Subsurface Micro-Reservoirs for Rural Water Supply in the Ethiopian Highlands

TAWI – Tigray and Afar Water Initiative, Ethiopia

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Summary

The Tigray and Afar Water Initiative (TAWI) is a collaboration between the Mekelle University (Ethiopia), the Muenster University of Applied Sciences (Germany) and the Westfalian Wilhelms-University Muenster (Germany). This special initiative is concerned with the rural water supply for the particularly water-scarce regional states of Tigray and Afar in the semi-arid north of Ethiopia.

This paper describes a pilot project near the village of Koraro, Hawzen county in the Tigray region and deals with river reaches or creeks which carry water for short periods and only after the longer of two rainy seasons. When these waters run dry, water is still often to be found under the dry beds and is used casually by local people for agricultural purposes.

An impermeable wall constructed as a subsurface dam to retain water in the ensuing subsurface micro-reservoir under the bed of such rivers could enable this usage to be intensified and hence enhance the water supply of small local user-groups, while at the same time positively influencing the landscape water balance. Here, the word "micro" refers to the fact that only the pores of the granular soil of an alluvial river bed are used to store water.

Furthermore, storing water underground also avoids the danger of increasing the incidence of diseases such as malaria, a consequence of open water ponds that has been shown by Mekonnen et al. [2005].

This project was set up with the specific intention of enabling the resulting know-how for this adapted technology to be disseminated within the region and among the stakeholders. The construction of the dam in 2009 was prepared through explorations in 2007/08 and planning in 2008. The reservoir is now in operation and is inspected sporadically by the project partners.

Keywords: *Subsurface, water, micro reservoir, groundwater dam, rural water supply, malaria*

Zusammenfassung

Die Tigray and Afar Wasser Initiative (TAWI) ist ein Kooperationsprojekt der Mekelle Universität (Äthiopien), der Fachhochschule Münster und der Westfälischen Wilhelms-Universität Münster. Gegenstand der Initiative ist die Wasserversorgung im ländlichen Raum der besonders wasserarmen Regionalstaaten Tigray und Afar im semi-ariden Norden Äthiopiens.

In dem Projekt, über das hier berichtet wird, geht es um die in der Regel trockenen Oberflächen-Fließgewässer, die nur kurze Zeit Wasser führen, und zwar nur nach länger anhaltenden Regenfällen in der längeren der beiden Regenzeiten (Juni-September). Hier wird über ein Pilotprojekt in der Nähe der Ortschaft Koraro, Kreis Hawzen, Region Tigray, berichtet. Im Untergrund dieser Gewässer ist häufig noch Wasser zu finden, das gelegentlich auch von Menschen zu landwirtschaftlichen Zwecken extensiv genutzt wird.

Dichtwände im Untergrund der Gewässerläufe und die damit einhergehenden Micro-Reservoire können dazu dienen, diese Nutzung zu intensivieren und zusätzlich den Landschafts-Wasserhaushalt positiv zu beeinflussen. Die so aufgestauten unterirdischen Wasserspeicher sollen als kleine bzw. kleinste Anlagen dezentral die Versorgungslage kleiner, lokaler Bevölkerungsgruppen verbessern. Der Zusatz „Micro-“ trägt der absoluten Größe der gespeicherten Volumina im Vergleich zu Talsperren Rechnung. Die Speicherung findet nur in den Poren des sandigen Gewässerbetts statt.

Gleichzeitig vermeidet die unterirdische Speicherung die Gefahr einer Erhöhung der Inzidenzrate für beispielsweise Malaria, wie sie infolge von oberirdisch angelegten Speicherbecken nachgewiesen worden ist [Mekonnen et al. 2005].

Mit diesem Projekt soll das erzielte Know-How über diese angepasste Technologie in der Region und bei den maßgebenden Akteuren bekannt gemacht werden. Die Errichtung des Dammes im Jahr 2009 wurde durch Erkundungen in den Jahren 2007/08 und Planungen im Jahr 2008 vorbereitet. Derzeit ist die Anlage in Betrieb und wird in unregelmäßigen Abständen von den Projektpartnern überprüft.

Schlüsselworte: *Unterirdische Wasserspeicher, Grundwasserdamm, Untergrunddamm, ländliche Wasserversorgung, Malaria*

1 Scope of work

The rural water supply emanates from a number of sources: groundwater, surface waters and surface runoff, and according to usage will vary with regard to amount and quality required. The highest consumption is due to irrigation practices, followed by water needed for cattle. The amount of Water reserved for daily personal usage is much lower, but water for drinking purposes has to be of a far higher quality. Since very often groundwater in semi-arid regions can have a high mineral content, it is necessary to store rain or other surface waters in artificial structures during the whole hydrological cycle to balance the gap between demand and available resources in order to cover total demand from the user-groups.

Storing water in open ponds is suitable for irrigation purposes as well as cattle watering. However, once cattle have used the ponds, the water is contaminated and is no longer appropriate for human consumption. It is not possible to deter cattle from using ponds which may be required for personal needs because fences are too expensive. In addition, mosquito larvae will find ideal living conditions in these ponds because they have no natural predators. Adult mosquitoes present a particular danger because they serve as a vector for diseases such as Dengue fever and Malaria. Therefore, water for household usage is commonly saved in cisterns, where it is easier to control quality as well as the breeding activity of mosquitoes. Water for the cisterns can be collected from rooftops or from rock catchments, but water stored in this way needs careful filtering and control of water quality. If these precautions are taken, this method can provide water of household quality.

This project, from the TAW-Initiative, investigates whether storing water in underground micro-reservoirs could be a viable alternative to the utilization of cisterns. One technique for harvesting rainwater from small-scale water supplies is gaining attention. Impermeable walls called subsurface dams are erected under the bed of rivers that fall dry in semi-arid climates (Fig. 2). The word "micro" in this context refers to the fact that only the pores of the granular soil of an alluvial river bed are used to store the water, and that the infiltrated water can never be completely extracted again because of the residual soil moisture. However, this means that extensive evaporation can be avoided. Usually, it is not possible to store the sufficient amount of water needed for irrigation in such reservoirs. In many cases, this method is adequate for cattle watering, however, not for the duration of the whole dry season (Nilsson 1988, Print 1997, Onder/Yilmaz 2005, VSF 2006). In addition to the health and landscape conservation benefits, underground storage of water in micro-reservoirs has the potential to be more cost-effective than cisterns, if local conditions allow this technology. The quality and amount of the stored water will depend on the specific situation, the size of the user group and the maintenance requirements of the dam, the reservoir area and the operation devices and facilities. Under optimal conditions, it might be possible to use this stored water for household purposes.

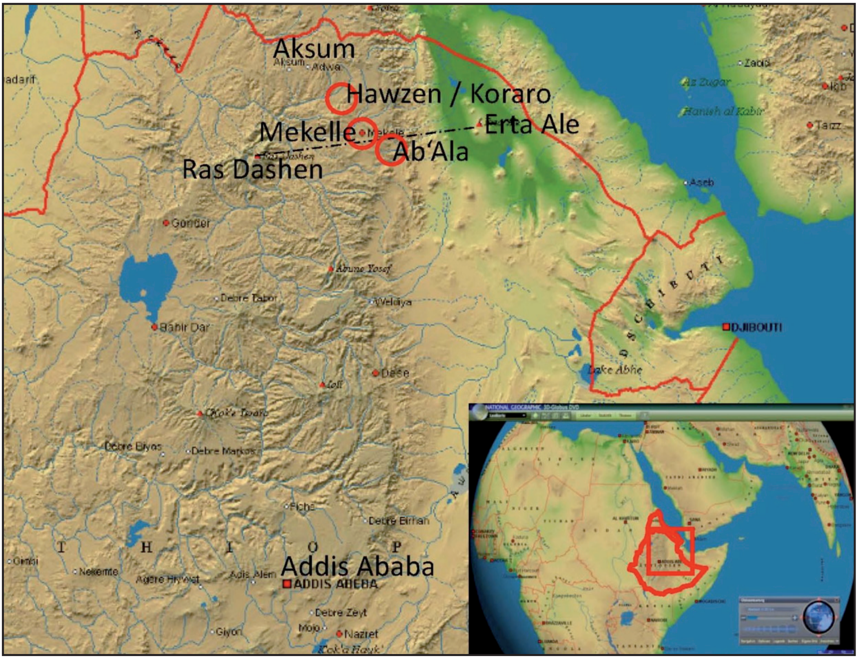

Fig. 1 | Project area location (Source: NATIONAL GEOGRAPHIC 3D Globe DVD)

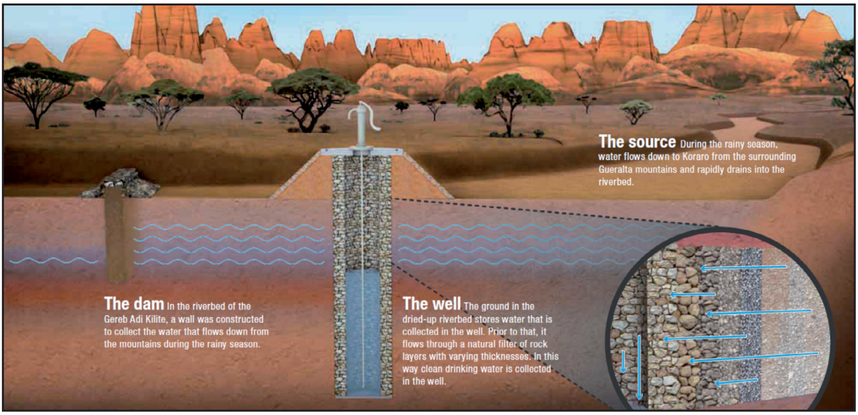

Fig. 2 | Subsurface dam and reservoir
(Source: company magazine "report" of Bayer AG, edition 2/2010)

The source of the stored water may be partly groundwater that is still flowing slowly under the dry river bed as well as infiltrated rain and surface water. Harmful mineral content can be diluted out, but bacteriological pollution is still possible. It might be possible to overcome these drawbacks, if the self-purification process during percolation of the surface water and during its retention in the storage is sufficient, and if a suitable filtration or treatment of the water is available. If the reservoirs are built in a chain along a riverbed or decentralized in the landscape, they will also have a positive effect on the landscape water balance because they can serve to increase the subsurface water level.

If local conditions allow the employment of this technology, the underground storage of water in micro-reservoirs has the potential to be more cost-effective than cisterns. Many questions have arisen concerning the exploration, planning, construction and operation of subsurface micro-reservoirs. For example: Will it be possible to find enough suitable dam locations? Is it possible to infiltrate enough water to fill the reservoir? Is the underground aquiclude tight enough to hold the water, and is the exploration of the aquiclude dense enough? Will it be possible to stabilize the river bed in the dam location surrounding to avoid erosion of the impermeable wall? Will the user-committee be able to run the operation, including maintenance and access control for the reservoir area? Will it be possible to measure the effect of retaining water underground on the incidence of malaria?

Phase	Subject	Schedule
1	Exploration and data collection, including the investigation of water-related diseases in the population (esp. Malaria)	2007
2	Design of the construction and planning of the construction phase	2008
3	Construction of pilot dams and subsurface dams that should be developed to best practice examples	2009
4	Operation and monitoring of subsurface dams; optimization and development of best practice examples	Ongoing
5	Design and operation manual in local languages	2012
6	Training of local experts to operate and to design subsurface dams by their own	2013
7	Training of farmers to build water committees and organize construction and operation of subsurface dams	2014 ff

Tab.1 | Project Phases

Previously, it has not been possible to answer these questions.But now that the pilot plant is in operation, problems can be addressed during the initial operation and monitoring by the project group. The group want to optimize the construction of the pilot plant and minimize the maintenance requirements in such a way that both can be completely assigned to the water committee.

The aim of this initiative is to create a pilot project that also functions as a teaching basis for the practical instruction of experts who are working together with the farmers every day. The experts should be able to propagate the new ideas and instruct the farmers to be able to erect such facilities by themselves in the future.

The exploration team of the Muenster and Mekelle Universities visited two project areas in 2007 and 2008, one in the Tigray region (Hawzen woreda/county, Koraro tabia/village) and one in the Afar region (Ab-Ala, tribal area of semi-nomads in the neighborhood of Ab-Ala town). Based on the knowledge of the elder local people, sites were identified where it had been possible to find water under the dry river beds in the past. Potential reservoir areas were visited and the scope of the exploration was defined. In addition, the geology was investigated by project partners of Mekelle University. Site exploration of the surface-near underground was carried out by digging, probing with sampling tube and sounding. The focus was finally set on a location near the village of Koraro in the Tigray region (Fig. 1), since in the Ab-Ala basin the groundwater table is 70 m below ground level and it was not possible to find river bed conditions that were suitable for subsurface dams.

2 Local situation

The project area is located in the northern highlands of Ethiopia (13°52’06”N, 39°16’30”E, 1730 masl) that suffered severely under the civil war and is therefore, among the poorest regions of Ethiopia. Since the landscape is affected severely by erosion and drought, Koraro is dependent on assistance from the international community. Outside of the rainy season, none of the rivers and creeks carry any water. A few wells with handpumps deliver brackish water out of the surface-near aquifers.

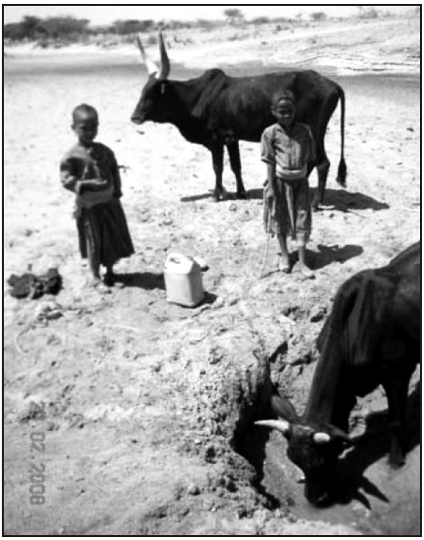

Fig. 3 | Girls and cattle rival for water (Source: Berhane/Aynalem 2008)

The annual rainfall ranges roughly between 350 and 550 mm/a, but it is very erratic. From this amount 80% fall in the three months of main rainy season from mid-June to mid-September. The dam location is situated in a small river referred to as Nda’Gabatat (also called Gereb Adi Kilite). The catchment area there is 2,36 km^2 and the length of the river course is only 3110 m, originating directly in the very steep slope of the nearby Gueralta mountains. The peak discharge for a one-year theoretical return period (prob.=1) was determined to be about 3 m^3/s and for a ten-year period (prob.=0.1) to 11 m^3/s. The peak of a flood (if there is any runoff) will reach the dam location less than half an hour after the rain started (Mohammed 2008).

2.1 Water supply in Koraro, Tigray

Koraro's new village is an artificial settlement of stone houses with welded iron roofs. Around the new village, for a distance of up to 45 minutes by foot, additional farmhouses are spread out in the hard-to-access countryside. A part of these farms belong to the original old village of Koraro, from which the name for the whole new community comes from. The inhabitants are not yet willing or not able to move to the new village to any great extent because of numerous social reasons.

In the old village of Koraro the women and children, mainly girls, who are responsible for collecting water, have to walk long distances to get fresh water. When conditions are favorable, they have access to piped spring water located near the new health post, only 20 to 30 minutes away. But later, during the dry season they have to walk one hour or more to other springs. In this situation, the people tend to take their household water from sources which are normally used for cattle (Fig. 3).

Another acting NGO (Millennium Villages Project, MVP) was not able to improve the situation regarding the water supply for those people living far from the centralized supply points. For this reason, the designated Water Bureau of the Hawzen county assigned this task to the TAWI project group. From the old village of Koraro, a water committee of 25 households was set up with the help of the community administration.

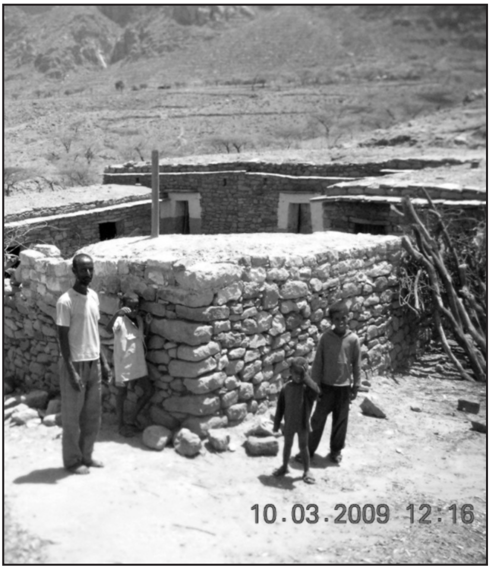

Fig. 4 | Traditional farmer's house (Foto: MOHN)

The groundwater level in that area is up to 7 m below the surface with a somewhat high electric conductivity and is not acceptable for human consumption. In most of the surrounding rivers brackish water can be found for a depth of 3 to 4 m below the river bed level. Below the river Nda'Gabatat the water is less salty. The harvesting of water from rooftops or other surface water collection techniques are not yet in practice because the roofs of traditional houses are not appropriate for collecting water (Fig. 4), and rock catchments are not suitable because the top soil is sandy or loamy. In addition, useful bedrock, located in the nearby mountains, could not be found at an accessible depth. Percolation ponds have been erected for some distance along the river reaches by another NGO (MVP). The aim being, to decrease the power of the floods, to infiltrate the less mineralized runoff and to raise the groundwater level with freshwater.

2.2 Malaria situation in Koraro, Tigray

Epidemiologically, in 2006 4% of all malaria cases in Africa occurred in Ethiopia. About 54 million people in Ethiopia were at risk from a malaria infection in 2008. During the time period between 2001 and 2008 more than 26 million cases of malaria infections were reported at the national health facilities, this number represents up to 12% of all outpatient contacts at the national health facilities in 2008 (Herbst 2011, Federal Ministry of Health 2008, WHO 2008, WHO 2009).

Tigray, being one of Ethiopia's regional states near the border to Eritrea is burdened with droughts, food insecurity and moreover with poor general infrastructure and health services. Malaria is endemic in Tigray area with about 75% of the population being at risk. A community based malaria control program has been established in 1992 (Ghebreyesus, Witten, Getachew 1999 and 2000, WHO 1999).

However, malaria is still the most prevalent disease and leading cause for morbidity and mortality in Tigray (Tigray Health Bureau 2008). Intensive epidemiological and clinical investigation in the Tigray village of Koraro, between August and October 2008, have verified the proposition that malaria, being a major health problem, has a big influence on local development (Herbst 2011).

Jobin (1999) has suggested that the geological situation as well as civil engineering constructive works for harvesting or storing rainwater facilities have to be taken into account as being important variables influencing the incidence and prevalence of malaria in this region. The Millennium Village Project (2005 und 2006) proposed a sporadic transmission pattern for malaria, highly dependent on rainfall and the local surface water situation. Due to this pattern of transmission, the population has an inherently low immunity to malaria.

Herbst (2011) confirmed the intermittent nature of the transmission of the disease in the Kararo village region with a peak transmission rate in September and October after the rainy season (lasting from mid-June to mid-September). Water harvesting facilities such as household ponds and small scale irrigation schemes may have an impact on the local malaria situation by provide optimal breeding grounds for malaria transmitting mosquitoes. Added to the low immunity to malaria found in the region, constructive works for water harvesting projects will constitute a particularly high risk for an increase in transmission of malaria, morbidity and mortality.

3 Preparations

3.1 Pilot dam installations

In the spring of 2008, a team of the Mekelle University erected an initial subsurface model dam near the new village of Koraro to get familiar with the local populations and other conditions (Berhane/Aynalem 2008). All construction material was found nearby and the work was carried out by local dayworkers. In summer 2008 another experimental dam was constructed by another team (Dietmar Klopfer, Aadil Belgriri) from the Muenster UAS to detect the soil densities and other mechanical parameters that could be achieved by compacting clay with different water contents only by using hand-tools.

3.2 Site exploration, design and construction of subsurface dam Koraro-01

Fig. 5 | Construction site of the subsurface dam Koraro-01during digging of the trench for the clay sealing wall (Foto: Klopfer 2009)

Soil and construction material

The soil in the reservoir area consists of sand and loamy sand, with permeability coefficients of $k_{fs} = 1 \cdot 10^{-4}$ m/s resp. $k_{fls} = 5 \cdot 10^{-5}$ m/s. The percentage of pore volume from which water is extractable in such material was set to 20% of a total soil volume. The surrounding soils in the neighborhood of the water course are strongly compacted by natural conditions and have a high clay content, resulting in a permeability coefficient of $k_{fc} = 1 \cdot 10^{-7}$ m/s.

However, this was not good enough to serve as the construction material for the subsurface dam. The clay for the wall sealing with $k_f < 1 \cdot 10^{-8}$ m/s was found nearby in some termite nests, stones and boulders for rockfill protection of dam and well were found in the countryside nearby.

Water management calculations

The water resources calculation of the catchment area, using a catchment area of 1.2 km^2 and a runoff coefficient of 0.2, gave a runoff of more than 73 000 m^3/a (Mohammed 2008).

Ethiopian standards for saved water supply postulate only 20 l/d/head in a distance of max. 1 km (Klopfer 2010). For the whole water committee of 175 persons this sums up to a total consumption of 3500 l/d resp. about 1300 m^3 for a complete year. The household water portion is thus less than 2 % of the estimated runoff.

Simulations of the behavior of the reservoir have been carried out under mean rainfall conditions (Tab. 2) for the region of Koraro and a reservoir size of 351 m³ extractable pore water volume. The results showed that the household water demand could not be covered completely by this initial installation of a micro-reservoir. Different scenarios have been tested where only a part of the daily consumption was supplied (4, 10 or 20 l/d/head). With only 4 l/d/head the supply period could be stretched up to 306 days. The losses from seepage and evaporation were higher than expected and led to a worse efficiency (extracted volume vs. sum of extracted volume and losses) of the reservoir of only 0.32. For 20 l/d/head the efficiency was more than doubled to 0.68 but the supply period shrunk to 196 days. An extraction of 10 l/d/head was therefore recommended, which allows for mean rainfall conditions (Tab. 2) an efficiency of 0.53 and 236 days of supply (Fig. 6). The total extraction from the well is then 402 m³/a, while the whole yearly demand in this case would have been 639 m³/a. The losses from seepage sum up to 168 m³/a and the evaporation is 187 m³/a.

Calculations on the site Koraro-01 showed that gross a reservoir volume of 1755 m³ including sand and not extractable pore water is possible, with a surface area of 675 m² and a mean depth of 2.6 m. For the extraction of the water a hand-dug well with a handpump is necessary. The extractable volume of the well is 8.8 m³ for a net diameter of 0.7 m (Klopfer 2010).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4,7	6,1	28,8	43,1	31,7	30,7	140,9	146,9	20,4	15,4	13,9	6,0

Tab.2 | Artificial mean rainfall data for reservoir content simulation

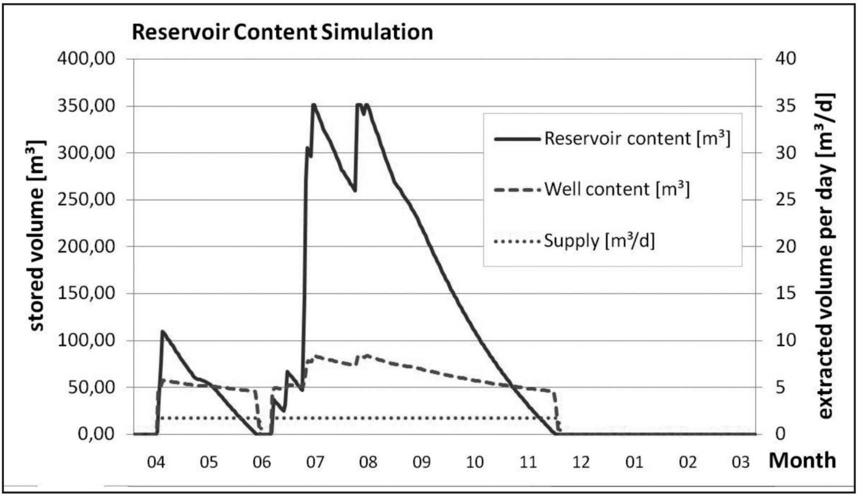

Fig. 6 | Reservoir Content Simulation over one year of mean rainfall activity (Tab. 2)

Subsurface/Sand Storage dam

The subsurface dam has a crest length of 11 m, a depth of 3.6 m and a thickness of 0.8 m. This results in a cubature of 32 m^3 compacted clay. The dam crest, stilling basin, river banks near the dam and the well head above the reservoir surface (about 1.5 m high) have been protected with rockfill (mean diameter 250-300 mm).

In its original version, it had a crest 0.6 m above the surface to store sand in order to increase the storage volume. Since the effect of this additional storage volume was found to be minimal, as well as the accident (described below) which occurred, the crest was corrected to be at the level of the riverbed.

On the basis of these preparations, the construction of the first subsurface dam in the Tigray region began in March 2009 in the river Nda'Gabatat. For realization and financing, the project group set up a cooperation with the German section of Engineers without Borders (Ingenieure ohne Grenzen e.V.) who mobilized several private and institutional donators. In addition, the water committee was further supported by the German Embassy Addis Ababa. The work was finished in May 2009 and the micro-reservoir of the subsurface dam Koraro-01 saved water for several months in the dry season 2009/10.

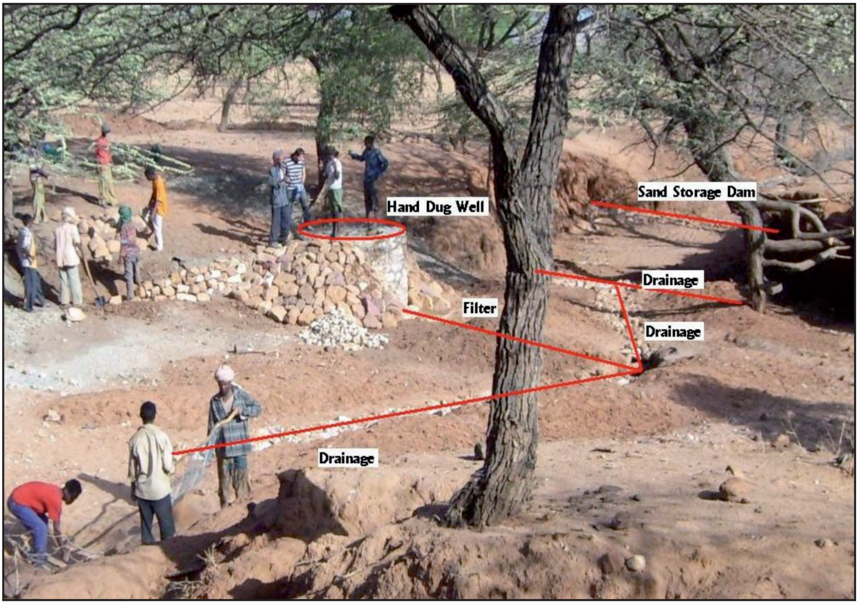

Fig. 7 | Micro-reservoir area Koraro-01 (Foto: KLOPFER 2009)

4 Initial findings

Construction

About 3 weeks after the first runoff incidents in the following rainy season the installed handpump delivered the first water. Shortly after this flooding, as a result of catastrophically rain, breached an above situated percolation dam due to uncontrolled flow over its crest. The released flood wave damaged parts of the crest of the subsurface dam Koraro-01 and the protection of the hand-dug well located adjacent to reservoir area. Fortunately, the reservoir and the hand-dug well still functioned and delivered water for the next three months. The percolation dam has now been repaired and the crest fixed at the natural river bed level without substantial loss of reservoir volume.

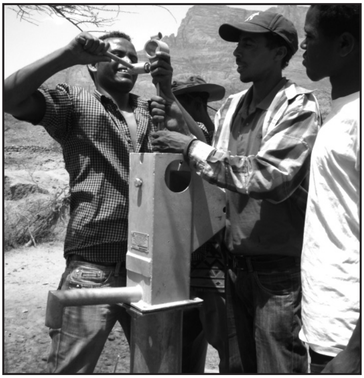

Fig. 8 | Installation of the handpump (type: AFRIDEV) (Foto: Klopfer 2009)

Even if such accidents are not anticipated, it is still recommendable to avoid sand storage dams above the riverbed in such erosive highland situations, since the construction of the crest and the protection of the river bed below (stilling basin) and the river banks must be very massive (probably under additional use of concrete – very expensive in such remote sites) to avoid erosion of the foundation or of the construction itself.

Water quantity

The user group consisted of 150 to 170 people. They were able to extract 15 l/d/head over a time span of 89 days (Klopfer 2010). The reservoir efficiency due to losses (evaporation, seepage) was recalculated to be 0.62 with this information with a total supply of 492 m^3/a and losses of 306 m^3/a due to seepage and evaporation. This was comparable to the estimates of the magnitude of the micro-reservoir in the underground and the water management calculations. It is the task of the water committee to organize the water extraction and to organize or limit the daily consumption.

Water quality

Before installation of the micro-reservoir Koraro-01 the water supply of the user group for domestic use was entirely dependent on groundwater. Both the cattle and human population obtained water from the available groundwater resource which has not been studied systematically. Furthermore, the community had complained about the taste of water from the existing hand-dug wells.

The subsurface dam Koraro-01 not only addressed the problem of lack of water but also improved the quality of the water. The chemical analysis results of already existing shallow hand-dug wells in the surrounding countryside and that of the hand-dug well in the micro-reservoir Koraro-01 are compared (Tab. 2). Accordingly all water samples collected from hand-dug wells in the nearby area are unfit as per the World Health Organization (WHO) with respect to Na^+, Cl^-, B^- and SO_4^{2-} concentrations which are well above recommended values.

But the water from the newly constructed hand-dug well (KOHWN), which taps water reserved by the subsurface dam, is suitable for human consumption according to standards set by WHO. This is mainly because this water, in geological terms, goes through a quick cycle, accumulating during the rainy season in the nearby sand deposit and being extracted again in the following dry season.

Sample ID	UTME	UTMN	pH	EC	TDS	Na^+	K^+	Ca^{2+}
	[m]	[m]	[-]	[µS/cm]	[mg/l]			
Kow2	528517	1533677	7.2	6630	5058	1280	3	110
Kow1	527646	1532585	7.7	6970	5536	810	3	370
Kow3	530409	1535405	8.1	3680	2839	660	3	40
Kow4	529469	1533245	7.4	4950	3659	820	6.2	200
KOHWN	**529656**	**1532933**	**7.3**	**1030**	**856**	**51.2**	**0.5**	**74.9**
Ethiopian standard			*6.5 - 8*		*1776*	*358*		

Sample ID	Mg^{2+}	F^-	Cl^-	B^-	HCO_3^-	SO_4^{2-}	SiO_2
	[mg/l]						
Kow2	110	1.3	797	1.2	1000	1673	34
Kow1	360	1.2	929	0.77	305	2671	25
Kow3	90	4.1	335	8.7	864	795	19
Kow4	50	0.53	755	4.5	1013	749	30
KOHWN	**72.06**	**0.98**	**80.9**	**0.239**	**460**	**54.8**	**30.67**
Ethiopian standard		*3*	*533*	*0.3*		*483*	

Tab.3 | Comparison of existing hand dug wells (Kow1-4) with the Koraro-01 water (KOHWN)

From July to October 2010 two medical students from the German Muenster University (Lisa Hartkemeyer, Stefanie Willems) took water samples for bacteriological analyses at the Koraro-01 reservoir and other water points and stills in the surrounding countryside. Although the water from Koraro-01 seems to have a better quality than most of the natural sources it was obvious that the bacteriological quality was affected by cattle crossing the reservoir area and cattle watering at the percolation pond upstream. A detailed report will be presented in their medical theses.

5 Outlook

In the coming project phases the project partners will monitor the situation relating to technical and hygienic issues. For disclosed or occurring problems solutions will be designed and realized. It is planned to elaborate training materials in Tigrinya, the local language, and to train local experts of administrations and NGOs on design and operation as well as water quality control.

The multiplication effect should be maximized by erecting more subsurface dams at other locations. In the scope of the TAW-Initiative it is also possible to propagate other adapted water storage techniques like cisterns with roof or rock catchments.

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