SUPPORT ASRP IN THE ASSESSMENT OF HYDROGEOLOGICAL EFFECTS. DEVELOP A GROUNDWATER MONITORING SYSTEM IN THE IMPLEMENTATION AREA IN AFAR REGION TO EVALUATE THE INFLUENCE OF WATER SPREADING WEIRS ON GROUNDWATER RECHARGE

PHASE II

Final Report

Johannes Münch

muench-johannes@outlook.de

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1. INTRODUCTION

The majority of Ethiopia's people (83%) live in rural areas, over 25 million of them in the low-lands. The Afar Region in north-eastern Ethiopia is one of these lowland areas. The region's variable and unreliable rainfall regularly leads to droughts and flooding, which frequently jeopardise agricultural production and the life of animal herds on which people's livelihoods depend. Most of the people use traditional agro-pastoral and pastoral farming systems that were previously sustainable, but now lead to soil degradation and production shortfalls due to rising intensities of use. Consequently, Afar is one of the country's poorest regions. More than half of its 1.4 million inhabitants (56%) live below the poverty line. So far, no new approaches have emerged for sustainable farming of the pasture lands and cropland, or for restoring the fertility of degraded soils.

The 'Afar Soil Rehabilitation Project (ASRP)' makes part of the global programme "Soil Protection and Rehabilitation for Food Security" under the umbrella of a special initiative launched by the German Government: One World – No Hunger (SEWOH). It is also an integral part of the Strengthening Drought Resilience (SDR) Programme and cooperates closely with the respective projects in the Afar and Somali region. The activities of ASRP focus on the eight districts (Woredas) of Chifra, Gulina, Yalo, Awra, Ewa, Mille, Kurri and Teru in the Afar Region. The lead executing agency of the project at national level is the Ministry of Agriculture and Natural Resources (MoANR) with its Natural Resources Management (NRM) directorate. At regional level, the respective agricultural office in the capital of Samara and its line authorities at district and village level are partners in the implementation.

The present study aimed on the assessment of the influence of GIZ SDR and ASRP implementations on groundwater recharge. Therefore, a groundwater monitoring system was developed and activated during a first phase of groundwater monitoring activities. Major partners for the research are the Water Resources and Irrigation Engineering Department of the University of Samara and the regional Bureau of Water (BoW). This report will give an overview of the geologic and hydrogeologic conditions in the implementation area and the collected data as well as the undertaken activities will be presented. Furthermore, an outlook and further recommendations regarding groundwater monitoring activities will be provided.

2. BACKGROUND AND OBJECTIVES OF THE ASSIGNMENT

The implementation area of the ASRP project is influenced by floods which are stemming from the adjacent highland regions. These floods may yield to dramatic damage in terms of erosion and land degradation. To avoid these damages and to increase the available water resources in the implementation areas, the SDR programme and the ASRP project introduced the technology of the Water Spreading Weirs (WSW). These are flood management measures that decrease water flow velocity and erosion while sedimentation, surface water availability and agricultural potential is increased. Due to the design of the WSW, the water is forced to spread over a certain area where the surface water is retained for a certain time. Especially the increased water covered area as well as the decreased water flow velocity indicate, that groundwater recharge may be increased by these implementations as well.

Since the implementation area of the ASRP project is lacking groundwater monitoring activities, the objective of this assignment was to develop a groundwater monitoring system to evaluate the influence of the Water Spreading Weir structures on groundwater recharge. Therefore, groundwater data loggers were installed into three groundwater wells to monitor and record groundwater data. The monitoring system was developed in close cooperation with the local University of Samara and also with the support of the regional Bureau of Water (BoW). Knowledge exchange activities especially with the Water Resources and Irrigation Engineering Department of Samara University were an important field of activity during the course of this assignment. Thus, local partners were supported by the development of capacities regarding groundwater monitoring activities.

Beyond the previously defined objectives of the assignment, the local University in Samara was advised in setting up a Hydrogeology course containing groundwater monitoring activities and further hydrogeologic investigation techniques. Thereby further research approaches that can be linked to the evaluation of the influence of WSW structures on groundwater recharge can be developed.

3. CONDUCTED INVESTIGATIONS

With regard to the abovementioned aim to establish a groundwater monitoring system and groundwater monitoring capacities in the implementation area in Afar region, the following investigations and tasks were performed.

3.1. LITERATURE RESEARCH AND DATA REQUEST

In order to develop an understanding of the geologic and hydrogeologic conditions in the implementation area, a literature research was conducted. Especially the research of Varet (2018) and of the British Geological Survey (2019) provided helpful information.

Furthermore, local institutions as the regional Bureau of Water (BoW), the University of Samara and further local partners of the ASRP Project were consulted to get detailed geological and hydrogeological information about the implementation area. During this discussion on data request it turned out, that the data basis of the consulted institutions is very rare. For instance, only very few drilling logs or Vertical Electrical Sounding profiles could be found and no information on historical groundwater level fluctuations was available. This highlights, that the approach to record long-term groundwater data via groundwater monitoring activities by means of data loggers was not performed before in the considered Woredas.

The regional BoW of Semera provided a so called "Inventory Report" which gives information of the available groundwater wells regarding their location, the current status, depth to groundwater, well depth and the installed pumps (see appendix 2). At this point, it has to be stated that this data basis is characterized by a certain inaccuracy. For instance, it was not unusual that the coordinates given for the well sites deviate up to hundred meters from the real coordinates in the field. Nevertheless, this information was very useful for the conductance of this assignment. Based on this report, the location of groundwater wells could be matched with the locations of WSW and it could be checked if the wells are stated to be operational or non-operational. This information was then verified via a field mission.

3.2. SITE SELECTION

One specification for the selection of monitoring wells in the framework of this assignment was to concentrate on already existing groundwater wells. To avoid possible damage of operating water supply schemes and to improve the success of community awareness programmes, only non – operating groundwater wells were considered in the site selection process. The consideration of these specifications and requirements led to a limited number of wells that meet the demands of potential monitoring wells.

To allow statements regarding the influence of WSW structures on groundwater level fluctuations from the already limited number of wells, the ones that are closest to existing WSW structures were identified and considered for the selection of monitoring wells. At a monitoring well, groundwater level fluctuations may only be linked to the effect of WSW in case the well is located within the hydrogeological area of influence of the WSW structures. Therefore, one has to be aware, that the hydrogeological area of influence is not congruent with the hydrological area of influence. This means, that the groundwater relevant effected area cannot be directly deduced from WSW water spread effects on surface water. This is due to the hydraulic and physical conditions of the aquifer as porosity, permeability and hydraulic conductivity as well as due to infiltration pathways and groundwater flow patterns.

Under the abovementioned restrictions, two groundwater wells were identified that are located in close distance to existing WSW structures (Shakayburo, Chifra and Duba, Ewa). Moreover, one additional site which is not located in the vicinity of existing WSW structures was included in the monitoring activities (Regdan, Ewa). This site was intended to deliver control data of an uninfluenced control point. To allow detailed comparability it was planned to include a further comparative well in Waagera, Chifra. Due to well rehabilitation activities in Waagera, this well had to be cancelled for the monitoring activities. For the selected monitoring well in Duba, the closest WSW at the time the logger was installed was located approximately 950 meters downstream (WSW EW1W-030). According to information from the GIZ SDR engineering team, two WSW structures further upstream were planned to be constructed (EW1W-040 and EW1W-050). The monitoring well would then have been situated between these WSW structures, around 380 meters upstream of EW1W-040 and around 300 meters downstream of EW1W-050. It was intended to correlate the data collected in this monitoring well before and after construction of the new WSW structures to see if an influence may be observed.

The inventory report of the regional Bureau of Water (2008) delivered very valuable baseline data for the site selection (see also appendix 2). Information regarding well locations and the status of the wells could be gained from the report. Based on this data a preselection of sites was compiled and verified during a field mission from 10th to 19th of December 2018. Further details on the site selection processes are discussed in Münch (2019).

3.3. INSTALLATION OF DATA LOGGERS – GROUNDWATER MONITORING

The monitoring wells that were selected for the groundwater monitoring activities were equipped with groundwater data loggers during a field mission from 29th of January to 12th of February 2019. The master data of the monitoring wells are given in table 1.

TABLE 1: MASTER DATA OF THE MONITORING WELLS

Well site	*Shakayburo*	*Duba*	Regdan
X	611483	609161	607971
Y	1283582	1297752	1300984
Altitude approx. m a.s.l.*	926	937	934
Depth to Groundwater m b.m.p.**	44,39	47,30	44,40
Groundwater level m a.s.l.***	882,06	890,40	889,75
Hanging depth of data logger m b.m.p.	54,39	57,30	50,00

**m a.s.l. = meters above sea level   ** m b.m.p. = meters below measurement point*
**** measured on the day of logger installation*

To access the groundwater wells, the welded covers were cut and removed and new lockable covers, where the data loggers could be properly fixed, were installed. The wells were then closed by means of padlocks and all involved parties (GIZ, Bureau of Water and Samara University) were equipped with one key for each well. Figure 1 shows the design of the developed well covers. To improve probability of success, community awareness programmes were integrated and field work as logger installation was conducted jointly with the BoW staff on Woreda level.

From 9th to 21st of May 2019 a first read- out field mission to collect the data recorded by the data loggers was conducted. The obtained data was presented in Münch (2019). A second read - out mission was conducted from 4th to 11th of December 2019. A third read - out mission was intended to be conducted in May 2020. Due to the COVID-19 pandemic this mission couldn’t be performed. Thus, online training on the setting and read - out of the data loggers was provided for the team of Samara University and the read - out mission was performed by Samara University in February 2021. The observations made and the data collected during these field missions will be presented in chapter 4.

FIGURE 1: WELL COVER AT THE SITE IN SHAKAYBURO

3.4. KNOWLEDGE EXCHANGE

With a view on capacity development in the field of hydrogeology and groundwater monitoring, the whole study was conducted in close agreement and cooperation with the Water Resources and Irrigation Engineering Department of Samara University. For the installation and for some read - out activities of the data loggers also the BoW staff on Woreda level joint the activities. Especially the Water Resources and Irrigation Engineering Department of Samara University showed high interest and took part at all of the field trips. Thus, all relevant processes as site selection, data logger configuration and installation as well as data read - out, data processing and data interpretation were conducted in close collaboration and training on the job was provided.

Further activities supporting the development of capacities were the performance of a workshop on hydrogeology and groundwater monitoring and online trainings on setting and read – out of the data loggers. Besides that, consultation regarding the development of a Hydrogeology Unit at the Water Resources and Irrigation Engineering Department of Samara University was provided. These activities are discussed in greater detail in chapter 4.4.

4. RESULTS

In the following, the results regarding the literature research, the groundwater monitoring activities and the knowledge exchange programmes will be presented.

4.1. GEOLOGY

The implementation area in Afar region is located eastward of the escarpment that marks the transition from the Ethiopian highlands to the Ethiopian Lowlands in the east of Ethiopia. This area is strongly influenced and characterized by the east African rift system. Thus, the geology of the project Woredas in Afar is dominated by rift related volcanic rocks. Mainly upper Miocenic to recent, predominantly basic, volcanic rocks are located in the rift floor of Afar. In general, the predominant petrographic units across the Afar lowlands are basaltic lava flows, silicic domes and lavas and pyroclastic deposits. According to the research of the British Geological Survey (2019) mainly igneous volcanic rocks and unconsolidated sedimentary formations may be expected in the implementation area (see appendix 3). Furthermore, this region is characterized by complex faults that are oriented mainly in NE-SW direction.

The data base regarding detailed geologic information in the monitored area is very limited and no drilling logs of the selected monitoring wells were available. Instead, one vertical electrical sounding (VES) profile for Chifra village could be found and one drilling log from a well in Sunata, Ewa was available (location see Appendix 3). The VES profile of Chifra village is in a distance of around 1.5 km to the monitored well in Shakayburo and the information given is expected to match quite good with the conditions at the monitoring site. The drilling log information gained from the profile in Sunata is around 21 to 24 km away from the well sites in Duba and Regdan and its transferability has to be treated with caution (location see appendix 3). Nevertheless, it was the closest location where detailed geologic information in terms of VES or drilling profiles was available and it gives an insight regarding the geologic conditions in the region. The profiles of the two sites can be seen in the table 2 and 3.

TABLE 2: GEOLOGIC CONDITIONS IN CHIFRA. GAINED FROM A VES SURVEY

Depth Below Ground Surface	Geologic Unit
0 – 1 m	Top Soil
1 – 2 m	Alluvial Deposits
2 – 11 m	Moderately weathered Basalt
11 – 72 m	Highly weathered Basalt
72 – 206 m	Moderately weathered Basalt
>206 m	Massive Basalt

TABLE 3: GEOLOGIC CONDITIONS IN SUNATA, EWA. GAINED FROM A DRILLING LOG

Depth Below Ground Surface	Geologic Unit
0 – 2 m	Top Soil
2 – 6 m	Fine Sand
6 – 12 m	Silty Clay
12 – 66 m	Gravel with coarse Sand
66 – 74 m	Fractured Basalt
74 – 78 m	Clay
78 – 100 m	Basalt, weathered

4.2. HYDROGEOLOGY

Weathered volcanic rock formations as well as unconsolidated sediments are the geologic formations that are expected to be the most important water – bearing formations in the implementation area. The complex geological conditions in the region may yield to intercalations of non - permeable aquicludes and to interlinking of different aquifer structures through fractures and joints. Furthermore, the groundwaters of the lowland region often show high electric conductivity and salinity values. This may be induced by high evapotranspiration rates (Ketema et al. 2016).

Regarding the publication of The British Geological Survey (2019) across the implementation area mainly unconsolidated sedimentary aquifers and igneous aquifers with moderate to high productivity may be expected (see appendix 4).

Interpreting the profile in table 2, the massive Basalt at a depth of around 206 m may be construed as the base of the aquifer around the investigation area in Chifra. Groundwater flow may here occur in the weathered – heavily weathered Basalt units. As can be seen from appendix 4, all three monitoring wells are located within the extent of igneous aquifers which are characterized by weathered Basalt units as described in table 2. Interpreting the profile in table 3, groundwater flow will mainly occur in the unconsolidated sediments (fine sands, gravel with coarse sand) and, depending on the degree of fracturing, in the fractured basalt unites. The highest groundwater flow velocities and the highest hydraulic conductivities can be expected in a depth between 12 – 66 meters in the gravel unit. With respect to infiltration capacities, only the silty clay section of the second profile will retard or restrict water infiltration processes. The description of the profile in table 3 is in accordance with the information provided by the British Geological Survey (2019) (see appendix 4).

Considering the limited information regarding the local geology, aquifer conditions seem to be unconfined or semi-confined. Thus, groundwater formation from surface water is possible and effects as induced by WSW are likely to have a positive effect on groundwater recharge.

The depth to groundwater in the implementation area varies from around 4 to 101 meters. Despite this huge range, groundwater levels may be expected for the most locations at around 40 meters. Appendix 2 gives an overview regarding the expected depths to groundwater across the region. The data was gained from the inventory report of the regional BoW.

4.3. Groundwater Monitoring

Since the implementation area of the ASRP project is lacking groundwater monitoring activities, a groundwater monitoring system was established during a first project phase. The groundwater monitoring activities were started at a small scale and three SEBA data loggers were installed in selected well sites. At two sites (Shakayburo and Regdan) a SEBA PT-Logger, which is able to record data on groundwater level fluctuations and on groundwater temperature fluctuations, was installed. At the site in Duba, a SEBA PTEC-Logger was installed, here additionally data on electric conductivity, salinity and total dissolved solids were recorded. The loggers were programmed to take a measurement every four hours. The monitoring system in the implementation area was established and developed in close collaboration with local partners as the University of Samara and the local BoW. It aims on the evaluation of the effect of GIZ-SDR implementations on groundwater formation.

To record the relevant data, the data loggers were placed in the selected wells below the groundwater level. The most important data to assess the influence of WSW structures on groundwater recharge are groundwater level fluctuations, since they show how groundwater develops in terms of quantity during the flood season. Data recorded by means of the PT and PTEC Loggers can be processed, analysed and interpreted. The data will show if changes in groundwater levels can be observed at the selected sites and if these changes can be correlated to the SDR and ASRP implementations. For more precise information regarding the technical details and the methodology of the measurements, the final report of the first project phase can be seen in Münch (2019).

After the installation of the data loggers in February 2019, one successful read-out mission was conducted in May 2019. During the second read-out mission, conducted in December 2019, vandalism at the well site in Shakayburo was recognized. The well was broken up and the data logger was damaged. This issue was discussed with Woreda administration officials and with the Woreda officials of BoW. The BoW agreed to write a report regarding the destruction and to assume the responsibility to reclose the well. The damage at the data logger occurred to the “drying cartridge” and was fixed by exchanging the broken “drying cartridge” with a new one. Thus, the data logger is reusable for future monitoring activities. According to the recorded data, the damage occurred at the 30th of September 2019 and the recorded data is not reliable starting from that day forth. A third read - out mission which was planned to be conducted in May 2020 had to be cancelled due to the COVID-19 pandemic. Instead, online trainings regarding the setting and read – out of the loggers were provided and the trained team of the Water Resources and Irrigation Engineering Department of Samara University performed a read - out mission in February 2021. During this mission vandalism at the two remaining wells in Duba and Regdan was recognized. At the monitoring site in Duba, the well was broken and the data logger was destroyed. Since the internal storage seems to be spared by the vandalism the data logger was send back to the supplier (SEBA Hydrometry) and it will be checked if data can be gained and if the logger can be repaired. At the monitoring site in Regdan, the well was broken and the data logger was removed and stolen. This was reported to the Woreda officials and they agreed to try to find the removed data logger. A letter, documenting the unfortunate destruction and removal of the monitoring equipment is attached to this report in appendix 7.

Due to the vandalism at the well sites, groundwater level and temperature data for the monitoring sites in Duba and Regdan could only be collected until the 6^{th} of December 2019. For Duba, besides groundwater level and temperature also electric conductivity and salinity was recorded. For the monitoring site in Shakayburo, groundwater level and temperature data were recorded until the day of destruction, 30^{th} of September 2019 (see figures 2 – 4 and Münch (2019)).

Figure 2 shows the fluctuations of groundwater levels in the three monitoring wells. Thereby the illustrated graphs concentrate on the fluctuations and the amount of increase or decrease of the groundwater level is presented. As one can see, the groundwater levels in Shakayburo and in Duba are both decreasing in a very similar manner from the day of installation until mid of June. In mid of June, the groundwater level at the site in Duba started to increase while the groundwater level in Shakayburo further decreases. This increase of groundwater level in Duba may stem from local floods which may have occurred at that time around Duba. Thus, the increase can be correlated with the infiltration of surface water which is an indication for unconfined aquifer conditions that allow groundwater recharge. Unfortunately, no precipitation data and no flood data for this site were available to allow a detailed correlation to the increase in groundwater level. Contrary to expectations, the groundwater levels recorded at the well in Regdan, which was planned as a control site, increased consequently to around 1.1 m above the initial hydraulic head. Analysis of water level data from the BoW in Samara showed that there is a hand dug well with shallow groundwater levels (approximately 6 m) around 3 km to the east of the monitored well in Regdan. This indicates, that the increase of groundwater levels in Regdan may stem from a local shallow aquifer which overlays the deep aquifer and which is infiltrating through a semi-permeable layer into the main, deeper aquifer.

The impressions of the groundwater level fluctuations are congruent with the recorded groundwater temperature data illustrated in figure 3. As one can see, the groundwater temperature at the well site in Duba is decreasing from mid of June onwards. Since surface water is expected to be cooler than the groundwater in the region, the decrease in temperature is likely to stem from surface water infiltrating into the aquifer. This development is supporting the assumption of unconfined aquifer conditions allowing groundwater recharge.

Furthermore, also the electric conductivity data at the Duba site (see figure 4) supports the observations that can be made from the groundwater level and groundwater temperature measurements. As one can see, at beginning of September a significant increase of electric conductivity can be observed. This increase may be linked with the infiltration of surface waters with higher salinity and thus with higher electric conductivity values. The higher salinity values in surface waters may stem from evaporation processes.

Due to a lack of comparability and due to the distances between wells and WSW structures, detailed statements regarding effects of WSW structures on groundwater formation cannot be made based on the recorded data. To allow statements regarding groundwater recharge potential of WSW structures, further data has to be recorded in wells that are located closer to WSW structures. This was expected to be performed at the monitoring well in Duba due to the construction of the WSW EW1W-040 and EW1W-050. The monitoring well would then have been located between these WSW structures, around 380 meters upstream of EW1W-040 and around 300 meters downstream of EW1W-050. This arrangement of WSW structures and monitoring well would then have been promising in terms of data collection and in terms of evaluating the influence of WSW structures on groundwater recharge. Due to the unfortunate destruction of the logger and the well in Duba no further data can be collected on this site. To allow a more detailed statement regarding groundwater recharge effects of WSW structures monitoring activities at wells that are located closer to the WSW structures has to be performed (see chapter 4.5).

Table 4 provides an overview regarding the highest and the lowest groundwater level as well as the mean groundwater level and the fluctuation range for the respective monitoring time.

TABLE 4: GROUNDWATER LEVEL STATISTICS FOR THE MONITORING WELLS

Well site	***Shakayburo****	***Duba*****	**Regdan*****
Highest Water Level m a.s.l.	882.09	890.64	890.85
Lowest Water Level m a.s.l.	881.60	890.03	889.75
Mean Water Level m a.s.l.	881.85	890.27	890.35
Fluctuation range m	0.49	0.61	1.10

* Monitoring period: 06.02.2019 – 30.09.2019
** Monitoring period: 07.02.2019 – 06.12.2019
*** Monitoring period: 07.02.2019 – 06.12.2019

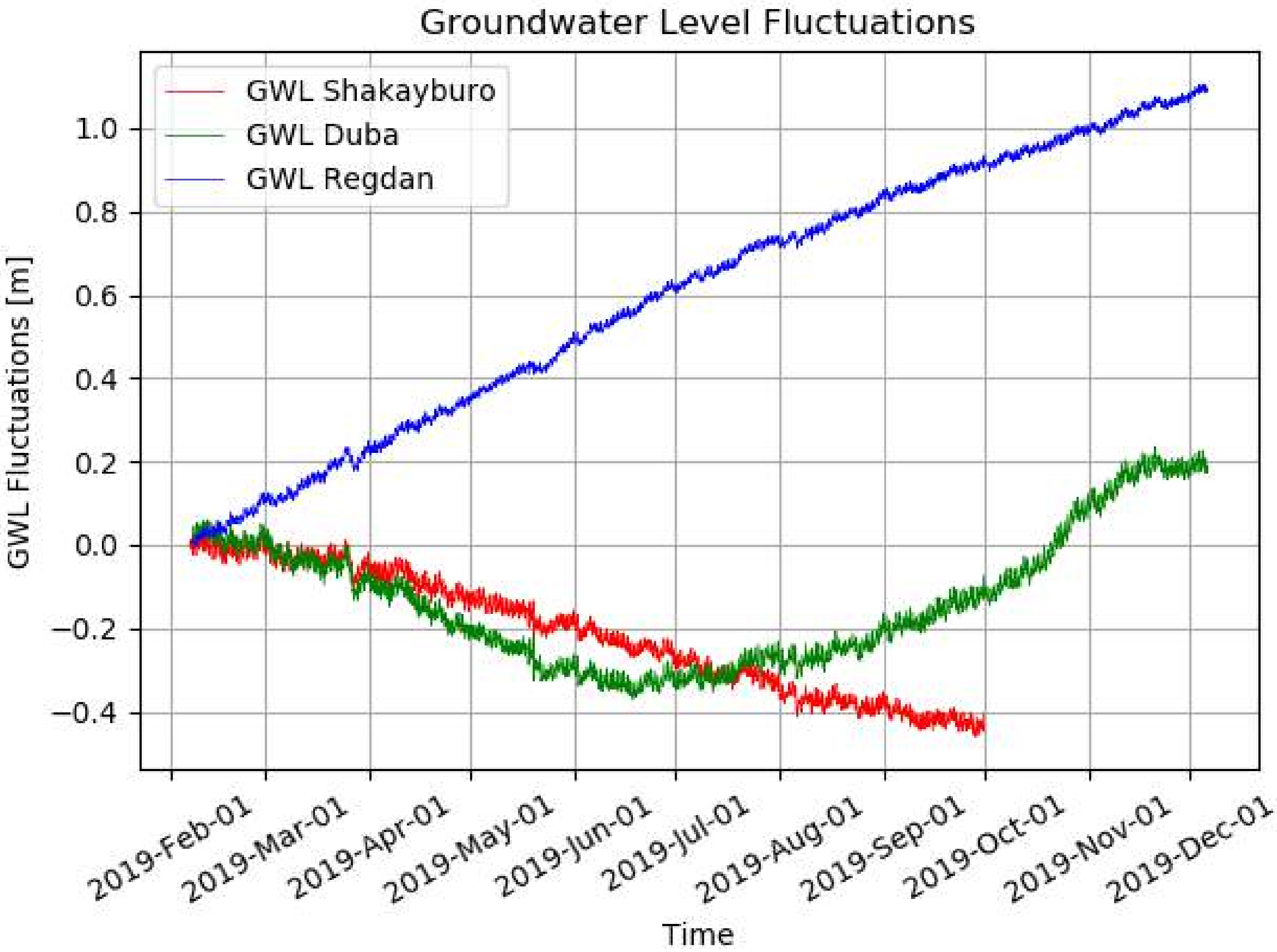


FIGURE 2: GROUNDWATER LEVEL FLUCTUATIONS IN THE MONITORING WELLS

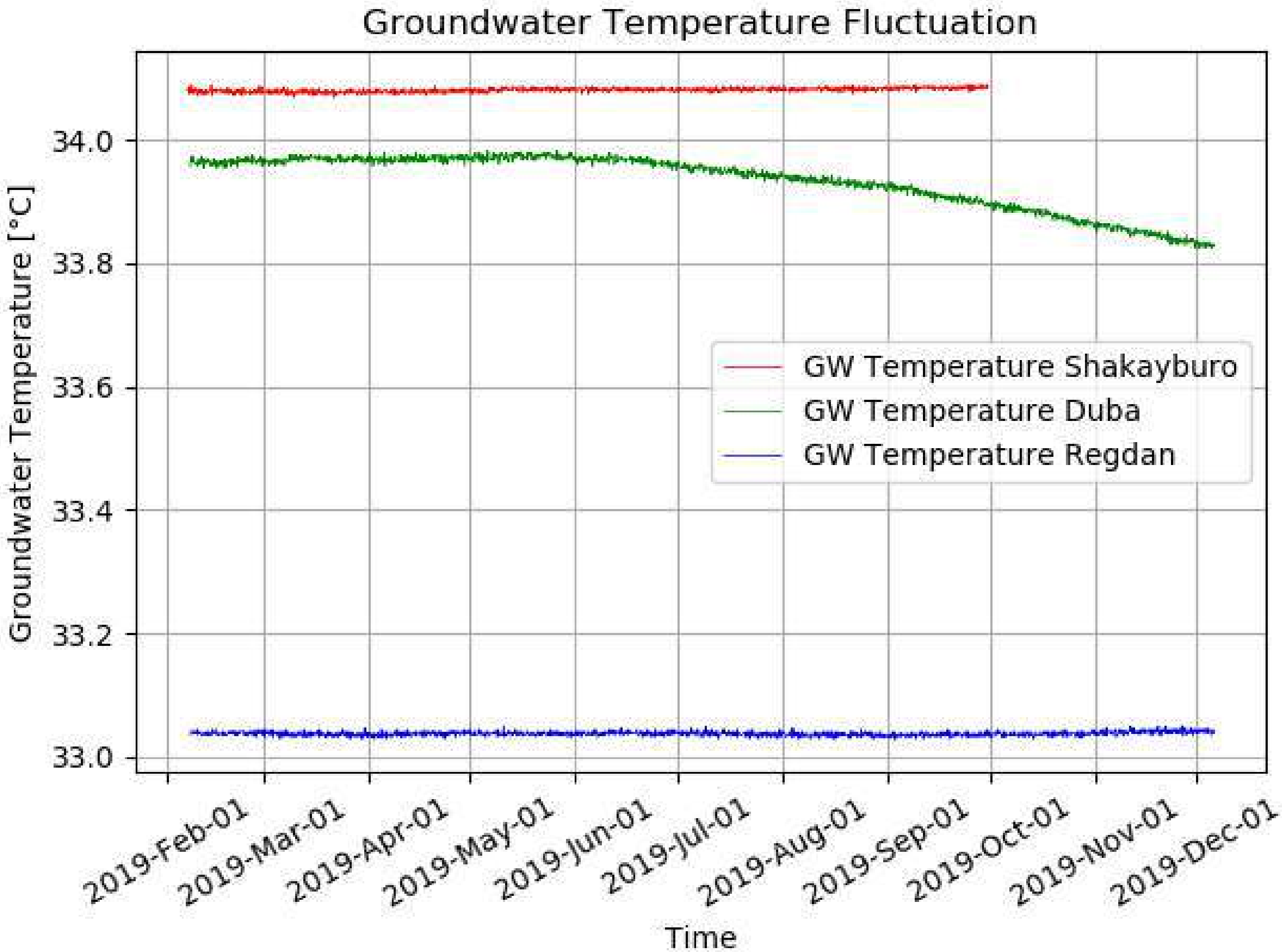


FIGURE 3: GROUNDWATER TEMPERATURE FLUCTUATIONS IN THE MONITORING WELLS

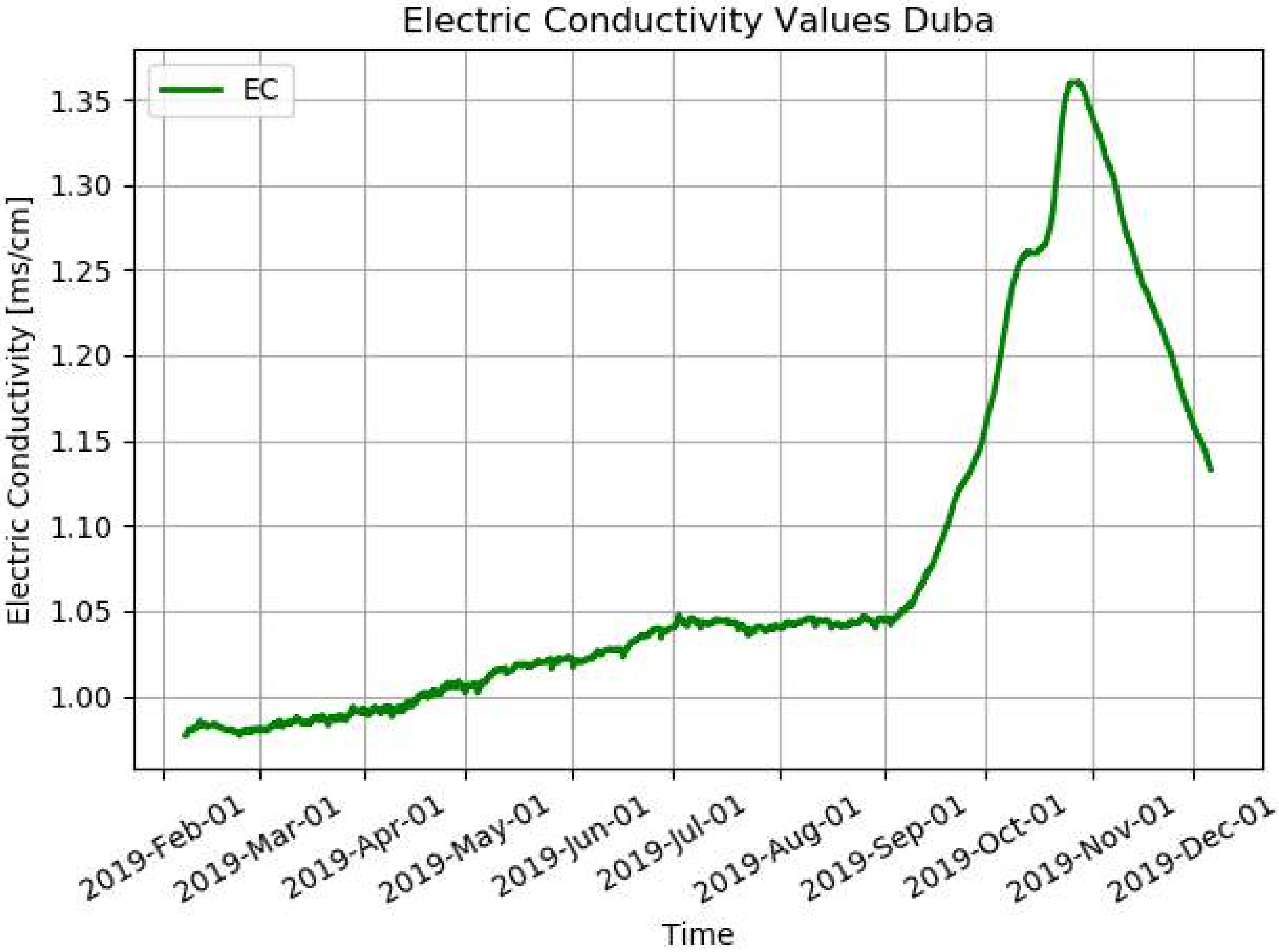


FIGURE 4: ELECTRIC CONDUCTIVITY FLUCTUATION IN DUBA

4.4. Cooperation with partners and knowledge exchange

To agree on common research and collaboration interests with the involved parties (BoW and University of Samara), a Memorandum of Understanding (MoU) was developed and signed with each of the two parties. The current MoU with Samara University is valid until 31st of March 2022. The MoU with the BoW was valid until February 2020. Since Samara University was trained on groundwater monitoring and since they will overtake the responsibility on groundwater monitoring activities with regard to GIZ implementations in the region, they confirmed that Samara University will develop a direct MoU treating the collaboration between Samara University and the BoW.

With a view on capacity development in the field of hydrogeology and groundwater monitoring, the whole study was conducted in close agreement and cooperation with the Water Resources and Irrigation Engineering Department of Samara University. BoW staff was also invited to all the field missions and also to the conducted workshop on hydrogeology and groundwater monitoring but the response and the participation was restrained and the BoW accompanied only to some of the site visits. Especially the Water Resources and Irrigation Engineering Department of Samara University showed high interest and motivation. Thus, all relevant processes as site selection, data logger configuration and installation as well as data read - out, data processing and data interpretation were conducted in close collaboration and training on the job was provided.

Another activity supporting the development of capacities was the performance of a workshop on hydrogeology and groundwater monitoring during the first phase of the groundwater monitoring consultancy. The workshop covered the basics in hydrogeology, including an introduction of different hydrogeologic investigation techniques. Furthermore, a detailed insight into the conducted research was given, introducing the WSW structures and their expected influence on groundwater recharge. Groundwater monitoring was presented in detail and a practical training with data loggers was involved, including logger configuration and data read - out. The workshop was addressed to the University of Samara. Staff members of the Water Resources and Irrigation Engineering Department, the Geology Department as well as staff from the Afar Supervision and Design Enterprise were participating. The curriculum of the workshop can be seen in appendix 5.

Furthermore, in January and February 2021 several online trainings on setting and read - out the data loggers were provided for the Water Resources and Irrigation Engineering Department of Samara University. This workshop trained the responsible staff members to conduct the read-out mission in February 2021. After this field mission further online trainings on data processing were provided.

Furthermore, the department heads of the Water Resources and Irrigation Engineering Department of Samara University were supported with the establishment of a hydrogeology course at the university. Therefore, a drafted curriculum from Samara University was discussed and consultation regarding the specific sections was given. According to the Department Heads, due to governmental University regulations, the curriculum is only editable up to 10%. Within these 10% of allowed changes, the responsible colleagues from Samara University agreed to include a section called "Hydrogeologic Investigation Techniques" as it was part of the workshop. Within this section, the methodology of

"Groundwater Monitoring" shall be integrated and the practical application of groundwater data loggers shall be transferred to the students. Thus, hydrogeologic investigation techniques in general and groundwater monitoring in detail could be institutionalized and integrated into the academic education in Afar region. In this context, also further groundwater related research in the GIZ SDR implementation area with Samara University as an implementing partner can be considered.

Due to the extensive training on the job opportunities on all relevant processes of the research (site selection, data logger configuration, data logger installation, data read - out, data processing and data interpretation), online trainings and due to the performed workshop, the relevant capacities concerning groundwater monitoring were developed at Samara University. In January 2021 all relevant groundwater monitoring equipment as data loggers, water level meter, Toughbook, read - out devices, etc. was handed over from the GIZ ASRP project to the Water Resources and Irrigation Engineering Department of Samara University. Thus, the Water Resources and Irrigation Engineering Department of Samara University is capacitated and equipped to perform independent groundwater monitoring activities.

4.5. Development of a long-term monitoring site

Due to the beforementioned limitations (concentrating on existing and non – operating wells) and due to the vandalism, that occurred during the course of this assignment, it turned out that a detailed statement regarding the effects of WSW structures on groundwater recharge can not be achieved. Although the study may give an evidence on the influence of WSW structures on groundwater recharge, it cannot cover detailed monitoring of WSW effects on groundwater. To provide this, a long - term monitoring site with a more detailed monitoring grid on one WSW site (as schematically illustrated in figure 5) is required. Therefore, further research was performed to recommend a location for the establishment of a long-term monitoring site.

Due to the review of further secondary data, it was determined that the location around the WSW Cascade GU1W shows favourable conditions for a long-term monitoring site. According to data gained from the BoW, shallow groundwater levels of around 17 to 20 meters are expected in Gulina, close to Kelewan and close to the GU1W cascade. According to appendix 4, this site is located within the extent of an unconsolidated sedimentary aquifer. Thus, one of the Weirs belonging to this cascade was recommended for the site selection regarding the establishment of the long – term monitoring site. Meanwhile the construction of this monitoring site is in progress under the guidance of MetaMeta in cooperation with Mekelle University and also with the Water Resources and Irrigation Engineering Department of Samara University.

Due to the long – term monitoring site, a more detailed arrangement of monitoring wells can be realized and a hydrogeological area of influence of the WSW structure can be assessed. To optimize the outcomes of that study, the experience, information and data gained within the framework of this consultancy was shared with the responsible colleagues.

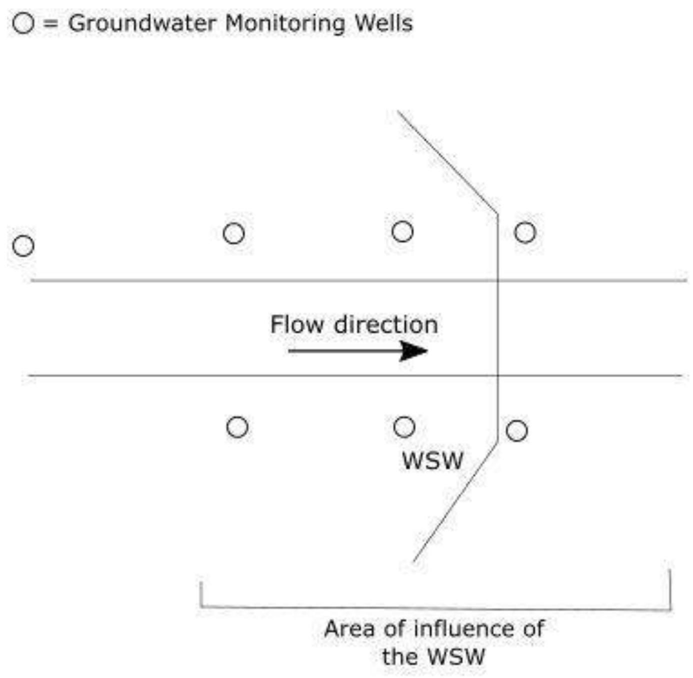


FIGURE 5: CONCEPTUAL MODEL OF A MODEL MONITORING SITE

5. LIMITATIONS, IMPROVEMENTS AND RECOMMENDATIONS

In the course of the groundwater monitoring assignment different limitations on technical and institutional level emerged.

As mentioned above, as a side selection criterion the assignment focused on already existing and non – operational groundwater wells. According to the well data obtained from the regional BoW, and according to several field investigations only few monitoring wells in the direct vicinity to a WSW could be identified. Furthermore, also the identification of appropriate control sites showing similar geological and hydrogeological conditions was challenging. Besides that, the monitoring activities at the promising site in Duba had to be cancelled due to vandalism and destruction. To allow a resilient statement regarding the effect of WSW on groundwater recharge the requirements couldn't be meet via the approach of focusing on existing well sites. Thus, drilling of monitoring wells or the establishment of a long-term monitoring site es proposed in chapter 4.5 and as currently conducted by MetaMeta, Semara University and further partners in the framework of the GIZ ASRP Project, will provide more detailed data to evaluate the influence of WSW structures on groundwater recharge.

Beyond this, the fact that vandalism occurred at all three monitoring sites highlights, that the approach regarding well protection as applied during the course of this assignment has to be developed and improved. Although a lot of effort was invested on community awareness and although the wells were closed and locked by well caps, all monitoring wells were broken and the loggers were damaged or stolen. Therefore, more extensive community awareness programmes focusing on the importance of monitoring groundwater resources and on the sensitivity of the measurement equipment should be included. Furthermore, also the physical protection of the wells may be improved by constructing fence or concrete structures around the monitoring sites.

In the framework of this consultancy, a lot of valuable experiences were made and a lot of limitations especially regarding data acquisition were faced. As mentioned above it was quite challenging to raise information regarding geology, hydrogeology and further environmental data. Regarding this difficulty, it is highly recommended to centralize and bundle data at a central authority which may be consulted in terms of data acquisition. Furthermore, it was found that different information is provided on the same fact. For example, regarding elevation of the well sites, different elevation data for the same site can be found. For instance, to allow a detailed evaluation of groundwater flow patterns, reliable information regarding elevation is mandatory. An elevation measurement campaign may help to solve this problem.

6. OUTLOOK

Although groundwater data in the ASRP implementation area could be collected for a period of around ten months, no detailed estimation of the effect of WSW structures on groundwater recharge could be provided. This is due to the beforementioned limitations concerning the selection of the monitoring sites and due to the vandalism, which occurred and which prevented data collection for a longer time period. Besides the groundwater monitoring data, a lot of valuable data regarding the hydrogeologic conditions in the implementation area could be raised in the course of the current study. Furthermore, groundwater monitoring as an innovative approach in Afar region could be entrenched and institutionalized in the implementation area and due to the knowledge exchange programmes with the Water Resources and Irrigation Engineering Department of Samara University a strong partner was qualified to conduct future groundwater monitoring activities in Afar region.

To evaluate the influence of WSW structures on groundwater recharge, the long – term monitoring site, as described in chapter 4.5 and as currently in development under the supervision of MetaMeta may provide relevant and detailed data. Besides the groundwater monitoring, the monitoring site may be equipped with measures that allow the collection of further important data as for instance precipitation, run-off and sediment load. This data may then be correlated with the measured groundwater level fluctuations and a more detailed estimation of groundwater recharge effects induced by WSW structures may be gained. Due to the intense capacity development activities in groundwater monitoring tasks, the Water Resources and Irrigation Engineering Department of Samara University is qualified to overtake the responsibility for monitoring activities required in the framework of the monitoring site.

7. APPENDIX

Appendix 1:	Overview map, Scale 1:2.500.000
Appendix 2.1:	Overview map of well sites in the implementation area, Scale 1:500.000
Appendix 2.2:	Overview of well sites in the implementation area, table
Appendix 3:	Geology map of the implementation area, Scale 1:500.000
Appendix 4:	Hydrogeology map of the implementation area, Scale 1:500.000
Appendix 5:	Curriculum of the Hydrogeology Workshop
Appendix 6:	Curriculum advice for the Hydrogeology Course at Samara University
Appendix 7:	Letter: Removal and destruction of monitoring equipment

8. References

- Abebe Ketema, Gezahegn Lemecha, Anna Schucknecht, Francois Kayitakire (2016): Hydrogeological study in drought affected areas of Afar, Somali, Oromia and SNNP regions in Ethiopia, Part 1: Remote sensing and overlay analysis, UNICEF Ethiopia.

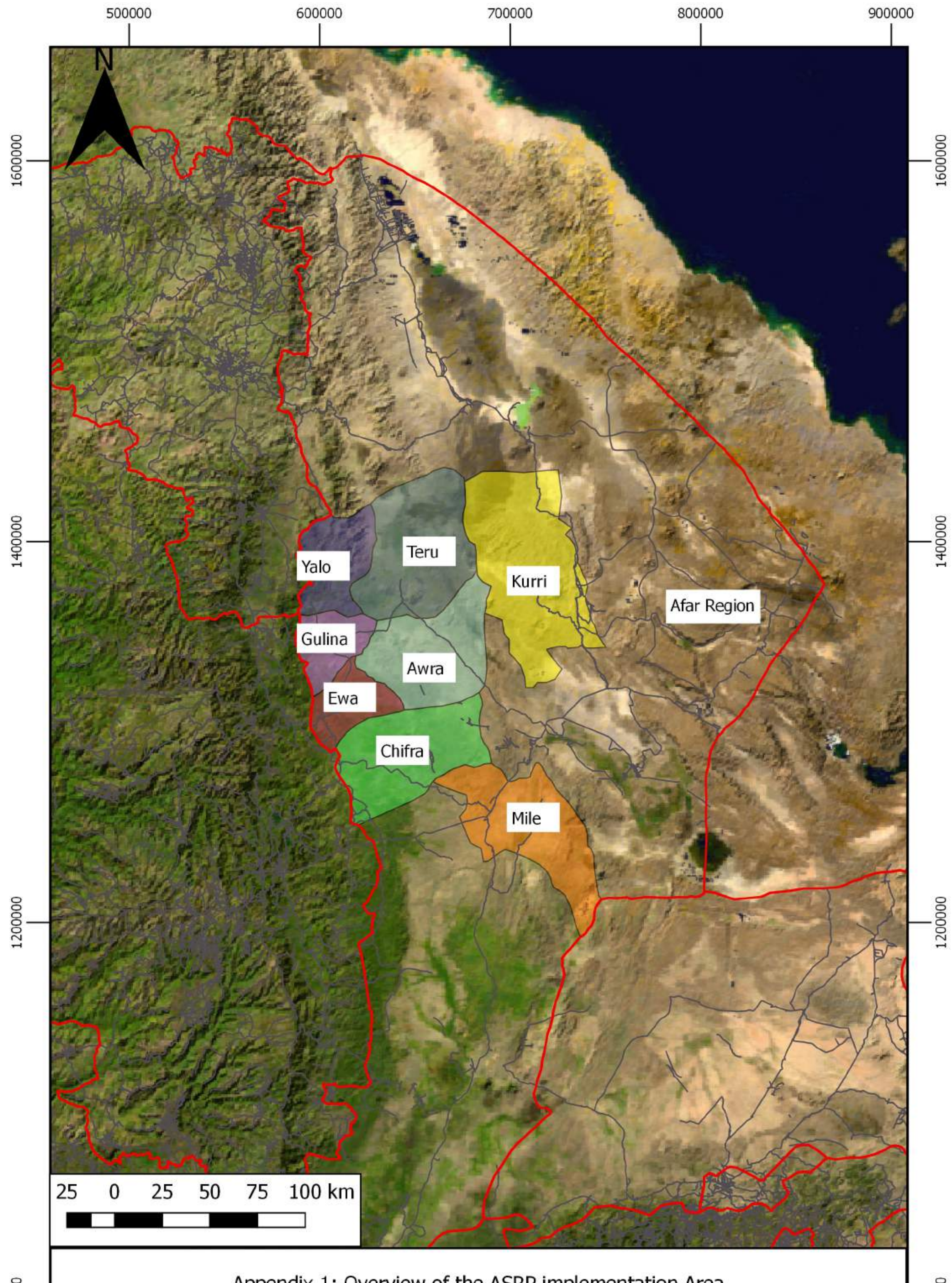
- British Geological Survey (2019): User Guide: Africa Groundwater Atlas Country Hydrogeology Maps, Version 1.1. Groundwater Programme. Keyworth, Nottingham British Geological Survey.

- Ghebremedhen Yohannes, Salih Solomon, HYDROLAND/YGRY/Consulting Engineers PLC (2017): Two Towns Water and Sanitation Project, Chifra Town WSSP. Study and Design of Deep Well Drilling Well Point Sites Selection. Hydrogeological and Geophysical Verification Report. Regional Bureau of Water.

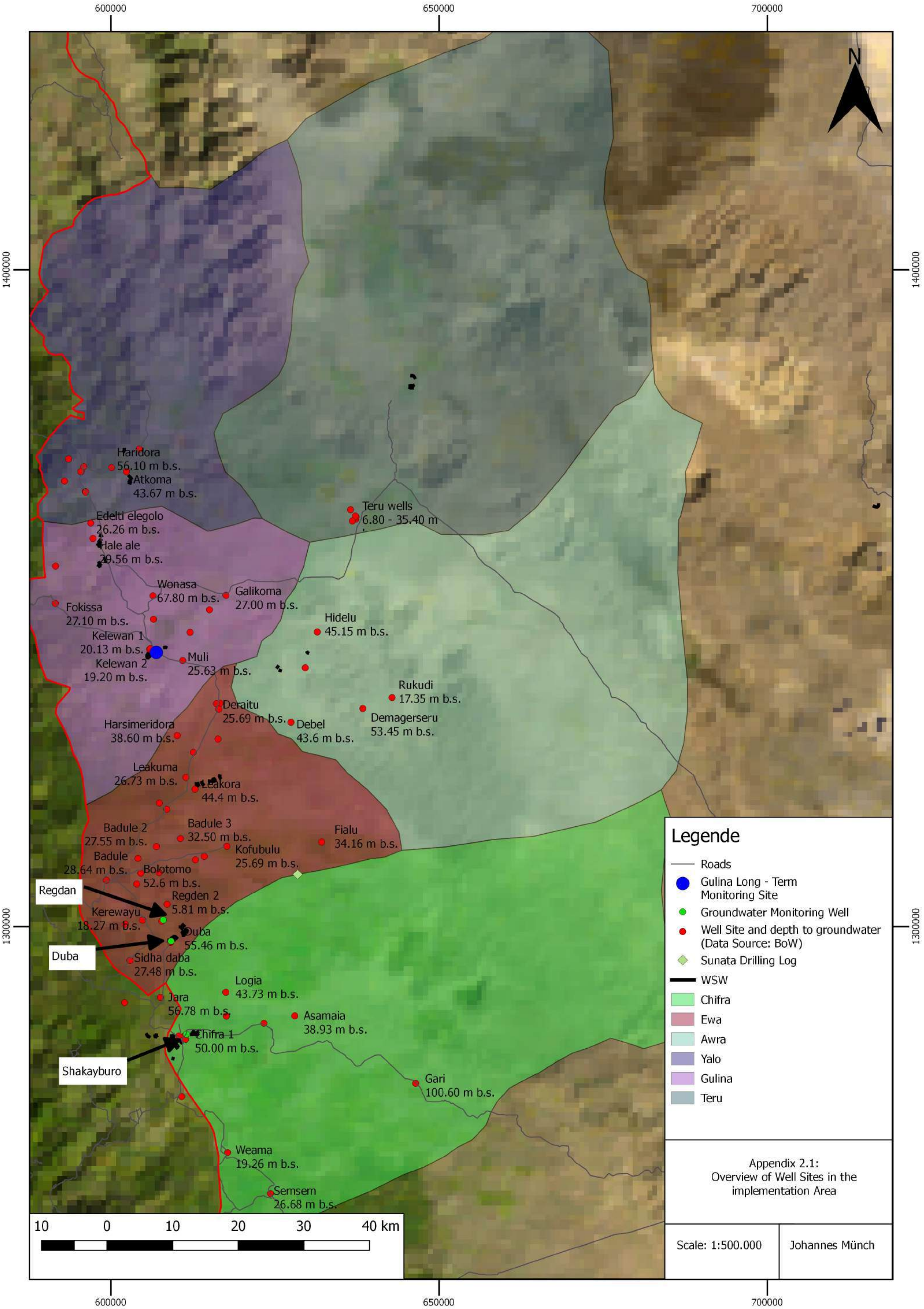
- Jacques Varet (2018): Geology of Afar (East Africa)

- Johannes Münch (2019): Development of a Groundwater Monitoring System in the GIZ SDR Implementation Area in Afar Region to Evaluate the Influence of Water Spreading Weirs on Groundwater Recharge – Final Report -.

- Regional Bureau of Water, Afar: Inventory Report of Water Supply Schemes in Zone 2, 5 and Zone 1. Excluding Mille Woreda



Appendix 1: Overview of the ASRP implementation Area
Scale 1:2.500.000



Appendix 2.1: Overview of Well Sites in the implementation Area

Appendix 2.2: Groundwater wells in the implementation area

Groundwater wells in Chifra:

No.	***Site Name***	***Kebele***	***X***	***Y***	**Elevation**	**SWL**
1	Weama	Weama & kusrele	617877	1265779	1011	19.26
2	Mesgid	Mesgid	617671	1286535	867	
3	Awagera	Awagera	623399	1285457	826	
4	Chifra 1	Chifra	611306	1283520	926	50
5	Chifra 2	Chifra	611459	1283004	923	
6	Under kelo	Underkelo & kelaitu	610862	1274312	976	
7	Logia	Asergid & meroli	617605	1290183	872	43.73
8	Semsem	Weama & kusrele	624394	1259535	969	26.68
9	Asamai	Meroli & asagisu	628102	1286573	831	38.93
10	Derokoma	Askoma & akibura	602165	1288599	1052	
11	Sidha daba	Duba	602995	1295034	1032	27.48
12	Gari	Meglala & lekebli	646513	1276316	784	100.6
13	Chifra 3	Chifra	610451	1283509	926	
14	Jara	Jara & contola	607624	1289396	974	56.78

Groundwater Wells in Ewa:

No.	*Site Name*	*Kebele*	*X*	*Y*	Elevation	SWL
1	Allele subula	Allele subula	599388	1307239	1068	
2	1st badule	Badule	604222	1310570	1013	28.64
3	Fialu	fialu	632187	1313051	806	34.16
4	Kofubulu	Kofubulu	617756	1312415	889	25.69
5	Bilu	Bilu	602277	1300545	1029	
6	Regden 1	Regden	607812	1301003	934	
7	Regden 2	Regden	608643	1303577	928	5.81
8	2nd badule 1	Badule	607015	1312377	980	27.55
9	2nd badule 2 (mesgid)	Badule	610679	1313591	938	32.5
10	Kerewayu	Regden	604920	1301166	983	18.27
11	Bolotomo	Bolotomo	604031	1306661	1042	52.6
12	Fularba	Bolotomo	604630	1308330	1013	36.8
13	Aliadaitu	Kofubulu	614307	1310867	905	
14	Buti (kofo)	Buti	612952	1310357	919	31.6
15	Habulemeri	Buti	607426	1308399	973	
16	Duba	Duba	609155	1297770	937	55.46

Groundwater wells in Awra:

No.	***Site Name***	***Kebele***	***X***	***Y***	**Elevation**	**SWL**
1	Debel	Debel	627519	1331305	824	43.6
2	Hida	Hida	607473	1319003	950	
3	Leakora	Leakora	612883	1321114	901	44.4
4	Deraitu 1	Deraitu	616709	1334181	841	25.69
5	Deraitu 2	Deraitu	616156	1334115	841	
6	Deraitu 3	Deraitu	616522	1333267	848	
7	Hayukeli	Hayukeli	616390	1328727	861	46.32
8	Leakuma	Leakuma	612649	1326699	882	26.73
9	Aliberimesgid	Segento & aliberimesgid	611530	1322904	902	21
10	Hida (agbiledale)	Hida	608593	1318047	936	33.18
11	Harsimeridora	Deraitu	610166	1329282	883	38.6
12	Hidelu 1	Hidelu	629696	1339582	807	
13	Hidelu 2	Hidelu	631539	1345046	761	45.15
14	Rukudi	Finto & Asale	642922	1335055	765	17.35
15	Dema’ gerseru	Finto & Asale	638458	1333380	800	53.45

Groundwater wells in Gulina:

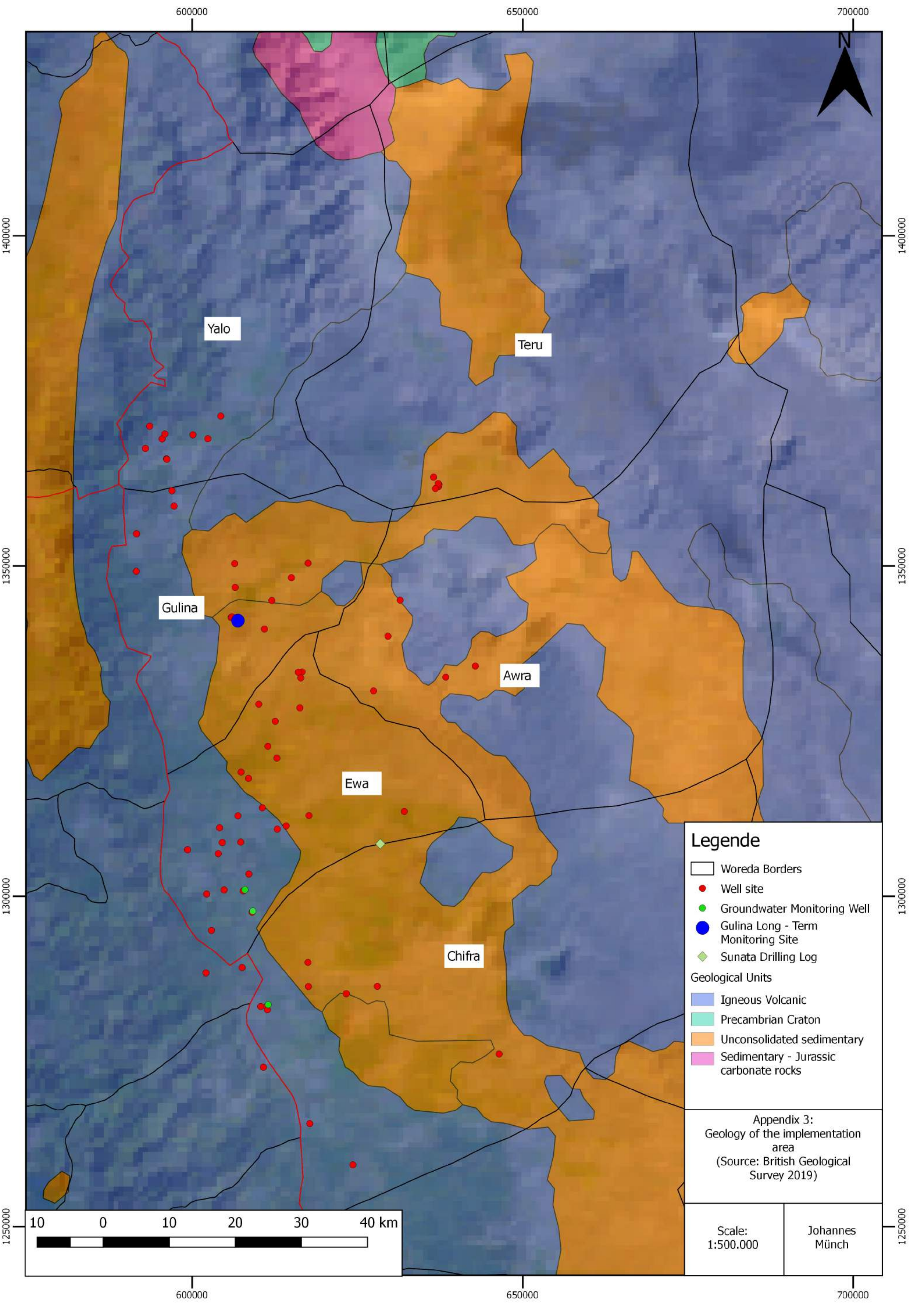
No.	***Site Name***	***Kebele***	***X***	***Y***	**Elevation**	**SWL**
1	Fokissa	Fokissa	591617	1349410	1119	27.1
2	Sebatena botene	Sebatena botene	591657	1355080	1133	
3	Galikoma	Galikoma	617625	1350639	774	27
4	Wonasa	Wonasa & harigerbo	606501	1350570	840	67.8
5	Muli	Muli & asale	611015	1340678	840	25.63
6	Kelewan 1	Kelewan	605982	1342394	868	20.13
7	Kelewan 2	Kelewan	606103	1342520	868	19.20
8	Haligerbo	Wonasa & harigerbo	606575	1346981	839	32.95
9	Gorele	Galikoma	615097	1348436	786	
10	Gezi	Galikoma	612139	1344990	819	29.4

Groundwater wells in Yalo:

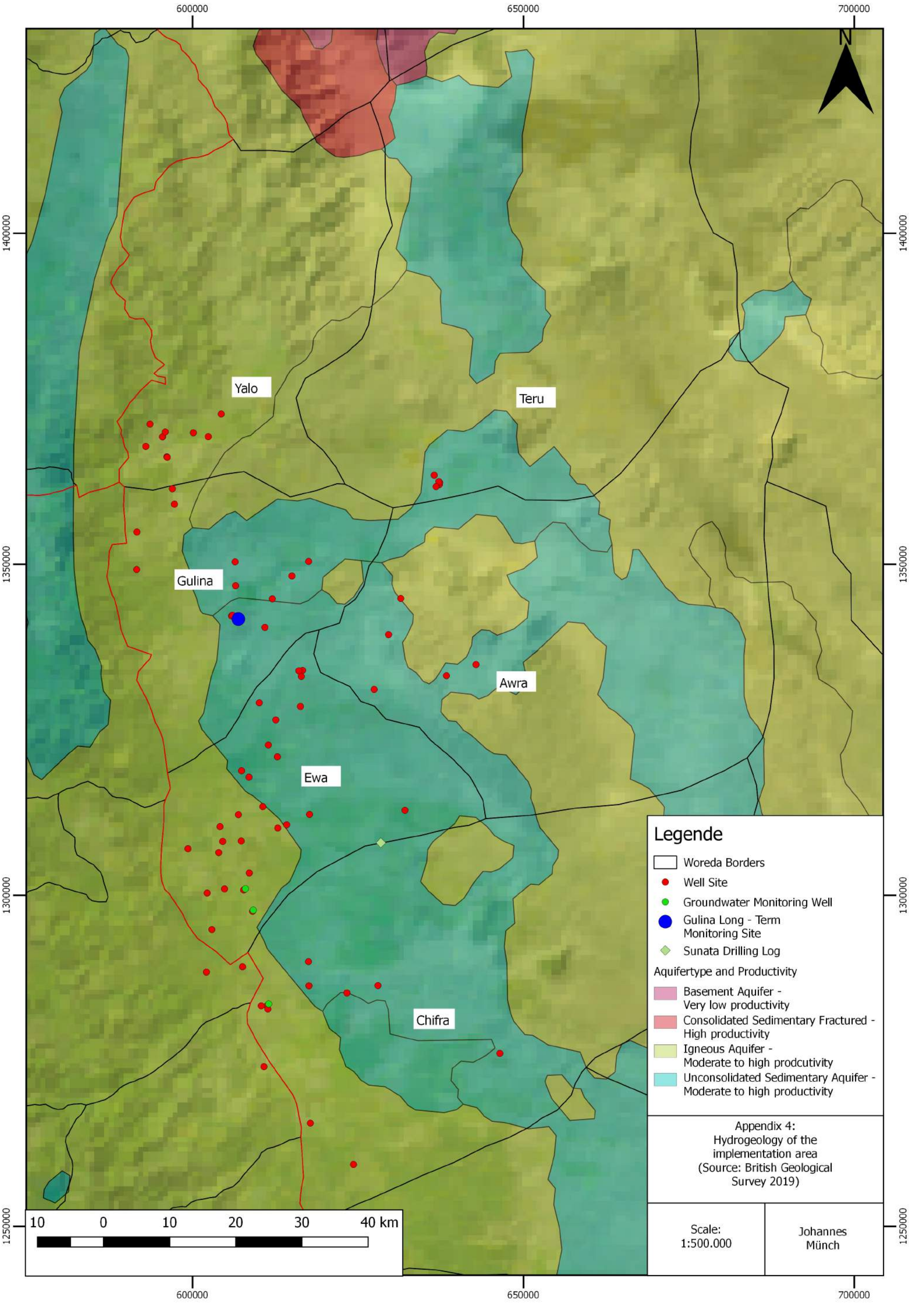
No.	*Site Name*	*Kebele*	*X*	*Y*	**Elevation**	**SWL**
1	Gubidora 1	Mesgid	596190	1366429	863	
2	Haridora	haridora	600189	1370079	814	56.1
3	Genjaba	Rekrek	593640	1371382	968	
4	Hale ela	Rekubdora	597350	1359281	947	29.56
5	Edelti elegolo	Mesgid	597014	1361621	935	26.26
6	Menafesha 1	Rekrek	595552	1369465	897	4
7	Menafesha 2	Rekrek	595527	1369463	898	
8	Mesgid (rekrek)	Rekrek	593003	1368020	915	15.78
9	Gubidora 2	Mesgid	596203	1366422	862	
10	Gubidora 3	Mesgid	596240	1366371	862	
11	Atkoma	Kolina gabule	602448	1369481	818	43.76
12	Naftu	Gide ela	604401	1372903	797	
13	Dibina	Dibina	595950	1370203	888	

Groundwater wells in Teru:

No.	***Site Name***	***Kebele***	***X***	***Y***	**Elevation**	**SWL**
1	Digdiga 1	Digdiga	637386	1362241	672	35.4
2	Digdiga2	Digdiga	637429	1362552	667	14
3	Digdiga3	Digdiga	637316	1362697	666	28.25
4	Digdiga4	Digdiga	636876	1361942	666	6.8
5	Digdiga5	Digdiga	636605	1363660	662	22.04



Appendix 3: Geology of the implementation area (Source: British Geological Survey 2019)


600000
650000
700000
1400000
1350000
1300000
1250000
N
Yalo
Teru
Gulina
Awra
Ewa
Chifra
Legende
Woreda Borders
Well Site
Groundwater Monitoring Well
Gulina Long - Term Monitoring Site
Sunata Drilling Log
Aquifertype and Productivity
Basement Aquifer - Very low productivity
Consolidated Sedimentary Fractured - High productivity
Igneous Aquifer - Moderate to high prodcutivity
Unconsolidated Sedimentary Aquifer - Moderate to high productivity
Appendix 4: Hydrogeology of the implementation area (Source: British Geological Survey 2019)
Scale: 1:500.000
Johannes Münch
10 0 10 20 30 40 km

APPENDIX 5: CURRICULUM OF THE HYDROGEOLOGY WORKSHOP

GROUNDWATER MONITORING TRAINING OUTLINE

1. CHAPTER ONE: BASICS IN HYDROGEOLOGY
    - 1.1. Introduction
    - 1.2. Global water resources
    - 1.3. Reasons to use groundwater
    - 1.4. Classification of aquifers
    - 1.5. Important hydraulic and physical parameters of an aquifer
    - 1.6. Mathematical expression of groundwater flow and solute transport
    - 1.7. Saturated and unsaturated zone conditions
    - 1.8. Setting assumptions to solve hydrogeological problems
    - 1.9. General rules for the design of groundwater extraction
2. CHAPTER TWO: HYDROGEOLOGICAL INVESTIGATION TECHNIQUES
    - 2.1. The need for hydrogeological investigation techniques
    - 2.2. Approaches of hydrogeological site investigations
    - 2.3. Introduction into different hydrogeological investigation techniques
3. CHAPTER THREE: GROUNDWATER MONITORING
    - 3.1. Objectives
    - 3.2. Measurement of groundwater level fluctuations
    - 3.3. Familiarization with the data loggers (logger configuration, data processing, data interpretation)
4. CHAPTER FOUR: CASE STUDAY: GROUNDWATER RECHARGE ANALYSIS
    - 4.1. Introduction of Water Spreading Weir structures
    - 4.2. Need for groundwater monitoring
    - 4.3. Site selection for groundwater monitoring sites
    - 4.4. Expected results and potential problems
5. CHAPTER FIVE: REFERENCES

Appendix 6: Curriculum advice for the Hydrogeology Unit at Samara University

SCOPE AND DESCRIPTION OF:

1. **Groundwater Hydrology ~~Engineering~~**
   - Ground water resources: Scope and occupancy; ground water in hydrologic cycle; different types of aquifers and their characteristics.
   - Ground water movement: Darcy's law, mathematical treatment of frequently occurring flow problems, one-, two- and three- dimensional flow in phreatic, confined and semi-confined aquifers.
   - Mathematical treatment of transport in aquifers
   - ~~Laboratory and field determination of hydraulic conductivity, determination of ground water flow parameters.~~
   - Hydraulics of wells: steady and unsteady states of flow in, phreatic, confined and unconfined aquifers. Solution methods; graphical methods, use of image wells;
   - Theory of Groundwater modeling: Mathematical, Physical and numerical models, Modeling of flow in porous media,
   - Theory of Modeling of pollutant transfer in porous media. Application of mathematical models to the study of ground water flow problems unsteady flow in leaky aquifers; partially penetrating wells; multiple well systems.
   - Pumping test, design of piezometres, analysis and interpretation of data, Management of groundwater systems.

2. **Water Wells Engineering**
   - Groundwater exploration: methods of groundwater exploration, surface and sub-surface exploration to locate potential sites for water well development.
   - Types of water wells: open wells and tube wells, design of open wells, construction of open wells, collector wells, infiltration galleries.
   - Well design: Design principles of collector wells: Design of tube wells. Construction of tube wells. When to apply screening and casing section in well tubes
   - Drilling technologies: Water well completion and water well development.

Kommentiert [h1]: I would recommend "Groundwater Hydrology" or "Hydrogeology" instead of "Groundwater Engineering"

Kommentiert [h2]: Adding this section, also transport mechanisms may be considered. For example, the movement and spreading of contaminants in aquifers may be included.

Kommentiert [h3]: Better place this point under the new section "3. Hydrogeologic Investigation Techniques"

Kommentiert [h4]: This one is a separate point to my understanding. I would separate if from the modelling of pollutant transfer and give it a specific point

Kommentiert [h5]: This should definitely be included. I found that a lot of wells in the region have incomprehensible screening-casing intervals which leads to less productive wells.

- Types of well screens: Gravel pack and pack design. Sanitary protection of wells.
- Types of springs, spring and spring development:
- Water lifting mechanisms: Pumps and pump installations, Water lifting for house hold use and garden irrigation.
- Groundwater pollution and remediation: Groundwater management. Groundwater balance: Recharge and Artificial Recharge.

3.) Hydrogeological Investigation Techniques

- Introduction into different methods for Laboratory and field determination of hydraulic conductivity, determination of ground water flow parameters.
- Sieve analysis
- Pumping tests in confined, leaky, and unconfined aquifers. Including the analysis, according to the relevant method.
- Single well tests: stepdrawdown test, flowmeter test, slug test, direct push-based methods
- Assigning transport parameters: Tracer tests
- Seepage tests
- Groundwater Monitoring. Including case studies and practical measurement campaigns at sites influenced by Water Spreading Weir structures

Kommentiert [h6]: Including this section, an overview about approaches that can be applied to get information about aquifers and groundwater movement, may be integrated.

Kommentiert [h7]: Copied from point "1. Groundwater Hydrology"

Kommentiert [h8]: Including this point, the university can continue with monitoring activities

~~3.~~ 4. Engineering Geology

Formatiert: Standard, Keine Aufzählungen oder Nummerierungen

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Here you can arrange the required content and also the modelling of ground water flow and aquifer.

Specially, the modelling of ground water for establishing ground water recharge analysis center in our university.

Appendix 7

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

giz Office Addis Ababa, P.O. Box 100009, Addis Ababa, Ethiopia

German Development Cooperation
GIZ Country Office Ethiopia and Djibouti

GIZ Office Addis Ababa
Kirkos Sub-City, Woreda 08
P.O., 100009, Addis Ababa, Ethiopia
T +251115180200
F +251115540764

Your reference
Our reference 2021/SDR/018
23.02.21

Woreda Administrator
Ewa Woreda

Subject: Removal and destruction of monitoring equipment

To whom it may concern,

In 2018 the GIZ implemented SDR programme started a long-term ground water monitoring to assess the impacts of the water-sperading weir approach on the aquafers in the direct surrounding of the land rehabilitation sites.

Data loggers were installed in local wells, which had fallen dry, under involvement of the communities. Our GIZ community facilitation team, in person of Abdulkadir Hassen and Mohammed Nasser, discussed with the local elders and a large part of the community the relevance, purpose and sensitivity of the installed devices. The sites were sealed and locked thereafter. There was a verbal agreement with the Woreda Bureau of Water to also check on the devices, a key of the lock was handed over to them and to the Woreda.

During our last read-out mission in cooperation with the regional Bureau of Water, University of Semera and our consultant hired for this, **they found the sites cracked open and the loggers removed.** One logger could be secured in a damaged state from one of the local community members. The second logger is still missing.

The vandalism / theft must have taken place between January 2020 – January 2021, we are trying to retrieve data from the broken device and will be able to specify the exact time if possible.

With this, we will not be able to continue the groundwater monitoring in Ewa Woreda, which was the chosen site for overall assessment of the water spreading weir impacts on aquafers in the Afar region. The well has been filled with stones by the community and is therewith irreparable.

We would appreciate your support in re-finding the still missing second data logger. We are also obliged to file a police report.

We thank you in advance for your active support in this unfortunate matter.

With sincere regards

Christina Ketter
Project Manager „Afar Soil Rehabilitation Project (ASRP)"
Strengthening Drought Resilience ASAL (Afar and Somali Region)
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

CC:
PADO, Woreda Bureau of Water
BoLAND, BoW