							
Gate Valves	4	in	Stainless steel	pcs	1	10000	10 000,00
Gate Valves	2	in	Stainless steel	pcs	2	10000	20 000,00
Check Valve	4	in	Stainless steel	pcs	1	3450	3450
Treatment							
Chlorination	-	-	-	pcs	1	295 000	295 000,00
Sub surface dam							
Damwall	Avrg	-	Concrete	-	1	800 000	800 000
Collectors well							
Manhole rings	1,2	m	ID 1.2 mm - H 1m	pcs	8	10 937	87 496
Well screen	5	in	PVC	meter	60	3 000	180 000
Sum							
5 700 000							

LM International

Desalination of lake water + irrigation

Type	Dimension	Unit	Type	price/unit	Amount	Cost/unit	Tot
Pipes							
Inlet Pipe	90	mm	HDPE SDR11- PN16	meter	650	847,00	550 550
Pipe to village	90	mm	HDPE SDR11- PN16	meter	1000	847,00	847 000
Pipe within system	50	mm	HDPE SDR17 - PN10	meter	20	263,00	5 260
Pipe/ha/Irrigation	-	Kit	1 Acre Irrigation kit	Acre	1	130 000,00	130 000
Storage and supply							
Water reservoir	10	m3	PVC	pcs	3	95 000,00	285 000
Reservoir Structure	-	m	Welded Steel	meter	2	1 750 000	3 500 000
Tapstand (plot)	-	-	4 taps/stand	pcs	1	25 000,00	25 000
Tapstand (village)	-	-	4 taps/stand	pcs	3	25 000,00	75 000
Supply System							
Inlet Pump + Solar panels	-	-	GRUNDFOS CR20-03 4KW 3PH	pcs	1	723 000	723 000
Booster pump + Solar panels	-	-	DAB JETCOM 82M 0.6KW 1PH	pcs	1	194 000	194 000
Valves							
Gate Valves	4	in	Stainless steel	pcs	1	10 000,00	10 000
Gate Valves	2	in	Stainless steel	pcs	5	10 000,00	50 000
Check Valve	4	in	Stainless steel	pcs	1	3 450,00	3 450
Treatment							
Chlorination	-	-	-	pcs	1	295 000,00	295 000
Desalination							
Pre treatment	-	-	-	pcs	1	250 000,00	250 000
Desalination	-	-	SolarRO BW30 REVERSE OSMOSIS UNI	pcs	1	7 204 247	7 204 247
Sum							
14 148 000							

Small -scale desalination at health clinic

Type	Dimension	Unit	Type	price/unit	Amount	Cost/unit	Tot
Pipes							
Pipe within system	50	mm	HDPE SDR17 - PN10	meter	20	263	5 260
Storage and supply							
Water reservoir	10	m3	PVC	pcs	2	95 000	190 000
Reservoir Structure	5	m	Welded Steel	meter	2	1 750 000	3 500 000
Tapstand (clinic)	-	-	4 taps/stand	pcs	1	25 000	25 000
Supply System							
Inlet Pump + Solar panels	-	kit	TAFLO SQ35 HM	pcs	1	180 600	180 600
Booster pump + Solar panels	-	-	DAB JETCOM 82M 0.6KW 1PH	pcs	1	194 000	194 000
Valves							
Gate Valves	4	in	Stainless steel	pcs	1	10 000	10 000
Gate Valves	2	in	Stainless steel	pcs	3	10 000	30 000
Check Valve	4	in	Stainless steel	pcs	1	3 450	3 450
Treatment							
Chlorination					1	295 000	295 000
Desalination							
Pre treatment	-	-	-	pcs	1	250 000	250 000
Desalination	-	-	SolarRO BW30 REVERSE OSMOSIS UNI	pcs	1	7 204 247	7 204 247
Solar power	-	kit	Package		1	347 699	347 699
Sum							
12 235 000							

Managed Aquifer Recharge

Type	Dimension	Unit	Type	price/unit	Amount	Cost/unit	Tot
Pipes							
Inlet Pipe	90	mm	HDPE SDR11- PN16	meter	1100	847	931 700
Pipe to plot	90	mm	HDPE SDR11- PN16	meter	600	847	508 200
Pipe to village	90	mm	HDPE SDR11- PN16	meter	1000	847	847 000
Pipe within system	50	mm	HDPE SDR17 - PN10	meter	20	263	5 260
Perforated spreading pipe	75	mm	HDPE SDR11- PN16	meter	50	558	27 900
Storage and supply							
Water reservoir	10	m3	PVC	Tank/reservoir	1	95 000	95 000
Reservoir Structure	5	m	Welded Steel	meter	1	1 750 000	3 500 000
Tapstand (plot)	-	-	4 taps/stand	pcs	1	25 000	25 000
Tapstand (village)	-	-	4 taps/stand	pcs	3	25 000	75 000
Supply System							
Inlet Pump + Solar panels	-	-	GRUNDFOS CR20-03 4KW 3PH	pcs	1	723 000	723 000
Booster pump + Solar panels	-	-	DAB JETCOM 82M 0.6KW 1PH	pcs	1	194 000	194 000
Valves							
Gate Valves	4	in	Stainless steel	pcs	2	10 000	20 000
Gate Valves	2	in	Stainless steel	pcs	1	10 000	10 000
Check Valve	4	in	Stainless steel	pcs	1	3 450	3 450
Treatment							
Chlorination	-	-	-	pcs	1	295 000	295 000
Collectors well							
Manhole rings	1,2	m	ID 1.2 mm - H 1m	pcs	8	10 937	87 496
Well screen	5	in	PVC	meter	60	3 000	180 000
Sum							
7 528 000							