Reporting of Analysis Results

Monitoring the impact results of Burqaa project: water retention analysis both in Harar and Bedele in the period 2021 - 2022

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Executive summary

Burqaa project aims to improve water retention and livelihood in the Hakim Gara and upper Dabena catchment. To achieve these goals, plant seedling and soil and water conservation practices took place in the selected project areas. In order to measure the impacts of the soil and water conservation initiatives implemented by World Vision Ethiopia under the BURQAA project and other community-based organizations Acacia Water team has been collecting data using the real-time method (by installing telemetric equipment) and by taking manual measurements for soil moisture(through externally hired monitoring experts) and discharge measurement every time of the field visit of the Acacia Water team.

This report reveals the monitoring of the dynamics of water flow (discharge), groundwater level, and soil moisture condition. In addition to the data collected on the field empirical data and remotely sensed data were used to evaluate the impacts of project interventions on water resources. The results of the impact analysis revealed that the Upper Dabena Catchment (UDC) interventions have achieved additional water retention of 86,190 m^3/year in Bedele zone (96% of objective) and 45,600 m^3/year in Hakim Gara catchment in Harar (190% of objective), opposed to the Burqaa Initiative's project objective to 'balance' 90,000 m^3/year and 24,000 m^3/year respectively.

Please keep in mind that these results are based on limited data acquired in less than two years and that at least five years of monitoring data is required for credible conclusions. We recommend that continuous monitoring continue for at least another five years (until 2027/2028).

Colophon

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3R	Recharge, Retention and Reuse
CHIRPS	Climate Hazards center InfraRed Precipitation with Station data
CN	Curve Number
EC	Electrical Conductivity
FMNR	Farmers Managed Natural Resources
NDVI	Normalized Difference Vegetation Index
UDC	Upper Dabena catchment
SWC	Soil and Water Conservation
WVE	World Vision Ethiopia

1 Introduction

The "BURQAA Initiative project" is being carried out by Acacia Water (AW) and in collaboration with World Vision Ethiopia (WVE) and the financial support from HEINEKEN Ethiopia. The aim of this programme is to compensate for the water use of the Bedele and Harar Breweries by increasing water availability. WVE has four primary objectives to achieve this: reducing environmental degradation, increasing the water balance, enhancing the standard of living in the target community, and improving institutionalization of water balancing. WVE has been carried out through multiple activities such as tree planting and soil and water conservation (SWC) measures, with the aim of increasing water availability while improving the local communities' livelihoods by 2023.

This initial project has been running for the period 2020 until 2022, during which time the AW team has visited the project sites multiple times and installed various types of equipment to gather data on water level, electrical conductivity (EC), temperature, and precipitation. Meanwhile, discharge and soil moisture data were collected manually by the AW team and by externally hired and trained experts. Surface and ground water monitoring divers and telemetric stations are installed at both Dabena and Hakim Gara catchments. The effects of soil and water conservation practices will be evaluated with several years of data observed at gauging stations.

However, the gathered data is insufficient to conduct a comprehensive analysis and draw major water balancing conclusions from. One of the main reasons for this, among other difficulties, is that the equipment has only been in place for less than two (2) years, with majority of equipment installed in July/August 2021 only. In Harar, the loggers have been evicted by the locals, impeding, and leaving a significant data gap. Concerning soil moisture data, two measurement results at the Harar intervention sites above Aba Wayne spring (Sofi-1 (Sm_1), Sofi-2 (Sm_2), and Sofi-3 (Sm_3), and one soil moisture sample at the intervention sites at the top of the Hakim Gara plateau (Barkele-1 (Sm_1), Barkele-2 (Sm_2), and Barkele-3 (Sm_3) have been collected. For the reliability of soil moisture data, several years field data measurements or digital sensors are required. Therefore, the monitoring task constitute both the theoretical and experimental activities. The empirical equation and remote sensing data was used to complement the 'water balancing' impact analysis of the monitoring process.

In this report, we demonstrate the monitoring impact findings using the analytical discussion with the empirical data and measured hydrological data from the installed (telemetric) monitoring equipment. The next chapters go into detail on the data that was gathered as well as the analytic procedure and outcomes. As the data collected through telemetric station were limited, analytical calculations are incorporated to monitor the impacts of the project interventions.

1.1 Overall Water Balancing targets

The project's goal is to save 90,000 m^3 of water per year by focusing on 5,521 ha of degraded land in five kebeles in Gechi woreda, which would mean a 150% compensation of the Bedele brewery's annual beer production of 600,000 hectolitre. In Harar, the project's measures intend to compensate 100% of the Ginela spring source only by saving 24,000 m^3/yr., while enhancing the quality of life for the targeted beneficiaries. See also Table 1 below.

Table 1. Burqaa Initiative's water balancing targets and main intervention sites

	Brewery production	Water Balancing target		Main intervention site(s)
	m3/year	m3/year	%	
Bedele brewery	60,000 (or 600,000 hectolitre)	90,000	150	5,521 ha restoration of degraded land in 5 kebeles in Gechi woreda through tree planting and soil and water conservation (SWC) measures
Harar brewery	24,000 (or 240,000 hectolitre)	24,000 (Ginela spring only)	100	Land management and SWC measures on Hakim Gara plateau, Sofi woreda

2 Methodology

As part of the monitoring and impact assessment of the implemented SWC measures and tree planting by World Vision Ethiopia and other initiatives, different methods are put into effect. The monitored data can be analyzed to measure the water balancing success rate or impact of implemented SWC interventions. The success of the interventions in the context of the Burqaa Initiative is hereby defined as improved water availability in the same (sub-)catchment as where extraction by the Bedele and Harar breweries is taking place, either in the form of:

1. Prolonged and/or improved baseflow in streams (especially towards end of dry season);
2. Increased groundwater levels;
3. increased soil moisture content in the soil.

Before going into detail, it is worth mentioning, that the lack of data availability – foremost soil moisture and surface water discharge – at the intervention – and control sites has resulted in combining different methods to monitor the impacts of the interventions:

1. analysis of hydrological and meteorological monitored data
2. evidence support from empirical methodologies and literature
3. verification with remote sensed data (e.g. NDVI changes), if possible

Soil moisture monitoring has only commenced as of May and July ,2022 for Bedele-Dabena and Harar –Hakim Gara this year. The data measurements are not enough to represent the soil moisture variation. To analyze and compare hydrological responses, a measurement plan of at least three, or in an ideal scenario, at least 5 years is recommended. **(refBGR, 2012).**

For spatial comparison, a control site demonstrating analogous characteristics to the intervention site was selected. As stated above, temporal changes cannot conclusively be observed based on the current status of data available, and if analyzed, would lead to trivial interpretations. In addition to this point, it is worth mentioning that the intervention site is minor compared to the rest of the project area.

Hence, the monitoring results are supported by empirical methodologies and literature derived from studies conducted in the East-African region. These include ancillary data derivation from remote sensing; specifically observed changes of NDVI (Normalized Difference Vegetation Index) that compare the ''before-after'' situation of implementing SWC.

The empirical or theoretical water retention was calculated taking the following principles into account:

- Theoretical water retention was calculated with the Curve Number (CN) methodology. CN numbers are used to analyze the water retention of SWC measures. The water retention results depend on amount of annual rainfall and land use land cover data. The curve number (C) values are assigned to a particular land use changes including SWC (interventions) measures.
- The hydrological soil group (A-D) are involved to derive the minimum and maximum values for curve numbers, ranging from Group A (soil in this group have low runoff throughout the wet season) to Group D (high runoff potential when thoroughly wet) (source: Hydrology handbook, USA department of Agriculture).

- Then, soil water retention is estimated by considering the initial rainfall abstraction as 20% of total water retention (S).
- The global annual precipitation CHIRPS data were downloaded from online and clipped to the catchment areas. The annual precipitation values are mapped with QGIS software for the catchment area. The annual runoff in the catchment was estimated based on effective precipitation. The effective precipitation (P_e) is estimated as the difference between annual runoff and infiltration in the catchment.
- In theory the monitoring task involves how much water could potentially be retained, using CN values and available literature in East Africa. The amount of water retained behind SWC measures (e.g. stone bunds) were calculated empirically.
- As other organizations are involved with SWC and infiltration interventions within the project area, their calculated impact is calculated and considered too.

3 Monitored Data Review

3.1 Burqaa data access

Acacia Water developed an online web portal or dashboard for the Burqaa Initiative project (https://burqaa.fixeau.com/) where the telemetric (automated) monitored data can be accessed, viewed and simple comparisons between locations as well as between parameters can be made.

The web portal is only open for registered participants; however, more participants can be added upon request. Using the tabs in the top of the screen, the data can be accessed either in the 'map' or the 'analysis' tabs. Zoom in on the graph by clicking two points in the graph. Overlay precipitation data by clicking the cloud symbol in the top of the righthand field. In the web portal it is possible to search real time data series for water level, temperature, and electrical conductivity (EC; indicator for volume of minerals, and especially salinity, of water).

Figure 1. Hydrological Online-data portal

3.2 Harar

3.2.1 Water level loggers

All water level loggers have been checked for damage and proper data collection. Furthermore, all loggers received a sim card for automated data transfer to an online dashboard.

Ginela spring

The Ginela spring water level loggers have been working flawlessly since its installation in August 2021. The data (see Figure 1) shows a gradual decrease in water level, which is to be expected during the dry season. There seems to be one data point late August 2021 that falls out of the expected range, this is due to some maintenance performed to the well where the logger has been temporarily removed. Between February to October 2022, the precipitation logger ceased sending data. During our third field visit, from 11th -13th of August 2022, it was learned that it is due to algae and dust build-up on the water collector dish, as well as one of the wires being loose. The logger and all elevations were checked and amended during the visit.

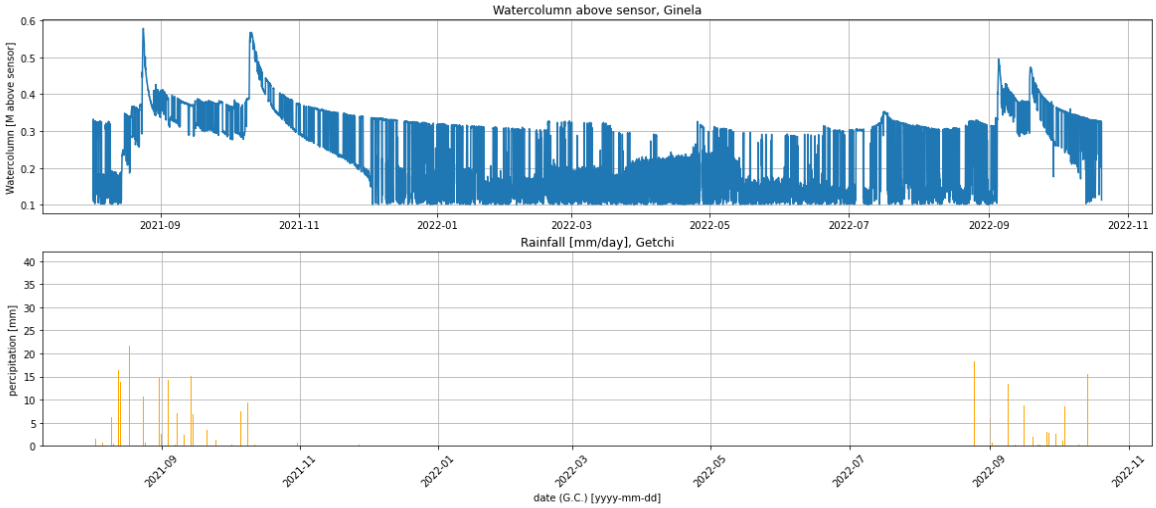


Figure 2. Raw data, Ginela spring. Top: water level. Bottom: precipitation.

Sofi spring

The logger at the Sofi spring was removed early in the measuring campaign (August 16th 2021) and reinstalled in mid-January 2022. During the field visit, all elevations where checked. The limited data available shows a decrease in water level of about 10cm in the dry season (August 2021 – January 2022). Just after reinstallation in January 2022, a significant rise in water level is visible in the data. It is our believe that this is not a rise in water level, but an increase in cable length, resulting in a larger water column above the sensor. Upon inspection it was noted that the cable length was longer than at the first installation. The cable has been returned to its original length. The logger started sending odd data on June 28, 2022. From the photos, which WVE's field program manager provided upon our request, the logger was in place, contrary to our initial concern that it might have been removed again. During the third-round field trip from August 11-13, 2022, it was learned that one of the cables was broken; the logger was repaired during this field trip and is now sending regular data.

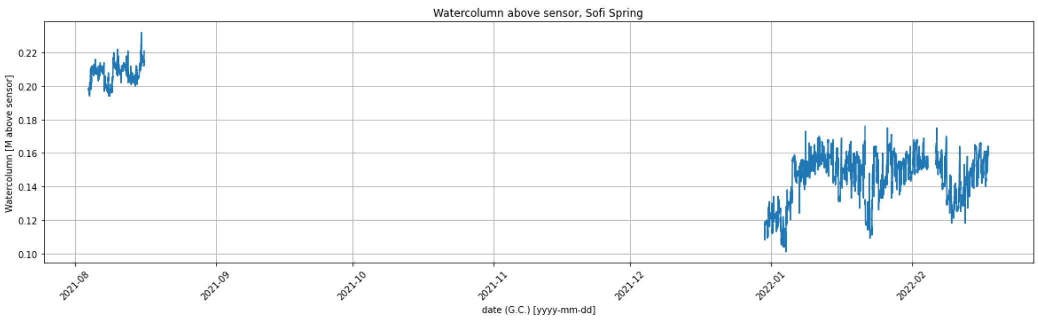


Figure 3. Processed data, Sofi spring. Water level.

Abawayne spring

This logger was demolished early in the measuring campaign (late 2021) and reinstalled in mid-January 2022. Upon close inspection during this visit, a plethora of abnormalities where uncovered. The cable got pulled out of the logger by force, which might have damaged the logger on the inside. Furthermore, the loggers elevations seem to have moved down in the last half of January 2022 (see the upward curve in the data). Manual measurements confirm this. The pole to which the logger is attached has been tightened to the bedrock to stabilize it. In May 2022, all batteries where changed, after which the logger has been sending data regularly.

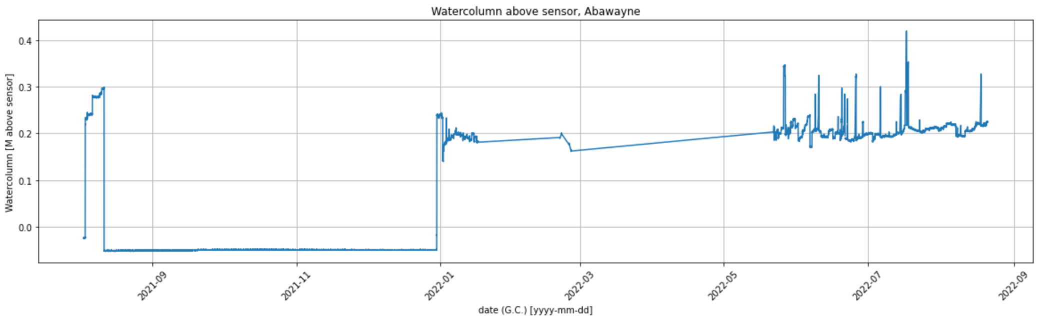


Figure 4. Processed data, Abawayne spring. Water level.

Burqaa spring

The Burqaa logger has been operating flawlessly since its installation in August 2021. The fixings of the pipe to the bedrock had been insufficient at first but has been taken care of by the Woreda. The installation is solid and regular data uploads are being made due to the added sim card. The data shows a normal decrease in water level during the dry season of about 25 cm in the period October 2021 – March 2022.

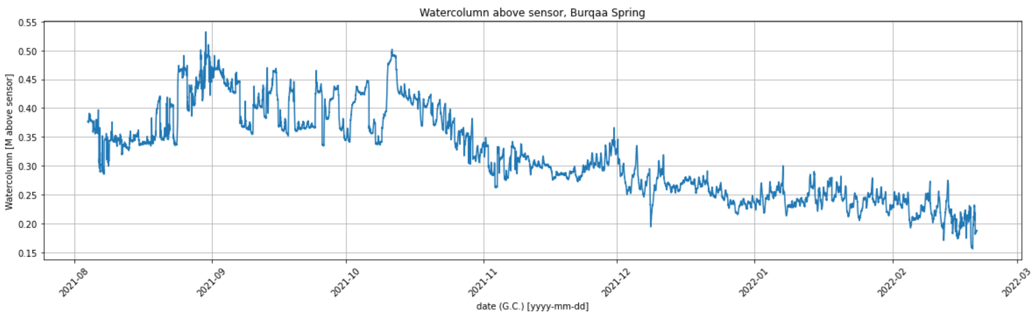


Figure 5. Raw data, Burqaa spring. Water level.

3.2.2 Discharge

At three sites (Sofi, Abawayne, Burqaa) discharge measurement has been performed. Over time, multiple measurements were taken at different water levels to draw a relation between water level and discharge, the so-called Q-H curve.

Table 2. Discharge measurements result, Harar.

Site	Date Time	Water level [m above sensor]	V(max) [m/s]	Q [m3/s]
Sofi	2022-02-21 13:05	0.16	0.035	0.000639
	2022-05-23 0:900	0.20	0.01	0.000305
	2022-08-22 16:00	-	0.011	0.000370
Abawayne	2022-02-21 11:02	0.18	0.054	0.001005
	2022-05-22 11:05	0.20	0.048	0.001267
	2022-08-22 14:50	0.224	0.05	0.001765
Burqaa	2022-02-21 09:54	0.19	0.09	0.003513
	2022-05-23 10:00	0.18	0.0416	0.001499
	2022-08-23 09:45	0.302	0.049	0.001816

The flow in the channels just below the springs was too low at the time of field data collection to perform the measurement with the OTT C31 propellor. The propellor can constitute more accurate measurements and over a greater variety of depths compared to the float method. However, the float method, in this case, was the only available option to collect flow data. A float (leaf, stick, etc.) was placed in the channel, of which the time to travel over a fixed distance was measured, resulting in an average velocity at surface level. Given the wet area and the assumption that flow along the channels edges is zero, a splined interpolation has been performed to give an estimated total discharge in cubic meter per second (m3/s). The results for the three channels are given in Table 2 and the figures below.

From the data it becomes clear that, so far, no direct relationship between water level and discharge can be made. An increase in water level, does not coincide with an increase in flow velocity or discharge. This could be expected, given the limestone geology of the Harar plateau, where springs can be fed by multiple underground streams and where hysteresis plays a large role. On the other hand, it could be that the measured data is simply not accurate enough to draw meaningful conclusions. The flow method is very susceptible to outside factors like wind and waves. To rule this out, it is our recommendation to perform more flow measurements in these streams.

Having a good understanding of the flow of these streams is of paramount importance to the water balance calculations. Knowing how much water comes into the system and how much of it runs out are very important factors in assessing what amount of water gets stored in the project area.

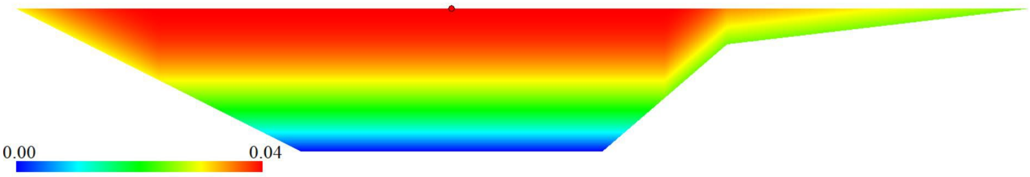


Figure 6. Flow profile Sofi Spring. Red: fast, blue: slow.

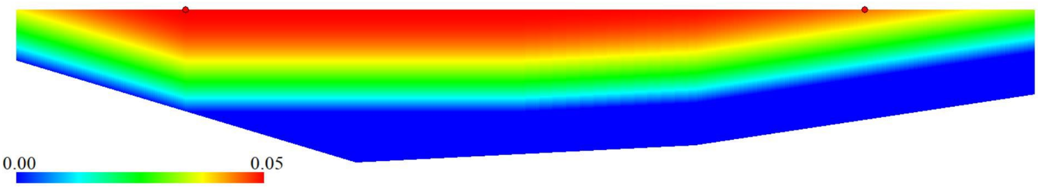


Figure 7. Flow profile Abawayne Spring. Red: fast, blue: slow.

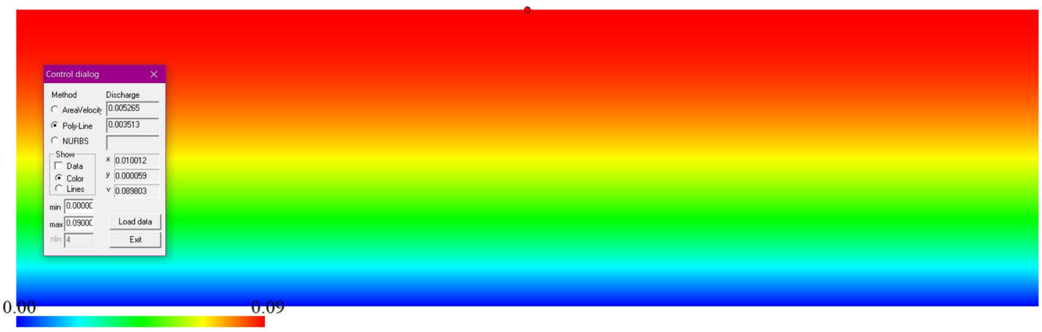


Figure 8. Flow profile Burqaa Spring. Red: fast, blue: slow.

Figure 9. Abawayne spring, discharge measurement with a leaf as float.

3.2.3 Soil Moisture

The community and WVE participated in SWC activities on the Hakim Gara plateau. The soil moisture measurement was done in two locations on the Hakim Gara plateau, where the intervention actions took place. The first is at the top of the plateau, near to the Ethio Telecom towers. The second is located just above Abawayne spring. For each location, a reference point/location has been chosen to correlate to the difference in soil moisture content between areas where SWC practices were conducted and places where no measures have been taken place.

Finding the right person to gather soil moisture measurements, however, was a major challenge. Our data is insufficient for all places because we only have two rounds of data. AW experts took data once from all the locations, and an externally hired expert (Welid Abdi from HWSSA) took the second batch of data only from Sofi1, Sofi2, and Sofi3 (but quit after his first round of measurements). Hence, for a possible Burqaa Initiative Phase II, AW proposes telemetric (automated) soil moisture monitoring in order not to be dependent on manual measurements.

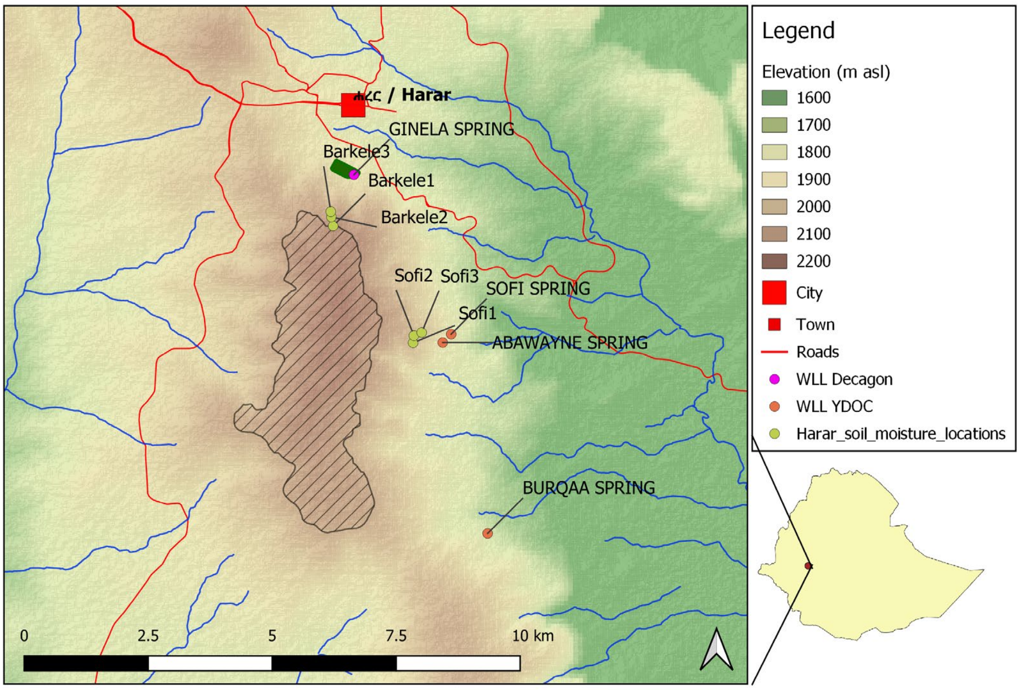


Figure 10. Map of Hakim Gara plateau with measurement locations.

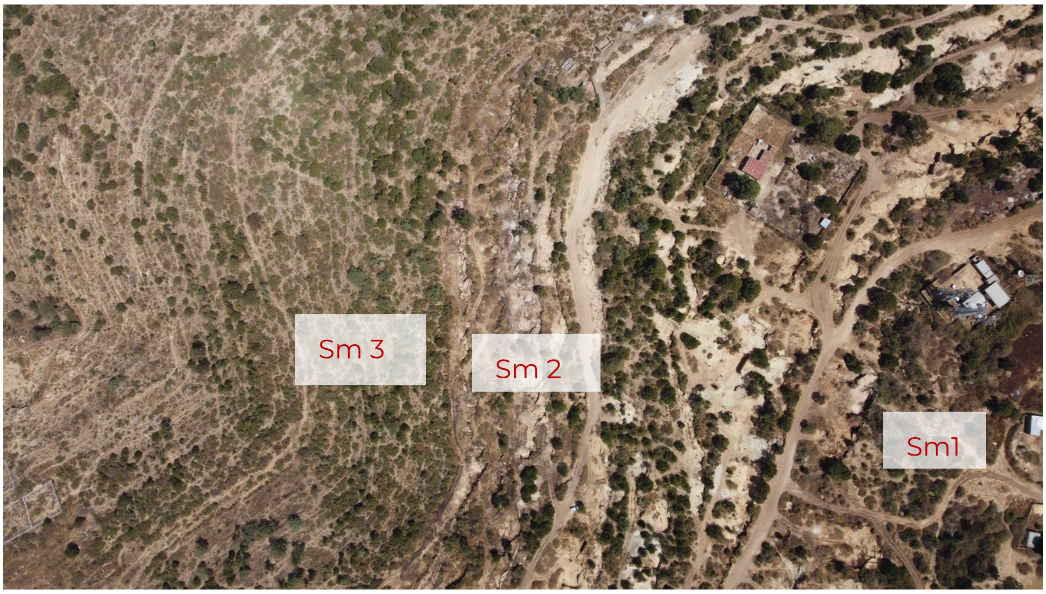


Figure 11. Overview of soil moisture measurement locations on top of the Hakim Gara plateau.

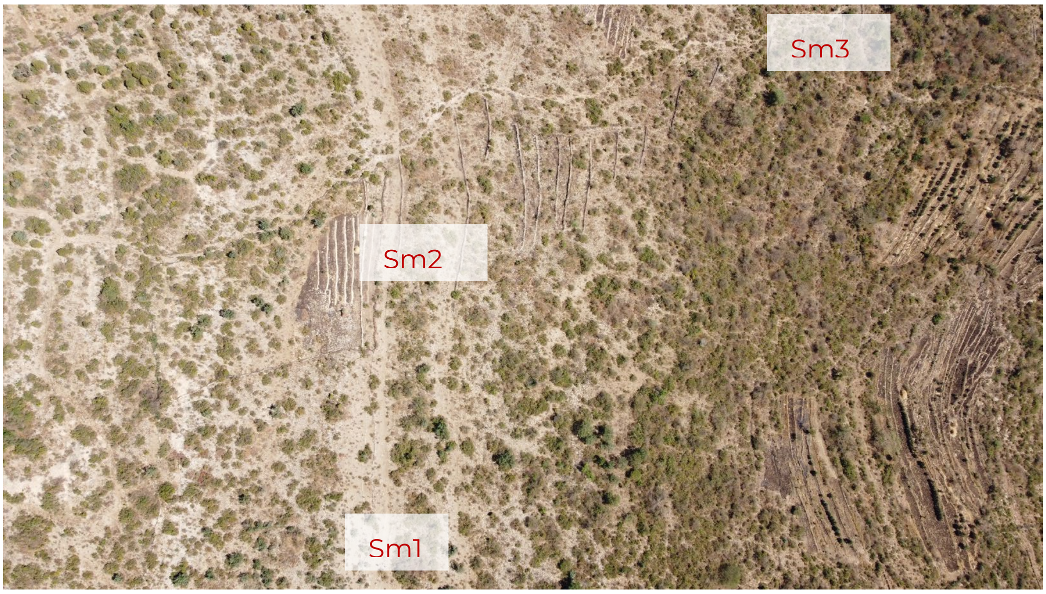


Figure 12. Overview of soil moisture measurement locations upstream from the Abawayne spring

The soil moisture locations and measurements can be found in Table 3 on the next page.

Soil Moisture measurement data									
Intervention Site	**Point ID**	**Location (lat)**	**Location (lon)**	**Month of measurement**	**Date of measurement**	**Time of Measurement**	**T in ˚C**	**EC in bulk ds/m**	**SM in m3/m3**
Above Abawayne spring	Sofi1 (Sm1)	9.268432	42.139034	July	7/7/2022	12:20	25	0.062	0.253
				August	24/08/2022	8:52	22.1	0.091	0.218
	Sofi2 (Sm2)	9.269737	42.139192	July	7/7/2022	12:30	23.9	0.292	0.329
				August	24/08/2022	9:05	20.5	0.233	0.331
	Sofi3 (Sm3)	9.270284	42.140628	July	7/7/2022	12:45	23.9	0.077	0.226
				August	24/08/2022	9:26	19.3	0.031	0.166
Top of Hakim Gara Plateau	Barkele1 (Sm1)	9.289856	42.124561	August	24/08/2022	12:42	25.3	0.263	0.25
	Barkele2 (Sm2)	9.291474	42.124256	August	24/08/2022	12:04	24.3	0.213	0.246
	Barkele3 (Sm3)	9.292467	42.124142	August	24/08/2022	12:14	22.5	0.262	0.281

Table 3. Soil moisture measurement locations and soil moisture data

3.3 Bedele

3.3.1 Water level loggers

All water level loggers have been checked on damage and proper data collection. furthermore, all loggers received a sim card for automated data transfer.

Gechi groundwater well

The Gechi logger, unfortunately, fell dry on mid-December 2021. The well is not empty, but the water level is lower than the sensor (current length: 10m). A manual measurement at the time of visit showed the water level to be 50cm beneath the sensor. In May, a new sensor with longer, 15-meter cable has been installed to fully maximize the measurements. The sensor was placed 3.55m deeper compared to the previous sensor.

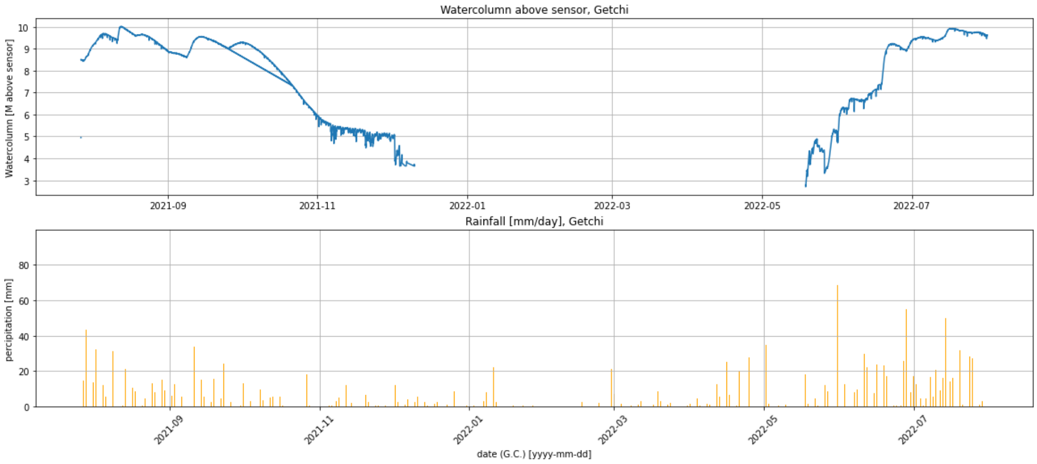


Figure 13. Processed data, Gechi well. Top: water level, Bottom: precipitation (rainfall)

Brewery intake

The logger at the Bedele brewery intake has been steadily collecting data since its installation in July 2021. The raw data shows some unwanted variability in water level (cause still unknown), therefore some post-processing had to be performed on the data. The post-processed data is given below. A clear downward trend over the period September '21 – May '22 is visible, as well as some large peaks during the rainy season (June – September).

No sim card was added to this logger since the cell reception is insufficient for any telemetric data uploads. Hence, data can only be manually downloaded during physical visits to the monitoring location.

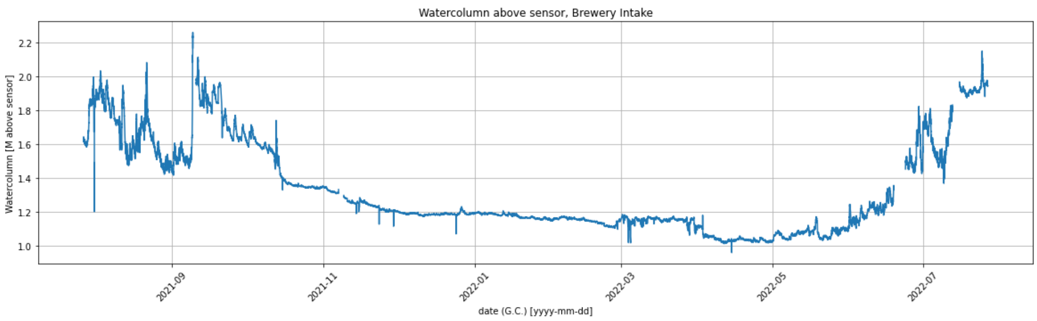


Figure 14. Processed data, Brewery intake. Water level.

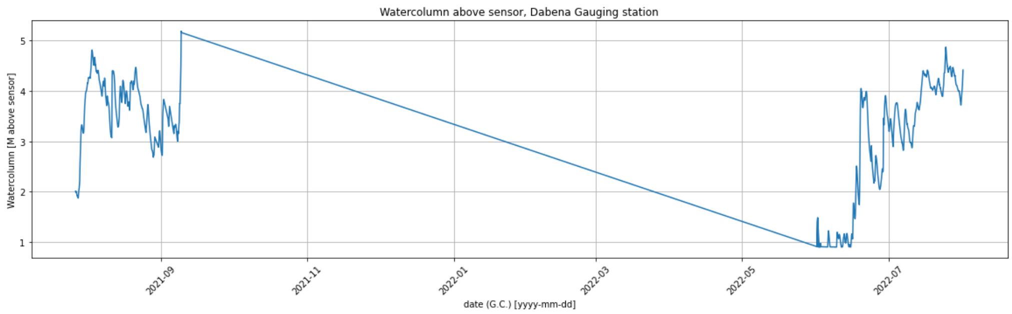
Table 4. Manual water level measurements at Brewery intake.

Date Time	Manual water level measurement [m below ref]	Water level above sensor [m]
2022-02-27 09:05	0.50	1.115
2022-05-19 10:26	0.37	1.245
2022-07-27 09:00	-0.33	1.945

Dabena Gauging station

The logger at the Dabena gauging station was flooded during the rainy season of 2021 and reinstalled during the November 2021 visit. As of this visit it is still operating correctly. However, the data logged since January 2022 is of no use because the water level has fallen to a level below the sensor. Due to the nature of the construction which houses the logger, it cannot be installed any lower, making automated readings during this time impossible. The staff gauge next to the logger gave a reading of 0.56m (Chart Datum) at the time of the visit.

Figure 15. Raw data, Gauging station. Water level.



3.3.2 Discharge

At two sites (Upper Dabena and Gauging Station) flow discharge measurements have been performed at different water levels to construct a relation between water level (m) and discharge (m^3/s), the so called Qh-curve.

Table 5. list of discharge measurements, Bedele

Site	Date Time	Water level	Q [m^3/s]
Upper Dabena	2021-11-04 13:00 (EAT)	4.40m below top of bridge railing, 0.66m from bottom	2.418
	2022-02-27 13:16 (UTC)		0 (too little flow)
	2022-05-19 12:00	4.53m below top of bridge railing, 0.54m from bottom	0.831
	2022-07-27 13:00	3.1m below top of bridge railing, 1.97m from bottom	38.637
Gauging station	2022-02-27 15:30 (UTC)	6.50m below top of bridge railing. 0.56m C.D.	1.135
	2022-05-19 09:00	6.04m below top of bridge railing. 1.00m C.D.	10.53

	2022-07-27 09:00	1.84m below top of bridge railing, 5.20m C.D.	112.5

Using the OTT C31 current meter, accurate flow velocity readings can be taken at different depths across the river. Given the wet area and the assumption that flow along the channels edges is zero, a splined interpolation has been performed to give an estimated total discharge in cubic meter per second (m3/s). The results for the two river cross-sections are given on the next pages.

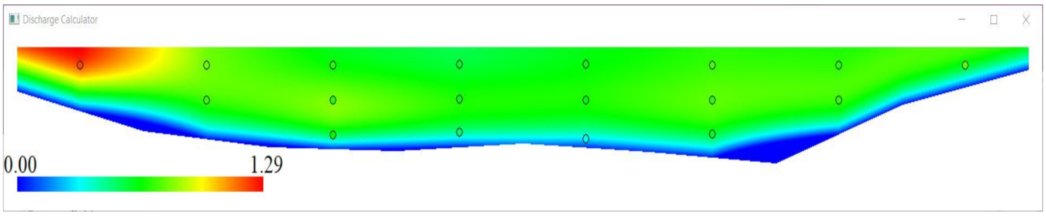


Figure 16. Flow profile Upper Dabena Spring. Red: fast, blue: slow.

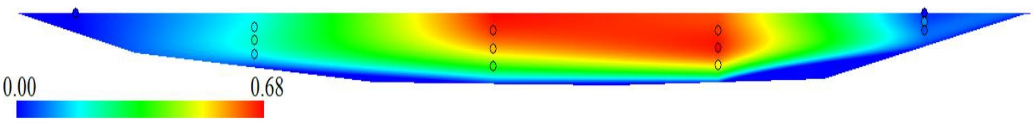


Figure 17. Flow profile Gauging station Spring. Red: fast, blue: slow.

Figure 18. Discharge measurement with OTT C31 at the gauging station.

3.3.3 Soil Moisture

The soil moisture data collection was delayed until the second mission (May 2022) due to a miscommunication with WVE Bedele. The Acacia Water team and the selected data collector went to the field and measured soil moisture in two locations in Gole Seka and four spots in Gole Maya. Other locations where later added as well. After that the data collector took 5 measurements from each location. See Annex 2 for an overview of the soil moisture measurement locations.

These measurements were taken every two weeks and recorded on a regular basis. Since the measurement started in May 2022, most of the data are from the rainy season. The soil moisture measurement data collected from May 2022 to August 2022, is shown in Table 6 on the next page.

3.4 WorldVision SWC and tree planting intervention sites

According to World Vision Ethiopia's 2022 annual report for the Burqaa Initiative project, 15% of UDC (Upper Dabena Catchment) households and 10% of HG (Hakim Gara) catchment households applied a variety of environmental restoration methods on their farmlands. Different plants and fruit seedlings were also planted in the catchments, 139,300 in both catchments (102,700 in Bedele/Gechi and 36,600 in Harar/Hakim Gara). The report states that 454,550 seedlings have been added to the forest system overall through direct planting and the established FMNR sites. While physical soil and water conservation (SWC) actions were carried out on 90.5 ha of land in UDC by WVE and 80.5 ha by CBO, meanwhile in Hakim gara catchments 150 ha of land by WVE and 350 ha by CBO.

In short, in both catchments 671 ha of land were restored in both catchments through farming practices, natural regeneration modeling, afforestation and reforestation projects, and applying SWC measures. Through the community participation the stone bunds are constructed at both Dabena and Hakim Gara catchments. The implementation of SWC activities and the planting of trees in project areas aims to improve soil moisture and groundwater infiltration and contribute to water balancing by restoring vegetation cover and reducing water runoff. The impacts of these interventions are analyzed in detail in Chapter 5.

Table 6. Soil moisture measurement locations and soil moisture data

Intervention Site	Point ID	Location (lat)	Location (lon)	Month of Measu	Date of measu	Time of Measu	T in ˚C	EC in bulk ds/m	SM in m3/m3
Jisa	Jisa SM1	8.383042	36.390790	May	23/05/2022	9:45	27.7	0.025	0.275
				June	8/6/2022	4:00	26.8	0.028	0.326
				June	22/06/2022	2:30	26.5	0.22	0.345
				July	5/7/2022	3:40	26.8	0.027	0.312
				July	20/07/2022	8:00	23	0.031	0.357
				August	8/8/2022	8:15	22.5	0.0375	0.375
	Jisa SM2	8.3834571	36.3909362	May	23/05/2022	4:10	27.5	0.024	0.295
				June	8/6/2022	4:15	26.8	0.029	0.325
				June	22/06/2022	4:45	22	0.102	0.417
				July	5/7/2022	4:00	23.5	0.068	0.379
				July	20/07/2022	8:20	24	0.098	0.395
				August	8/8/2022	8:30	22	0.09	0.391
	Jisa SM3	8.3838585	36.3910170	May	23/05/2022	4:35	26.6	0.025	0.298
				June	8/6/2022	4:45	27.1	0.032	0.325
				June	22/06/2022	4:20	25.5	0.054	0.41
				July	5/7/2022	3:50	25	0.039	0.374
				July	20/07/2022	9:15	22	0.0756	0.389
				August	7/8/2022	9:20	22.5	0.081	0.3
Gole Kora	Gole Kora SM1ref	8.4065138	36.4199838	May	22/05/2022	2:45	26.7	0.012	0.315
				June	6/6/2022	3:15	27.3	0.067	0.328
				June	21/06/2022	10:15	25.3	0.013	0.38
				July	6/7/2022	3:00	24	0.009	0.341
				July	20/7/2022	3:25	25	0.015	0.371
				August	5/8/2022	3:30	24	0.018	0.381
		8.4076511	36.4215844	May	22/5/2022	2:30	25.9	0.036	0.389
				June	6/6/2022	3:25	26.1	0.039	0.412

	Gole Kora SM2			June	21/06/2022	10:25	24	0.015	0.278
				July	6/7/2022	3:15	24.5	0.055	0.291
				July	20/07/2022	3:35	24	0.068	0.351
				August	5/8/2022	3:40	24.1	0.071	0.371
	Gole Kora SM3	8.4073105	36.4226821	May	22/05/2022	3:25	22.6	0.0025	0.364
				June	6/6/2022	3:35	23.6	0.0029	0.385
				June	21/06/2022	10:35	27.5	0.028	0.332
				July	6/7/2022	3:25	26	0.046	0.357
				July	10/7/2022	3:45	22	0.071	0.351
				August	5/8/2022	3:50	22.5	0.078	0.372
Koba Kela	Koba Kela SM1ref	8.377586	36.433760	May	24/05/22	3:15	26.2	0.028	0.261
				June	9/6/2022	2:55	27.3	0.049	0.375
				June	23/06/2022	1:30	21	0.036	0.389
				July	7/7/2022	9:40	21.5	0.024	0.309
				July	25/07/2022	3:30	21	0.031	0.327
				August	10/8/2022	3:40	21.5	0.035	0.315
	Koba Kela SM2	8.3776737	36.4329912	May	24/05/22	3:20	27	0.039	0.352
				June	9/6/2022	3:00	26	0.059	0.385
				June	23/06/2022	1:40	21	0.032	0.415
				July	7/7/2022	9:50	22.3	0.34	0.354
				July	25/07/2022	3:35	21.5	0.035	0.325
				August	10/8/2022	3:45	21	0.035	0.345
	Koba Kela SM3	8.3771483	36.4327337	May	24/05/22	3:30	26.3	0.041	-
				June	9/6/2022	3:10	26.6	0.798	-
				June	23/06/2022	2:00	23	0.009	0.336
				July	7/7/2022	4:00	23.3	0.006	0.233
				July	23/07/2022	3:35	21.5	0.051	0.357
				August	10/8/2022	3:45	21	0.041	0.381
Gole Maya		8.381344	36.465121	May	20/05/2022	-	28	0.01	0.335

	Gole Maya SM1ref			June	5/6/2022	9:45	27.3	0.02	0.345
				June	24/06/2022	4:15	26.1	0.008	0.292
				July	8/7/2022	3:00	26	0.009	0.208
				July	25/07/2022	4:20	26.3	0.013	0.218
				August	24/08/2022	4:30	26.1	0.015	0.325
	Gole Maya SM2	8.380502	36.466421	May	20/05/2022	10:00	27.7	0.018	0.298
				June	5/6/2022	9:55	27.6	0.016	0.328
				June	24/06/2022	4:35	27	0.012	0.304
				July	8/7/2022	3:15	28.1	0.01	0.348
				July	24/07/2022	9:10	27	0.014	0.257
				August	8/8/2022	9:30	27.1	0.012	0.301
	Gole Maya SM3	8.3851099	36.4671961	May	22/05/2022	10:15	29.6	0.061	0.364
				June	5/6/2022	10:10	28.9	0.071	0.385
				June	24/06/2022	4:45	30.9	0.038	0.341
				July	8/7/2022	3:35	29	0.046	0.336
				July	24/7/2022	10:00	28	0.051	0.356
				August	8/8/2022	10:15	28	0.05	0.361
	Gole Maya SM4ref	8.3853352	36.4668528	May	20/05/2022	10:25	27.8	0.052	0.393
				June	05/06/2022	10:45	28.2	0.062	0.384
				June	24/06/2022	4:55	28.5	0.045	0.327
				July	8/7/2022	3:45	29	0.037	0.331
				July	24/07/2022	10:20	28	0.041	0.361
				August	8/8/2022	10:30	28.1	0.039	0.372
Gole Seka	Gole Seka SM1	8.3668160	36.4577664	May	20/05/2022	10:00	28.6	0.023	0.218
				June	5/6/2022	11:00	27	0.028	0.318
				June	23/06/2022	2:35	24.8	0.012	0.295
				July	7/7/2022	10:25	22	0.018	0.32
				July	25/07/2022	3:45	22	0.035	0.35
				August	10/8/2022	3:55	22	0.032	0.298

	Gole Seka SM2	8.3667255	36.4571257	May	20/05/2022	10:00	24.5	0.027	0.304
				June	5/6/2022	11:25	26	0.029	0.385
				June	23/06/2022	2:45	24.4	0.01	0.291
				July	7/7/2022	10:35	25	0.009	0.26
				July	25/07/2022	3:40	24	0.015	0.325
				August	10/8/2022	3:50	23	0.04	0.331

4 Data Analysis

4.1 Modelled/remote sensing impact

Multi Spectral Images from the European Copernicus Sentinel-2 satellites[1] were used to create a Normalized Difference Vegetation Index (NDVI) image of the Dabena and Hakim Gara catchment. This index gives an indication of the plant health in the area. A higher number corresponds to a healthier, denser, and wetter canopy.

The images were later sampled over the target areas, including several reference fields. All data shows a significant decrease in plant health for the year 2022 compared to the three years prior. This, however, can be explained by the severe droughts across eastern Africa during that year **[EU JRC, 2022]**[2].

However, a comparison between the implementation sites and the reference fields can still be made, and project-relevant conclusions drawn from that. Three measurement locations are set up adjacent to reference plots, namely, Gole Kora, Gole Maya, Koba Kela. The reference fields are chosen to be of similar size, orientation, and vegetation levels.

4.1.1 Bedele

For each year that the sentinel data is available (2019-2022), several months of data have been analyzed.

- January – February, beginning of the dry season, when the soil starts to dry up and vegetation decreases.
- March – April, Dry season, to see the land at its driest and to assess if any water is being retained.

Gole Kora

Gole Kora consists of two intervention plots: one on each side of a small stream. Gole Kora 3 has a much denser canopy, due to its more developed plant cover. The implementation site on the other side of the river is new and is therefore still barren (Gole Kora-1). The reference plot, Gole Kora -2, is located to the west of Gole Kora -1, has a vegetation cover, however less developed compared to Gole Kora -3.

The graphs show the NDVI trend over a period of four consecutive years and are consistent with the trends in precipitation. This means, that an increase of precipitation will result in a higher NDVI and a decrease in precipitation will result in a lower NDVI. The implementation plots (Gole Kora- 1 and 3), however, show a smaller decline in NDVI value compared to the reference plot (Gole Kora -2). This shows that the taken SWC measures are having a positive effect on the local plant life and indicates a larger availability of groundwater in the area.

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[1] https://sentinel.esa.int/web/sentinel/missions/sentinel-2
[2] ISBN 978-92-76-55830-9

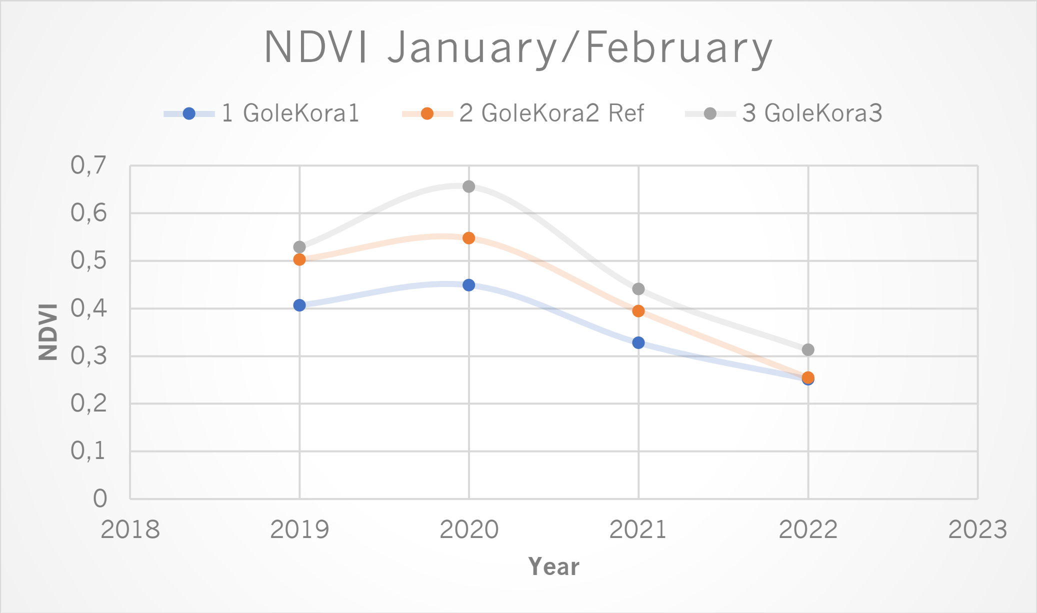


Figure 19. NDVI values of Gole Kora, between 2019 and 2022, for the months January and February

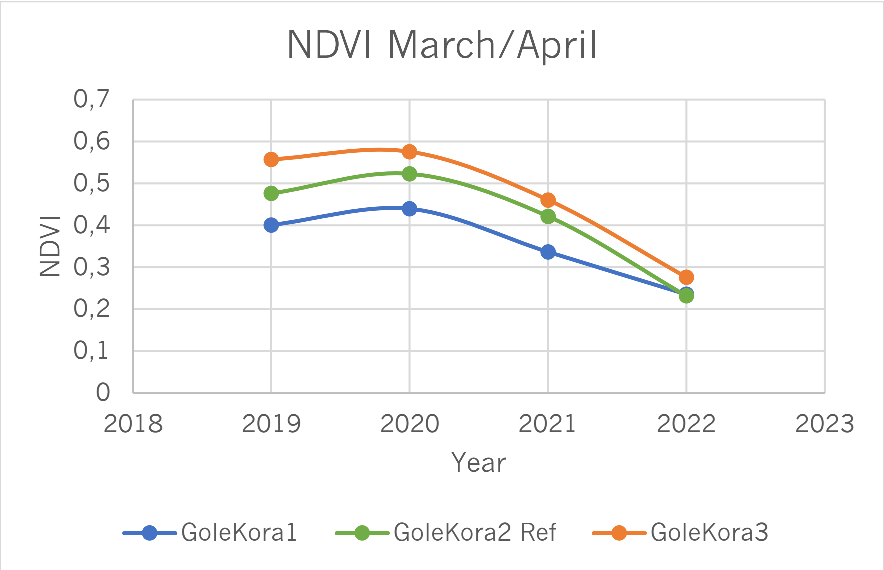


Figure 20. NDVI values of Gole Kora, between 2019 and 2022, in March and April

Gole Maya

The Gole Maya site consists of 2 locations, both with an adjacent reference plot. Gole Maya 1 and 2 sit next to each other, of which the reference plot is more heavily overgrown, compared to the implementation site, resulting in a larger NDVI value. Gole Maya 3 and 4 are more comparable. Both sets show a more positive trend at the implementation site.

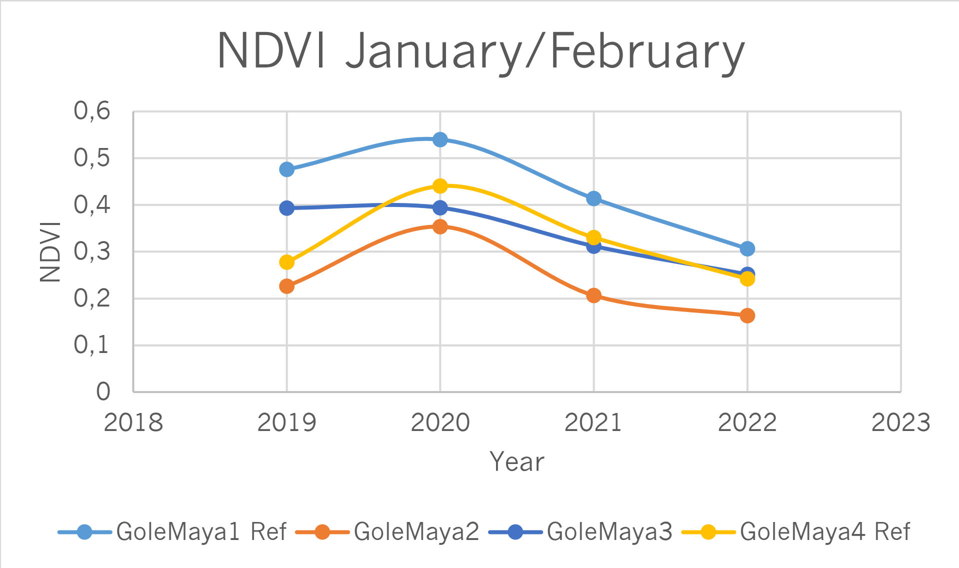


Figure 21. NDVI values of Gole Maya, between 2019 and 2022, in January and February

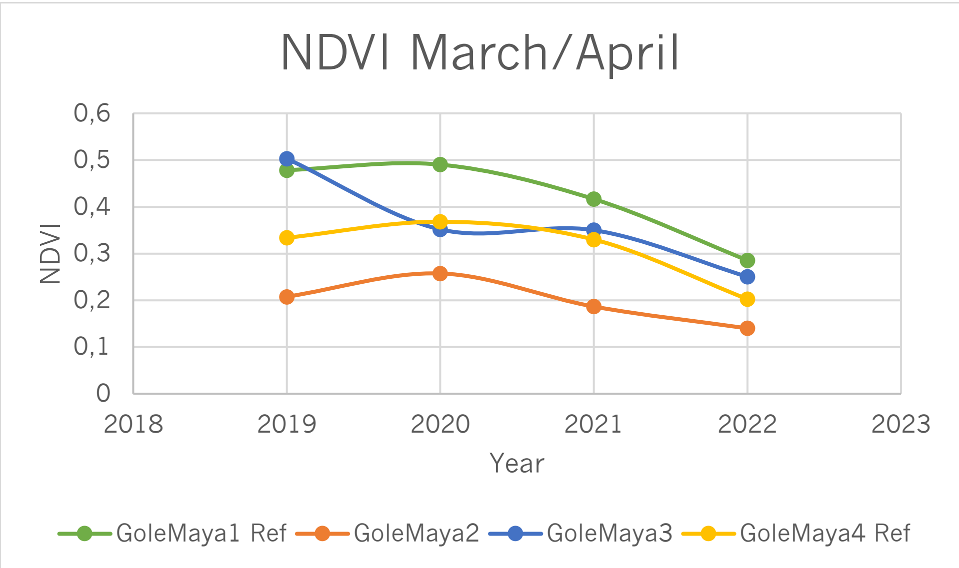
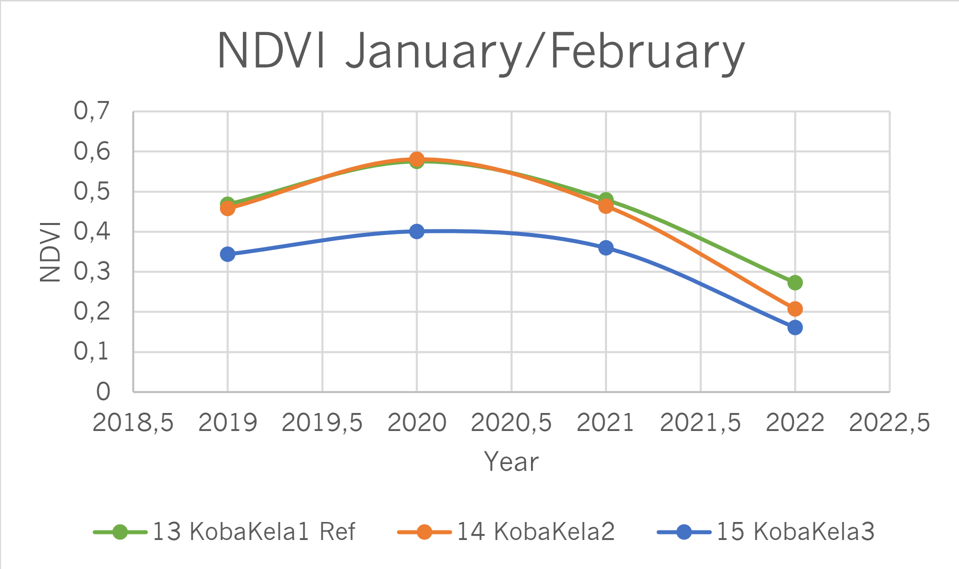
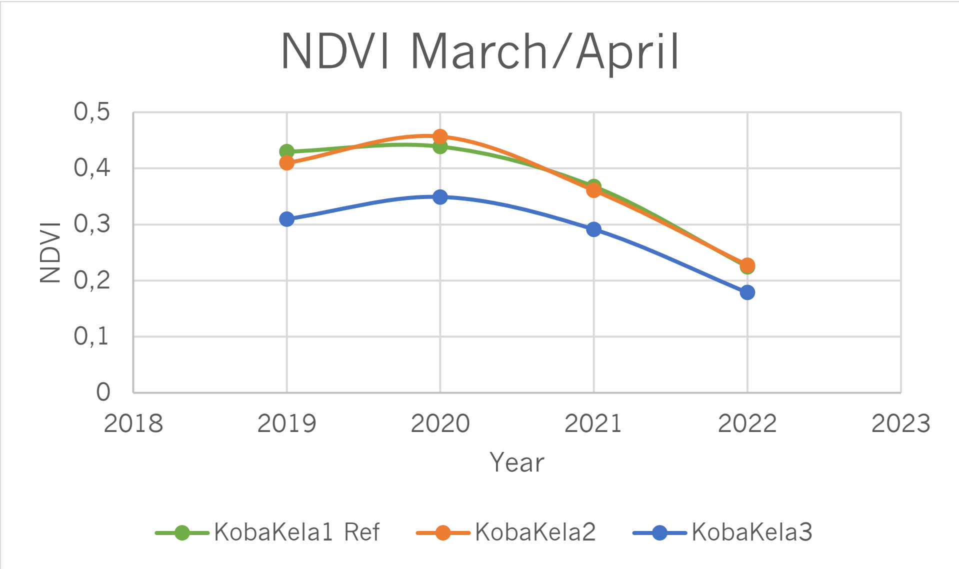


Figure 22. NDVI values of Gole Maya, between 2019 and 2022, in March and April

Koba Kela

For Koba Kela counts a similar situation as for Gole Maya site, consisting of two (2) experiment/implementation plots, with one adjacent reference plot. The results are shown in the figures on the next page.





4.1.2 Harar

Multi Spectral Images from the European Copernicus Sentinel-2 satellites[3] were used to create a Normalized Difference Vegetation Index (NDVI) image of the target areas. This index gives a good indication of the plant health in the area. A higher number corresponds to a healthier, denser, wetter canopy.

The images were later sampled over the target areas, including several reference fields. All data shows a significant decrease in plant health for the year 2022 compared to the three years prior. This, however, can be explained by the severe droughts across eastern Africa during that year.

[3] https://sentinel.esa.int/web/sentinel/missions/sentinel-2

However, the comparison between the implementation sites and the reference fields can still be made. Two measurement locations are set up with adjacent reference plots, namely, Sofi and Barkele.

For each year that the sentinel data is available (2019-now), several months of data have been analyzed.

- October – November, at the end of the rainy season, to see if a larger volume of water infiltrates into the upper soil layer;
- January – February, when de soil starts to dry up and vegetation decreases;
- March – April, to see the land at its driest and to assess if any water is being retained.

Sofi

The Sofi implementation site consists of various bunds along a slope. Measurement points Sofi 2 and Sofi 3 are at the top and bottom of the implementation site, respectively. The reference point is further south along the same height at Sofi-1.

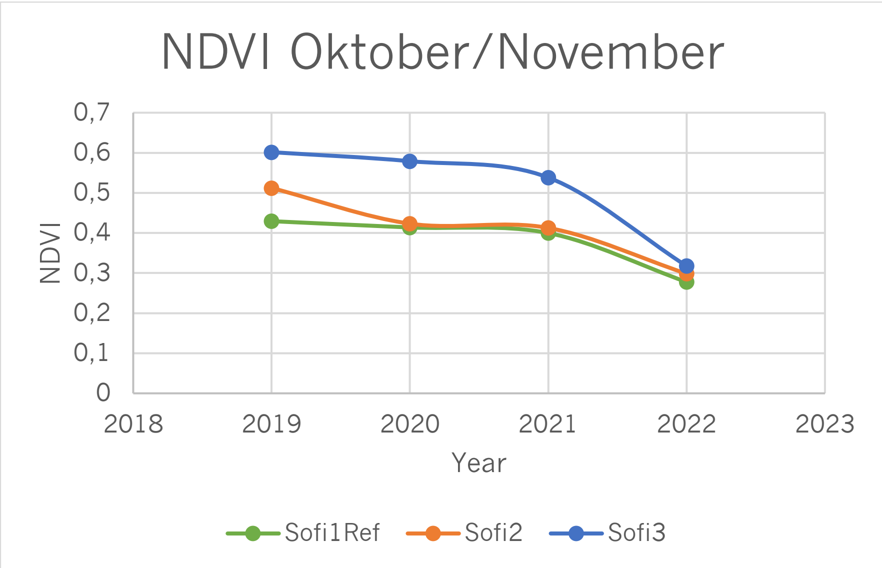


Figure 23. NDVI values of Sofi, between 2019 and 2022, in October and November

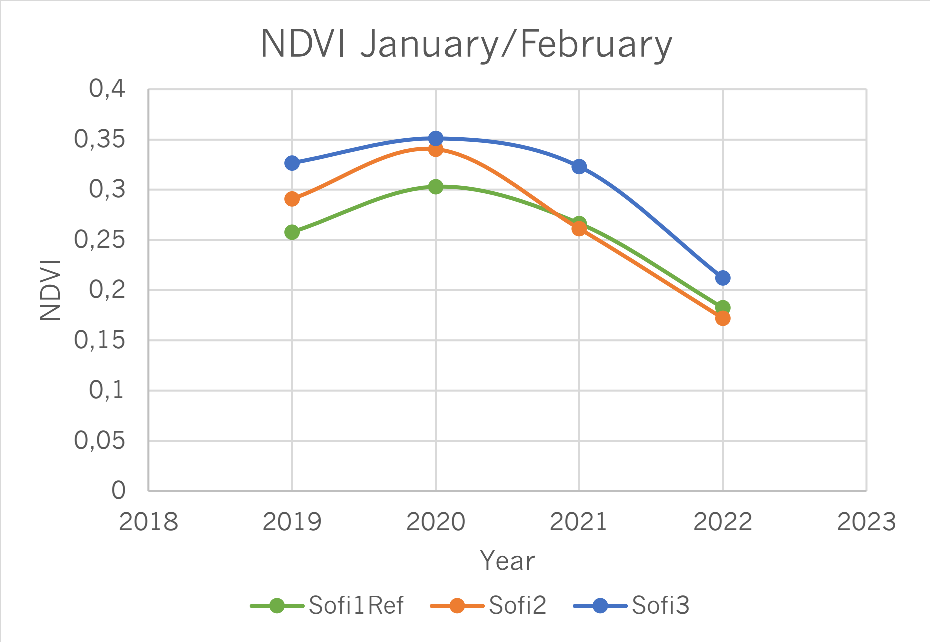


Figure 24. NDVI values of Sofi, between 2019 and 2022, in January and February

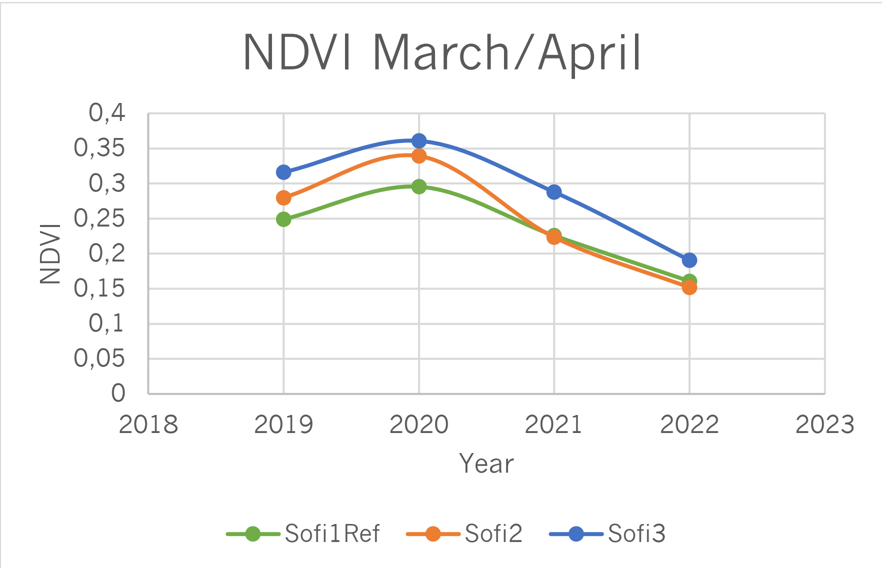


Figure 25. NDVI values of Sofi, between 2019 and 2022, in March and April

Barkele

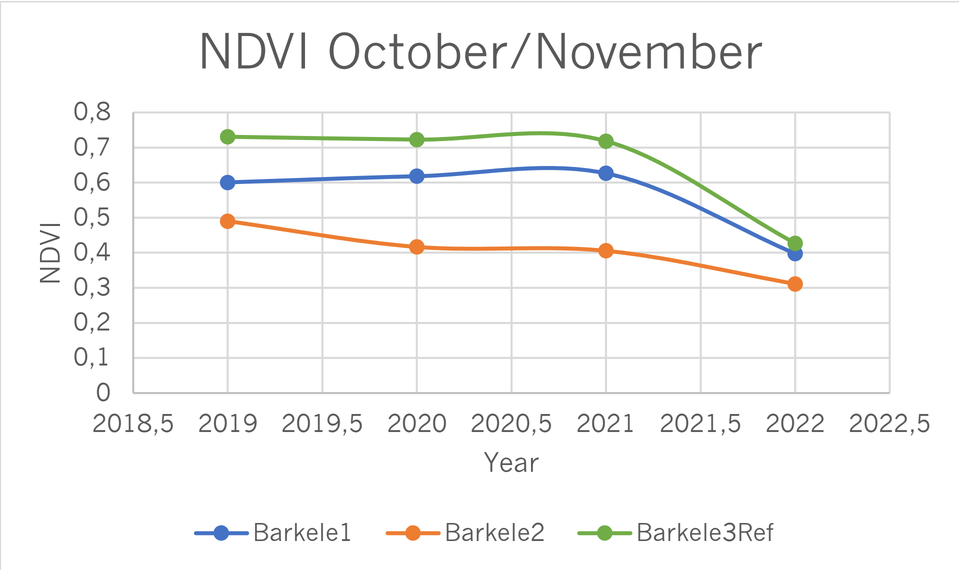


Figure 26. NDVI values of Barkele, between 2019 and 2022, in October and November

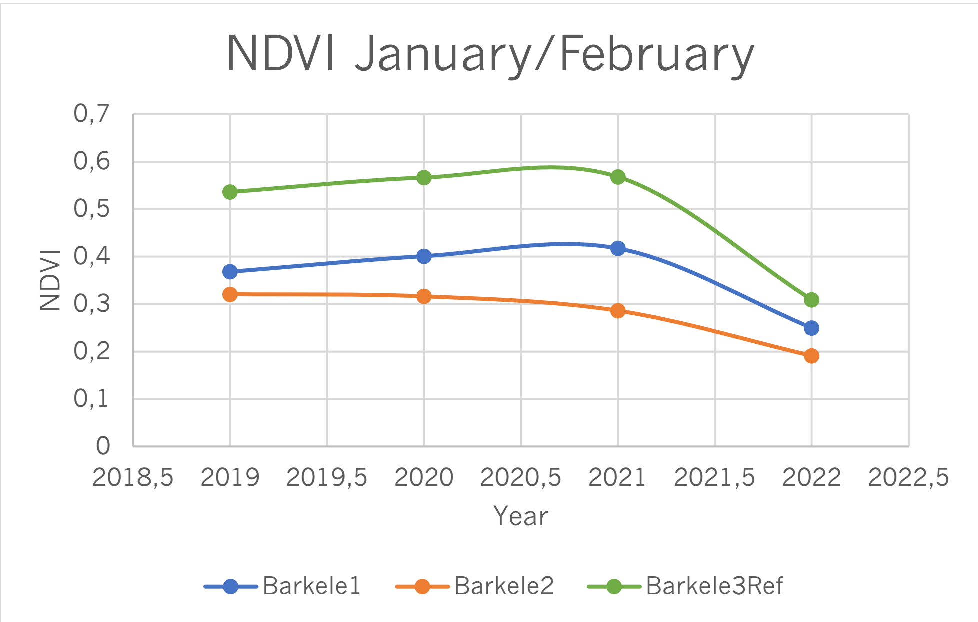


Figure 27. NDVI values of Barkele, between 2019 and 2022, in January and February

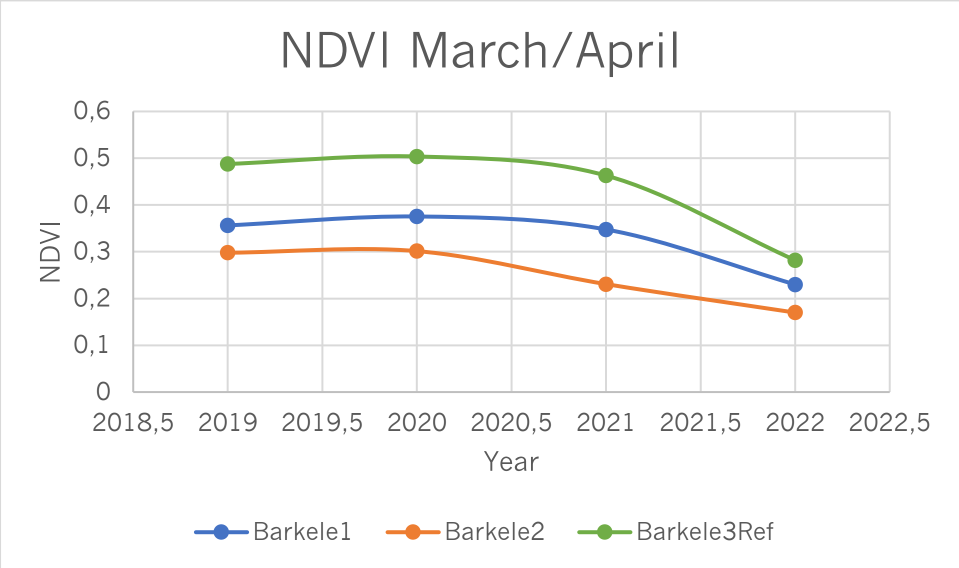


Figure 28. NDVI values of Barkele, between 2019 and 2022, in March and April

4.2 Calculated SWC-impact analysis

Telemetric stations and discharge gauging stations were installed at both Hakim Gara (Harar) and Upper Dabena (Bedele) catchments. However, as the impacts of soil and water conservation lagged from implementation season, monitoring the changes with only (telemetric) sensors and loggers data was challenging. There were only limited resources for installing telemetry monitoring, which were often placed more strategically downstream at a hydrological or watershed outlet. Now, in 2023, after 2 years of measuring, the Consultant has noticed that not all the hydrological impact that has been achieved at intervention plot level is observable at the monitoring locations downstream.

Therefore, it is proposed to evaluate the impacts of interventions potential on water retention using land use and land cover change and empirical-based analysis of SWC practices. The water retention as result of land use change were evaluated by soil conservation number (SCS) curve number (CN) method and empirical calculations were done based on the stone bunds dimensions implemented in the catchment. The amount of water that can be retained in the soil depends on the depth and width of the stone bunds.

The following Figure 29 shows the potential water retained by the implementation of stone bunds. The ponded area will increase during heavy rainfall and decrease with low rainfall magnitude. The amount of water retained in the stone bunds is equal to the difference between the magnitude of rainfall and effective rainfall (runoff generated over the surface that ends up to rivers or streams).

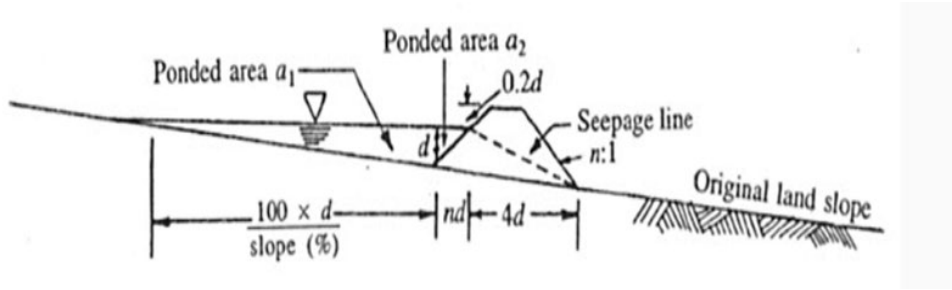


Figure 29. Water retention by the stone bunds. Source: Das, 2012

4.2.1 Land use and Land cover change

In Hakim Gara and Dabena catchments, the land use and land cover changes were observed between 1986 - 2020. Table 7 shows the land use change for both Dabena and Hakim Gara catchments from 1986 to 2020. The (re)forestation area has decreased by 23% from 1986 to 2000 and by14% from 2001 to 2020. Likewise, in Dabena area the rate of forestation decreased by 31% between 1986 to 2000 and by 46% between 2001 to 2020.

Table 7. Land use change detection for both Hakim Gara and Dabena (1986-2020)

	Hakim Gara catchment		Dabena catchment	
	Change (%) 1986 -2000	**Change (%) 2001 -2020**	**Change (%) 1986 -2000**	**Change (%) 2001 -2020**
Forest/ Plantation	**-23**	**-14**	**-31**	**-46**
Grass/ Scrubland	**-7**	**13**	**19**	**-12**
Bareland	**186**	**12**	**66**	**15**
Cultivated land	**4**	**15**	**80**	**68**

4.2.2 Hakim Gara catchment (Harar)

In Hakim Gara catchment, 150 ha under the Burqaa project and 350 ha of soil and water conservations implemented with other organizations. Particularly, 150 ha of project area were covered with trees through Burqaa initiative project by World Vision Ethiopia. Since the start of the project, about 3000 seedlings have been planted and 150 ha area of land covered with soil bunds implemented with community participation. In Hakim Gara area, soil and water conservation measures were widely implemented by the governmental and non-governmental organizations. In addition to the Burqaa project, other organizations are implementing soil and water conservation practices.

Table 8. Soil and water conservation measures implemented at Hakim Gara, Harar

Company/ Organization	Area of intervention site (until 30-06-2022)	Seedling planted	Soil bunds	Water collection contour trenches	Gabions	Hill side traces
Unit	*ha*	*pcs*	*ha*	*pcs*	*pcs*	*ha*
Other organizations	350	90,000	85	_	2300	265
Burqaa project	150	3000	150	40	_	_
Total	500	93000	235	40	2300	265

Therefore, the water and soil monitoring analysis encompass the influences of all interventions (World Vision and other organizations) implemented in the catchment area. Table 8 on the previous page shows SWC measures implemented at Hakim Gara catchment.

Soil and Water Retention

Soil and water conservation methods increase the rate of soil water retention. Surface water retention is calculated with SCS curve number method (Soil conservation services, 1964). The curve number method is applied to monitor and estimate the maximum soil water retention (S).

The curve number method is based on two parameters: The initial accumulation (Ia) of rainfall represents interception, depression storage, and infiltration before the start of runoff. After runoff has started, some of the additional rainfall is lost, in the form of infiltration; this is called actual retention (S). With increasing rainfall, the actual retention also increases up to some maximum value: the potential maximum retention. The maximum and minimum value of S curve depends on soil types of hydrologic conditions. The curve number values are derived for different land use and soil conservation practices (USDA,1985). The surface water retention (m^3) is estimated for the period from 1986-2022, considering that the curve number value changes over time and soil conservation practices. Maximum and minimum rainfall over the area is estimated using annual Global CHIRPS data with a resolution of 0.05 degree. The maximum rainfall ranges between 500 mm and 900 mm between 1986 and 2022. The effective runoff varies between 105 mm to 560 mm over 30 years. When the rainfall is low the effective precipitation over the area is low due to initial abstraction and high surface water retention. Likewise, when excessive amounts of annual rainfall occur over the area, the rate of surface retention decreases, due to saturation of the soil. This situation causes excessive amounts of effective rainfall that causes increased runoff. Between 2020 to 2022, the amount of annual rainfall was reduced by 279 mm. Also, the effective rainfall is reduced by 200 mm from the year 2020 to 2022. Therefore, because of reduction for the effective rainfall, the amount of runoff will be reduced and simultaneously the surface water retention is increased. See also the bar graphs in Figure 30, Figure 31 and Figure 32 on the next page.

Annual maximum total surface water retention (m^3) in Hakim Gara catchment was reduced from 3.2 Mm^3 to 2.9 Mm^3 because of land use change in 1986 to 2000. However, considerable soil water retention increment was observed in Hakim Gara catchment from 2000 to 2020. During this period, the maximum annual total surface water retention was improved from 2.97 MCM to 2.98 MCM. The actual surface water retention was improved by 5000 m^3 per year. The reason for the increased surface water retention could be that soil and water conservation practices were started 20 years ago in Hakim Gara catchment. In 2020 to 2022, while the other SWC implementing organizations were involved in addition to Burqaa project, the maximum total surface water retention potential in Hakim Gara watershed was improved. The following bar graph (Figure 31) shows Burqaa-Hakim Gara project implementation, the average water retention (S) was improved by 123,700 m^3/year. With other organization involvement in the SWC interventions, average soil water retention was 243,050 m^3 /year. The other organization's involvement in SWC practices was considerable in addition to Burqaa initiative project.

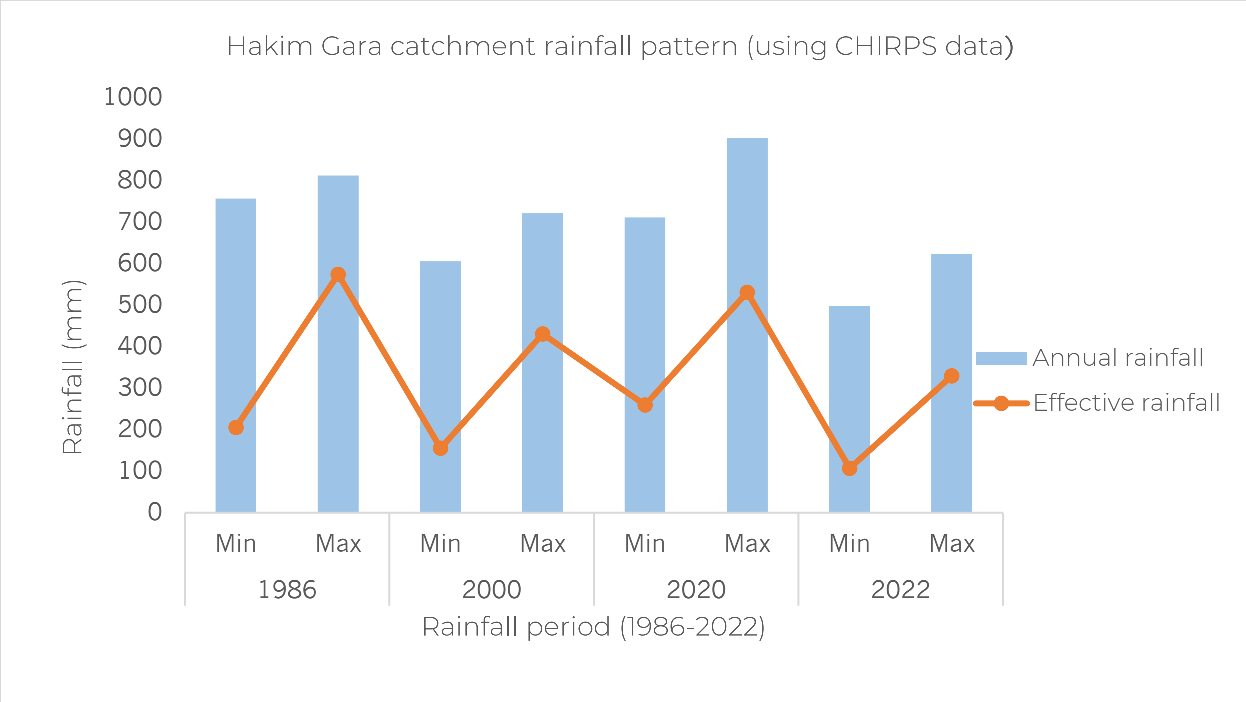


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Figure 30. Annual and effective rainfall at Hakim Gara catchment using CHIRP data.

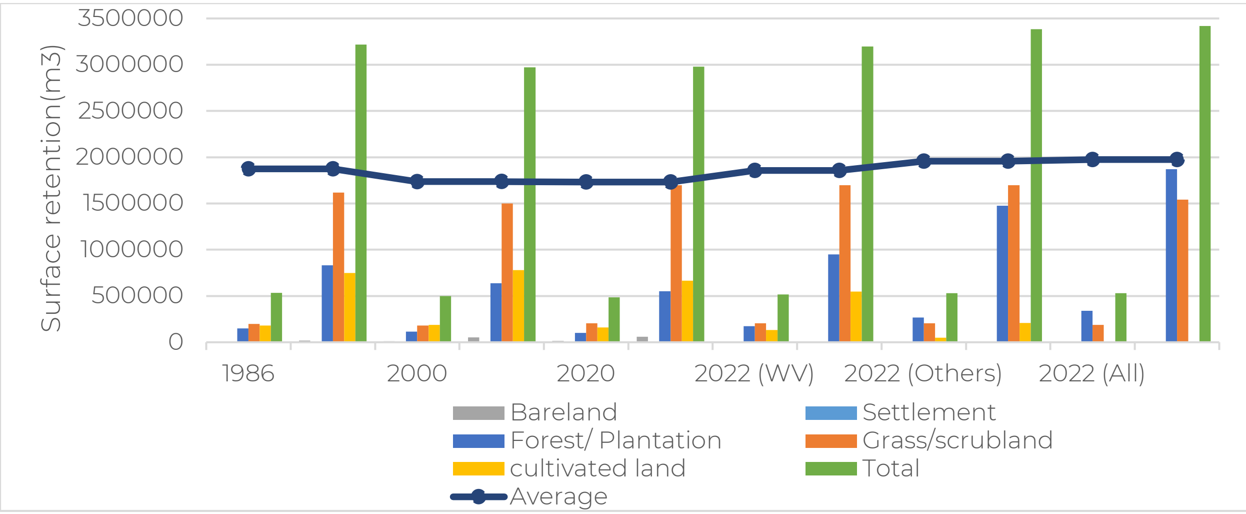

Figure 31. Estimation of soil water retention (m$^{3)}$ of different land use cover (1986-2022) with the influences of soil and water conservation measures under Burqaa project, Hakim Gara catchment

Water retention by soil and water conservation practices

Soil and water conservation works are done at the hilly areas of Hakim Gara catchment. The volume of water retained by SWC measures through Burqaa project was shown in the following Table 9. The stone bunds are implemented within 30 m horizontal spacing. The average length of the stone bunds was estimated 200m per hectare (shown in the Appendix Table 1A & Table 1B). The total volume of water retained by the stone bunds as SWC, were estimated as 45,600 m^3/year. A total 40 number of water collection trenches were implemented to retain 5 m^3 of water annually. Annual total water retention in Hakim Gara by Burqaa initiative was analyzed and estimated as 45,605 m^3/year.

Table 9. Estimation of water retention behind the SWC practices of Hakim Gara catchment.

SWC practices	Units	Quantity	Water retention (m^3/year)
Soil/stone bunds	Ha	150	45,600
Water collection trenches	Pcs	40	5.00
Gabions	Pcs		
Hillside terrace	ha		
Total			**45,605**

Run off estimation

The annual runoff of the Hakim Gara catchment significantly varies temporally before and after the project implementation. The average annual run off was reduced from 174 Mm^3 to 131 Mm^3 from 1986 to 2000. This reduction of runoff happened due to less rainfall over the area. Conversely, starting 2000 to 2020 the runoff in the catchment significantly increased to 177 Mm^3/year (Figure 32). In the period of 2000 to 2020 the runoff increased because of land use and land cover change (increased area of the bare land). Runoff increase happened because of the plantation / forest cover change (14% reduction) which causes low infiltration rate, also see Table 7 above.

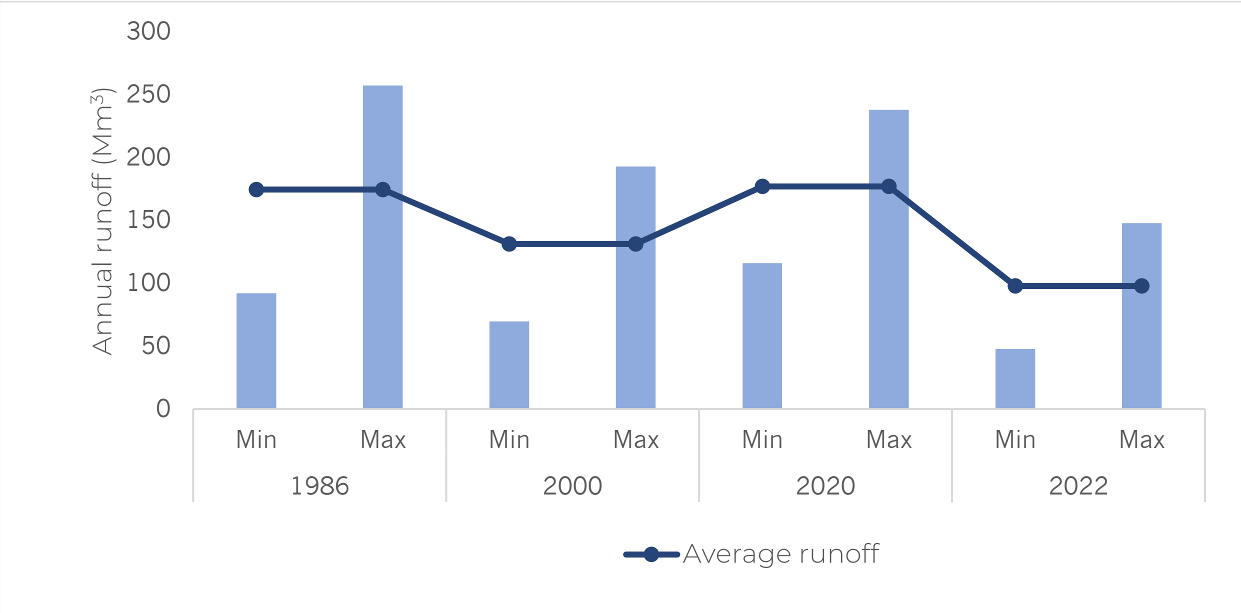

Figure 32. The annual runoff generated over the catchment at Hakim Gara catchment.

4.2.3 Upper Dabena Catchment (Bedele)

In upper Dabena catchment, a total area of 91 ha is implemented with interventions under Burqaa integrated project. The other organizations (governmental and non-governmental organizations) have implemented soil and water conservation measures that cover 80 hectares of land. Overall, in total 171 ha of the project area is covered with seedlings. Since the start of the project, under Burqaa project 97,000 trees were planted, and soil bunds implemented on 90.5 ha of area by World Vision. In Dabena catchment, gabions and hill side traces were implemented under Burqaa integrated project. The type of soil and water conservation practices in the catchment is depicted in the following Table 10.

Table 10. Soil and water conservation practices in Dabena catchment

Company/ Organization	Area of intervention site (until 30-06-2022)	Seedling planted	Soil bunds	Water collection contour trenches	Gabions	Hill side traces
Unit	*ha*	*pcs*	*ha*	*pcs*	*pcs*	*ha*
Other organizations	*80.5*	*59309*	*75*	*5170*	*3*	*7*
Burqaa project	*91.12*	*97875*	*77*	*5364*	*6*	*4.2*
Total	*171.62*	*157184*	*152*	*10534*	*9*	*11.2*

Soil and water retention

The value of surface water retention in m³/year is estimated in temporal variations (1986-2022), considering that curve number value changes over time and soil conservation practices implemented by Burqaa project. Also, the other government and non-governmental organizations' activities are involved in the surface water retention analysis. Runoff curve number for selected agricultural areas and improved conservation system is referred from runoff curve numbers for agricultural lands (USDA-SCS,1985). The annual rainfall in upper Dabena catchment was retrieved from remotely sensed global CHIPRPS data. Based on the analysis, the rainfall variation was (850 to 1962) mm as shown in the figure below Figure 33). Between 2020 to 2022, the maximum annual rainfall increased slightly to 1962 mm.

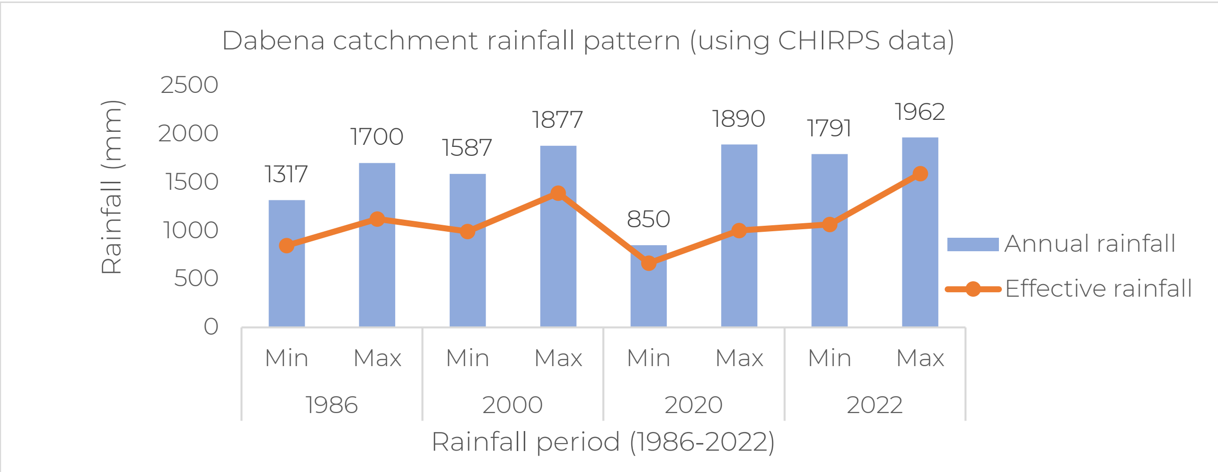

Figure 33. Annual and effective rainfall at upper Dabena catchment using CHIRPS data (1986-2022)

Based on analysis as shown in Figure 34, average surface water retention in upper Dabena catchment was reduced from 82.5 million m³ to 12.24 million m³ because of land use and cover change (1986 to 2020). To increase soil water retention, the Burqaa initiative project started in 2020. Due to SWC measures, through the Burqaa project implemented by World Vision, the total surface water retention was improved.

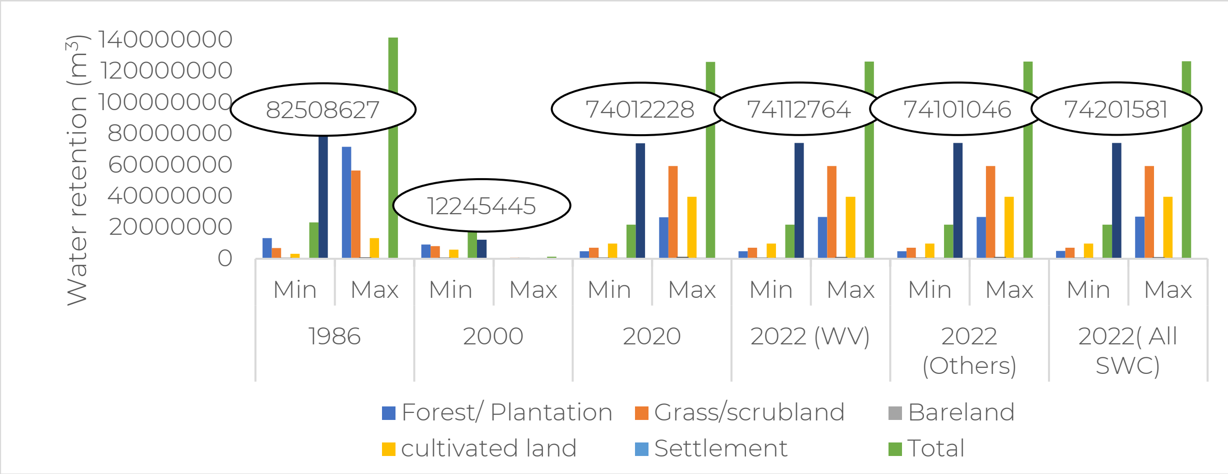

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Figure 34. Estimation of soil water retention: in(m^3) for different land use cover (1986-2022) with the influences of soil and water conservation measures under the Burqaa -Dabena catchment

In 2020 to 2022, the average surface water retention in upper Dabena catchment was improved from 74million m^3 to 74.2 million m^3. The reason is due to reforestation and soil and water conservation measures implemented in the area. The Burqaa initiative project has improved soil water retention through SWC measures. In Figure 34, the implementation of Burqaa- upper Dabena project increases the rate of infiltration due to plants cover change in the catchment.

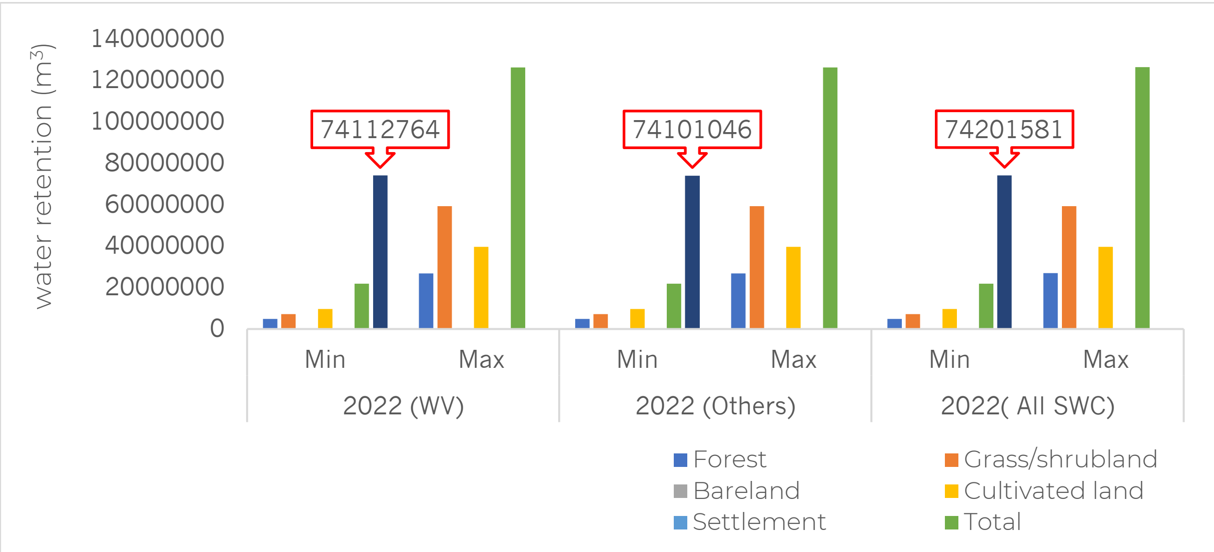

Figure 35. Comparison of soil water retention implemented through Burqaa initiative project with other implementing partners (2022)

In Figure 35, it is shown that the implementation of Burqaa- upper Dabena project reduces bare land while the number of plants increased. Burqaa- upper Dabena project has improved the catchment area average water retention by 11718 Mm^3 compared to other organizations (government and NGO) activities in soil and water conservation practices in 2022. The Burqaa initiative project at upper Dabena project improved the soil water retention maximum of 100,536 m^3/year. The following Figure 35 shows the average surface water retention (m^3/year) improved through the Burqaa initiative project and other organizations in 2022. The results were achieved through planting trees, construction of stone bunds and trenches implemented by World Vision.

Water retention by soil and water conservation practices

In Dabena catchment a total area of 90 ha was under intervention. The stone bunds were implemented at the hill areas of upper Dabena to reduce the runoff and increase water retention. The following Table 11 depicts the water retained because of stone bunds implemented at Dabena catchment. The average stone bunds horizontal interval (spacing) is 40 m and the average length of stone bunds per hectare was estimated 200 m. The stone bunds implemented at Hakim Gara could retain a water of 86,190 m^3/year. The water collection trenches could retain 1357 m^3 of water per year and hill side terraces improved water retention to 3443 m^3/year. Dabena- Burqaa initiative project improves the water retention by 90,990.7 m^3/year through soil and water conservation practices.

Table 11. Estimation of water retention behind SWC practices of Dabena Catchment

SWC practices	Units	Quantity	Water retention (m^3/year)
Soil/stone bunds	ha	77	86190
Water collection trenches	Pcs	5364	1357.5
Gabions	Pcs	-	Non-significant
Hillside terraces	ha	4.2	3443
Total			90990.7

Runoff estimation

The average annual runoff of Dabena catchment increased between the year 1986 to 2000 (Figure 36). Conversely, from 2000 to 2020 the reduction of runoff happened (533 -374) M m3 per year. In 2022, the estimated annual runoff was 595M m3/ year. The following Figure 36 depicts the runoff variations in Mm^3/ year from 1986 to 2022.

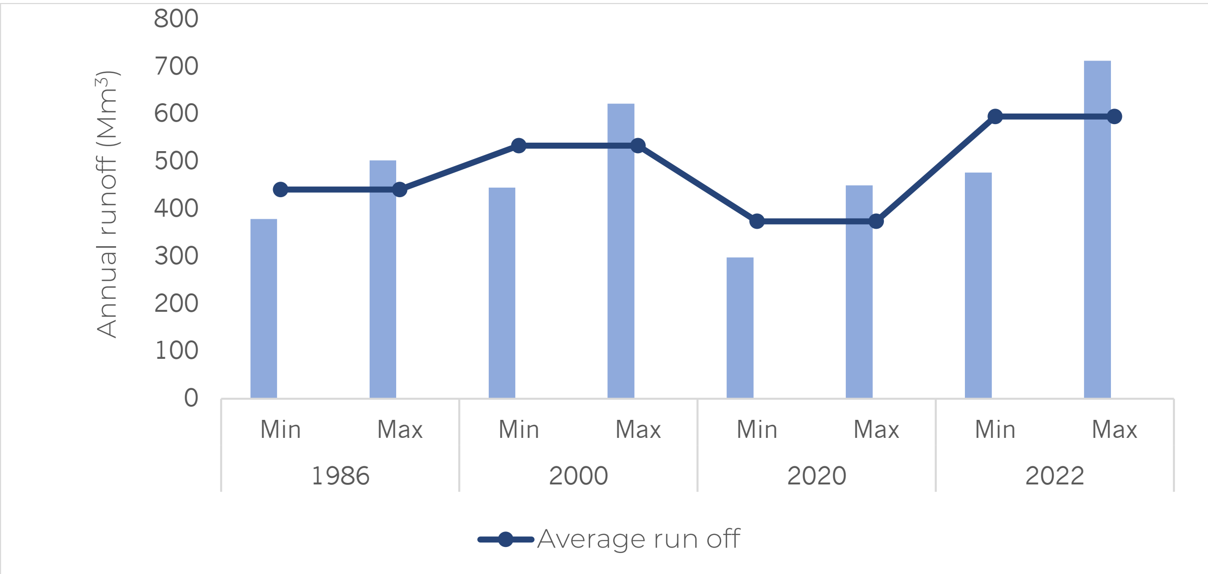

Figure 36. The annual runoff generated over the catchment at Upper Dabena catchment.

4.2.4 Calculated water retention

Based on the literature-based calculated impact analysis as result of implemented SWC interventions, water retention or water balancing achievements were derived for each brewery and related catchment. The results of the water retention or water balancing achievements are shown in the table below.

It should again be noted that this is based on calculated impact results, since the data series of monitored data that has been built up is currently still insufficient to present empirically measured results (based on experimentation and verifiable facts) with sufficient confidence.

Table 12. Calculated water retention for each brewery and related catchment

	Water Balancing target		Main intervention site(s)	Calculated Water Balancing achievement	
	m3/year	%		m3/year	%
Bedele brewery	90,000	150	5,521 ha restoration of degraded land in 5 kebeles in Gechi woreda through tree planting and soil and water conservation (SWC) measures	90,991	152
Harar brewery	24,000 (Ginela spring only)	100	Land management and SWC measures on Hakim Gara plateau, Sofi woreda	45,605	190

5 Conclusion and Recommendations

For the impact analysis of the water balancing target achievement of the Burqaa project, monitoring of rainfall data, surface and ground water flow and soil moisture data were collected digitally and manually. Telemetric gauging station, remote sensing data and empirical formulas are used to evaluate the water balancing task done through the Burqaa initiative project.

According to the data, water runoff has decreased significantly while soil moisture content has increased, implying that taken interventions by WVE (will) contribute to improved base flow and elevated groundwater levels. Based on the analysis results, we may conclude that the water balance target has been met nearly 100% in the Dabena catchments and well above target for the Hakim Gara catchment. It should be noted, however, that:

- these impact results are based on literature and calculated impact analysis, and not on empirical (based on experimentation and verifiable facts) evidence;
- evapotranspiration was not considered in the analysis, which may have an impact on predicted infiltration or runoff volumes.

There are certain constraints on the analysis. One of which is that there is not enough data available because the telemetric loggers have only been collecting and sending data since July/August 2021, which cannot be considered a sufficient and complete reliable data series for impact analysis. Moreover, gathering soil moisture data proved a challenge, particularly in Harar, whereby the Consultant - perhaps naively – relied and trusted too much on reliability of manual soil moisture (SM) measurements. Only two SM assessments were in the end usable for analysis.

Based on the challenges faced the following recommendations suggested, also for a Burqaa Initiative Phase II project development:

- due to the short built-up data series (< 2 years), continuation of monitoring for at least two to five years is required in order to be able to perform accurate and reliable data series, and thus impact analysis;
- Expansion of the hydrological monitoring network at strategic locations with regard to surface water, groundwater and soil moisture levels must be continued. This applies in particular to the Dabena catchment due to its sheer size to collect effective and sufficiently relevant impact data;
- telemetric soil moisture monitoring is proposed as it is less dependent on human labour;
- The designation of (monitoring) managers, and the development of ownership and community sensitization must be continued to prevent theft and vandalism of installed equipment.

Literature list

- **EU JRC, 2022,** ISBN 978-92-76-55830-9
- BGR report,2012, Federal Institute of Geosciences and Natural Resources.
- Das. (2004) Hydrology and Soil and Water Conservation Engineering book.
- EU JRC 2022, Drought in East Africa August 2022, GDO analytical report.
- USDA Soil Conservation Service.1973. National Engineering handbook.

Annexes

Annex 1: Equations for SCS curve number method

$$Pe = \frac{(p-Ia^2)}{(p-Ia)+S} \qquad (1)$$

$$Ia = 0.2S \qquad (2)$$

$$Pe = \frac{(p-Ia^2)}{(p+0.8S)} \qquad (3)$$

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

Table 1A: Estimation of water retention behind the stone bunds of Hakim Gara catchment

Parameters	Data
Contour bunds horizontal interval (HI)	30 m (Estimates from field visit)
Average length per hectare	200 m (Estimates from field visit)
Runoff volume retained per hectare	2,280 m^3/year

Table 1B: Estimation of water retention behind the Stone bunds of Dabena catchment

Parameters	Data
Contour bunds horizontal interval (HI)	40 m (Estimates from field visit)
Average length per hectare	200 m (Estimates from field visit).
Runoff volume retained per hectare	4310 m^3/year
Total runoff volume stored (Volume of water retained)	86,190 m^3/year

Annex 2: Geographic location of WVE intervention sites in UDC

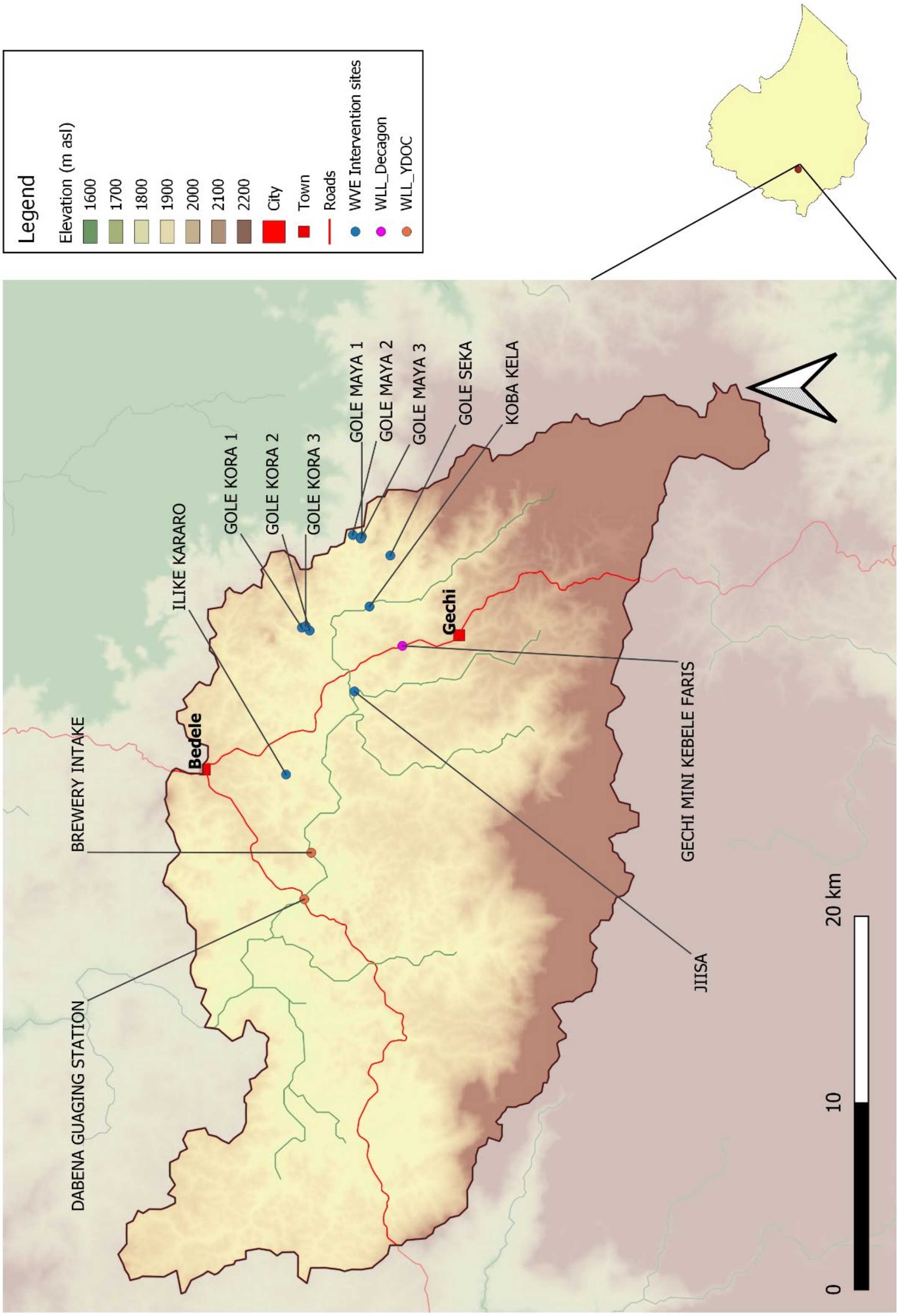

Figure 37. Overview of WVE intervention sites in respect to the installed loggers, Bedele

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