Report on the hydrogeological investigation in Dangila woreda, Ethiopia

AMGRAF Project Report, 2014

Previous Work

Various geological and hydrogeological works have been done in the area, including Geology of Ethiopia (M. Teferra, et al, 1996), 1:2,000,000 scale (V.Kazmin and Seife M. Berhe, 1996), and Geology of Bahir Dar map sheet 1:250, 000 scale compiled by Eferem Beshahwured et al (2010). An overview hydrogeology of Ethiopia (T.Chernet, 1984) provides a broad classification of the rock units into different aquifer systems. The hydrogeological mapping by Getachew Zewudie et al (2012) at 1:250, 000 scale indicates generalized groundwater potential areas. The Geomatrix Consulting group and Sogria also produced a regional hydrogeological map of Tana and Beles catchments in 2011. The hydrological study of the Abay Basin by the Ministry of Water some years back also covers the area though the data is regional and was not used for this work.

Methodology

This study was based on a pre-field/desk study and fieldwork. In the desk/study necessary data were collected from various sources. The data were organized, interpreted, gaps identified and method for the field work was chosen. However, some modifications were made during the fieldwork based on field information, density/scarcity of previous regional mapping data, and significant local variations seen in groundwater potential during the current mapping.

Then geological, hydrogeological, and hydrochemical information were collected from the study area during field work. Detailed evaluation of the controlling factors for groundwater movement and storage, and identification of geological structures (faults, lineaments, joints) and their role to control flow direction in relation to the direction of major and minor structures was evidenced by spring discharge, existing yield measurement of wells, measurement or estimation of spring discharge and estimation of dug well yield based on users information when the information is realistic, and measurement of some of the streams using current meter and floating methods were made to estimate water potential.

Some water quality parameters (EC, PH, Temperature) were measured at each spot visited and reasons for the variation of results were interpreted. Water samples were also collected for laboratory analysis from representative water points (boreholes, dug wells, springs, and rivers).

Based on geological/hydrogeological interpretation and field EC/pH measurement results, sites were selected for the geophysical survey. This investigation aimed at identifying the depth to the weathered section, depth to water bearing formations, water salinity variations, and tracing subsurface fracture zones. It was carried out in sites selected based on the analysis of the pre-field and field geomorphological, geological, hydrogeological, geophysical and hydrochemical information. Geoelectric sounding method was applied using Schlumberger array along with preexisting gravity data to get overlying sediment thickness and fractured portion of volcanic rock in selected localities in the study area. The results of the geophysical survey were presented in sections which basically show rock layers and the identified fracturing of the underlying rocks.

Geology

Based on field, lithological and structural relationships and petrographic studies made previously a tentative stratigraphic framework was constructed for the area from the oldest to the youngest rocks. The oldest rocks in the area are represented by Precambrian basement rocks, which consist of mix of metavolcano-sediments with little quartzofeldsphatic schist. This in turn is overlain by Eocene-late Oligocene flood basalts of Ashangi and Alajae. The latter is also mantled by shield volcanoes of Tarmaber-Gussa formation; ignimbrite, rhyolite, basaltic lava flows and scoria fall deposits of Quaternary age at some places.

Analyses of structural measurements from previous studies of Geological Survey of Ethiopia suggest that the area has experienced at least three phases of deformation. The earliest recognizable deformation (D1) is featured by NE-SW trending regional gneissic foliation and schistosity. This is followed by second phase of deformation (D2) characterized by NE-SW-trending compressional stress producing micro folds having a NW-SE trending axial trace. The same report further explained that the youngest regional deformation event (D3) is represented by low-angle brittle fracture, representing right-lateral strike slip fault (Efream Beshah Wured, et al, December 2010, unpublished report of GSE Memoir 30).

Hydrogeology

Groundwater in areas covered by soil, regolith and underlying fine grained basalt such as around Chara, south of Chara, and around Alefa Kacha

The shallow water availability around these areas, especially in the flat land is heterogeneous due to the presence of massive basalt at subsurface and the variable fracturing intensity, depth of the fractured section and shallow depth of weathering of the rocks. In few places there are springs that emerge from the fractured part of basalt but where the depth of weathering is shallow the water availability is limited. However, at places where there are penetrative fractures within the basalt, especially when thin layer of friable regolith is available, water storage and flow is seen to be good. Efforts made by local people to dig shallow dug wells have failed in many places due to the massive basalt underneath and they are usually using river water during the dry periods. But in some places the depth of weathering especially around Tigiri (south of Chara) area is higher (up to 12m commonly) and people use dug well water with good supply or limited scarcity of supply in peak dry period. The depth of weathering reaches 6m to 16m locally from geophysical information and dug well inventory works even within and around Chara and further north in Dengeshta area where the depth of massive rock is shallow, but aligned directionally. There is variation within small distances in depth of weathering and fracturing and many wells fail due to the heterogeneity of weathered depth which requires detailed subsurface information before digging.

The deep aquifer as evidenced from borehole data and geophysical investigation is as deep as 116m to over 200m depending on the area stratigraphy and fracture penetration variation in the different stratified rock layers. The aquifers in the area are layered aquifers with variation in the depth of the aquifers and with variable saturated thickness in the different places even for the shallow aquifers depending on various factors (morphology, stratigraphy, paleomorphology, structural penetration and other factors).

The water quality is very good and the shallowest groundwater is mainly water stored in soil and minor alluvium (EC below 60 µs/cm), mostly with variable pH of water.

The NS and EW local fracture systems have an important role in the flow and storage of shallow groundwater. The geomorphology is also suitable although the percolation of water is impacted by the basalt found at a shallow depth (below two meters soil layer) around Alefa-kacha.

There is limited and non-continuous regolith underneath the massive younger basalt. In places where there is some regolith, the water storage and movement is better, especially where the regolith and/or weathered basalt deposit is connected by fractures and where minor faults cut the basalt. When the water storage is mainly within the soil, the water flow significantly reduces seasonally in some of the springs inventoried during this field work. But when the aquifer has good vertical hydraulic connection between the saturated soil, or locally to the fractured or faulted basalt, or to the underlying weathered basalt and/or regolith, the yield of springs is good and flow fluctuation between the dry and wet periods is minimum.

The thickness of the basalt under the top soil is variable and the weathered layer at its top part next to the top soil varies between 2m to about 27m in different places as seen in river sections and dug well information within the area. The variation in the thickness of the weathered section of the underlying basalt is partly controlled by topographic setting. The saturated soil thickness is also seen to be variable depending on geomorphologic settings of the areas.

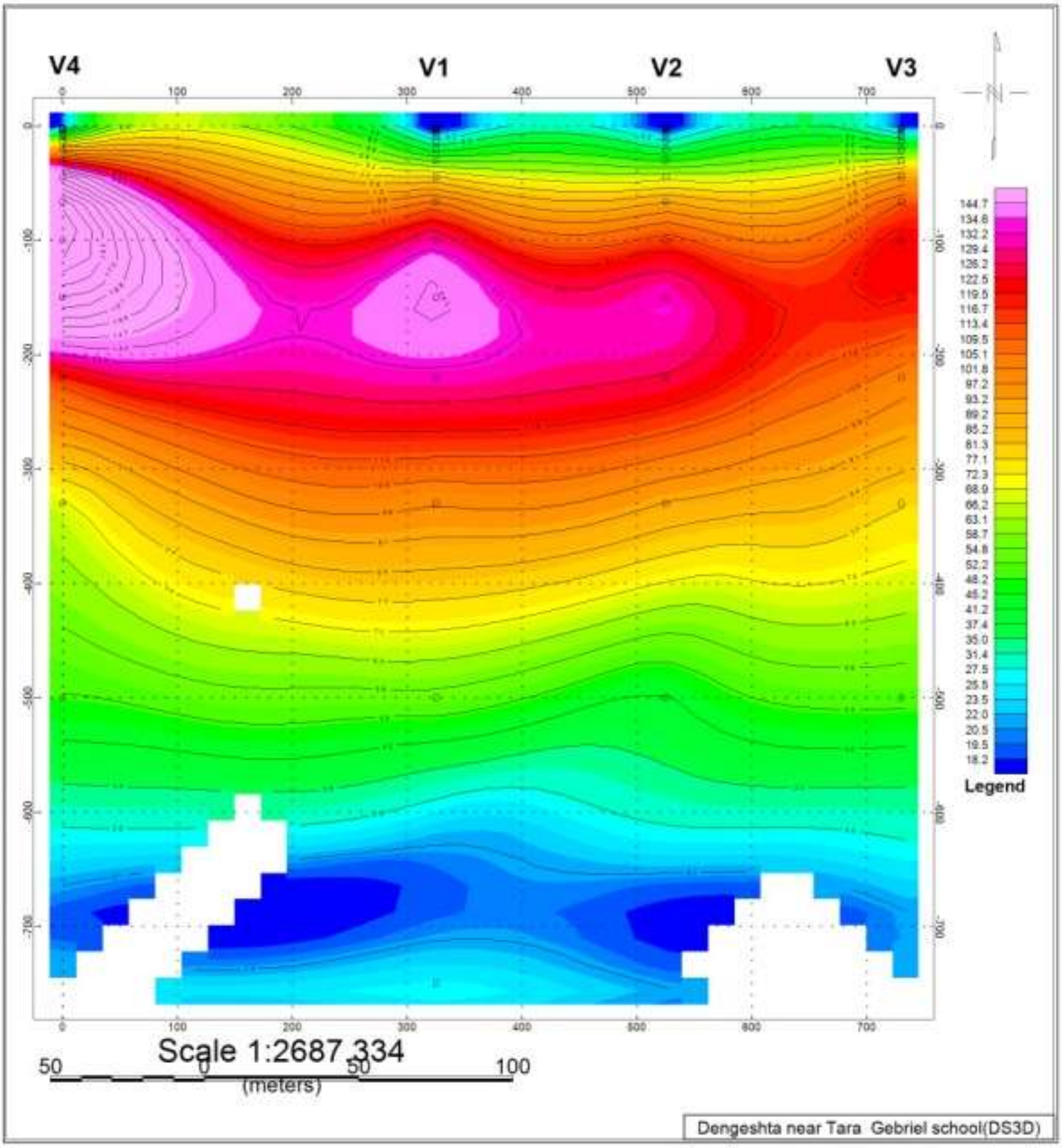

Figure 1: Pseudosection of rock layers in Dengeshta near Tara Gebreal school

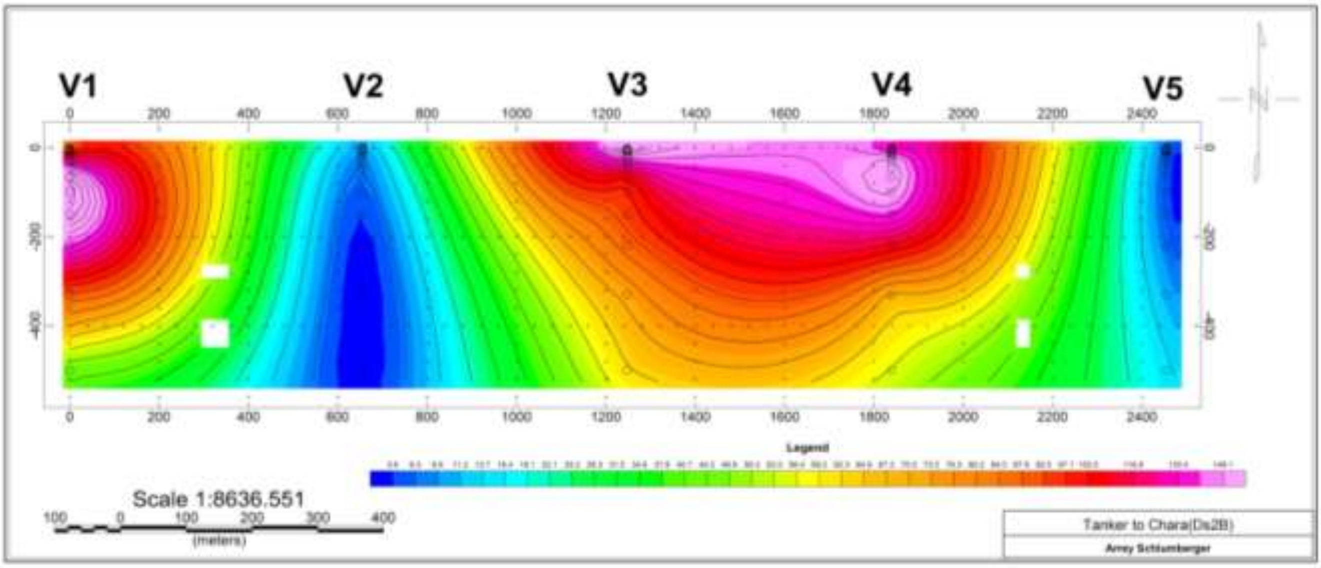

Figure 2 Pseudosection of possible lateral rock stratification variations around Chara, south of Dangila

There are seasonal and permanent wetlands formed due to either the presence of impermeable subsurface layer in places where geomorphologic setting controls shallow groundwater flow, or partly due to thick alluvial soil which is saturated with water due to morphologic suitability (local discharge areas). However, such swampy areas (wetlands) are reported to have been shrinking in the last few decades due to various reasons such as deforestation, climate change, and land use/ land cover change especially due to intensive plantation of eucalyptus trees plantation. In most places where there are permanent wet lands there is a thin layer of regolith and/or weathered section which is mainly iron cemented that hosts the local water in the wetlands. The EC of the water when it is stored in the top soil and regolith is lower (usually below 100µs/cm) as measured in many of the springs and dug wells. But if there is a contribution of the fractured underlying basalt or trachybasalt in few places the EC reaches up to 300µs/cm or a bit higher than this depending on the depth of weathering and flow nature of the groundwater (local or regional).

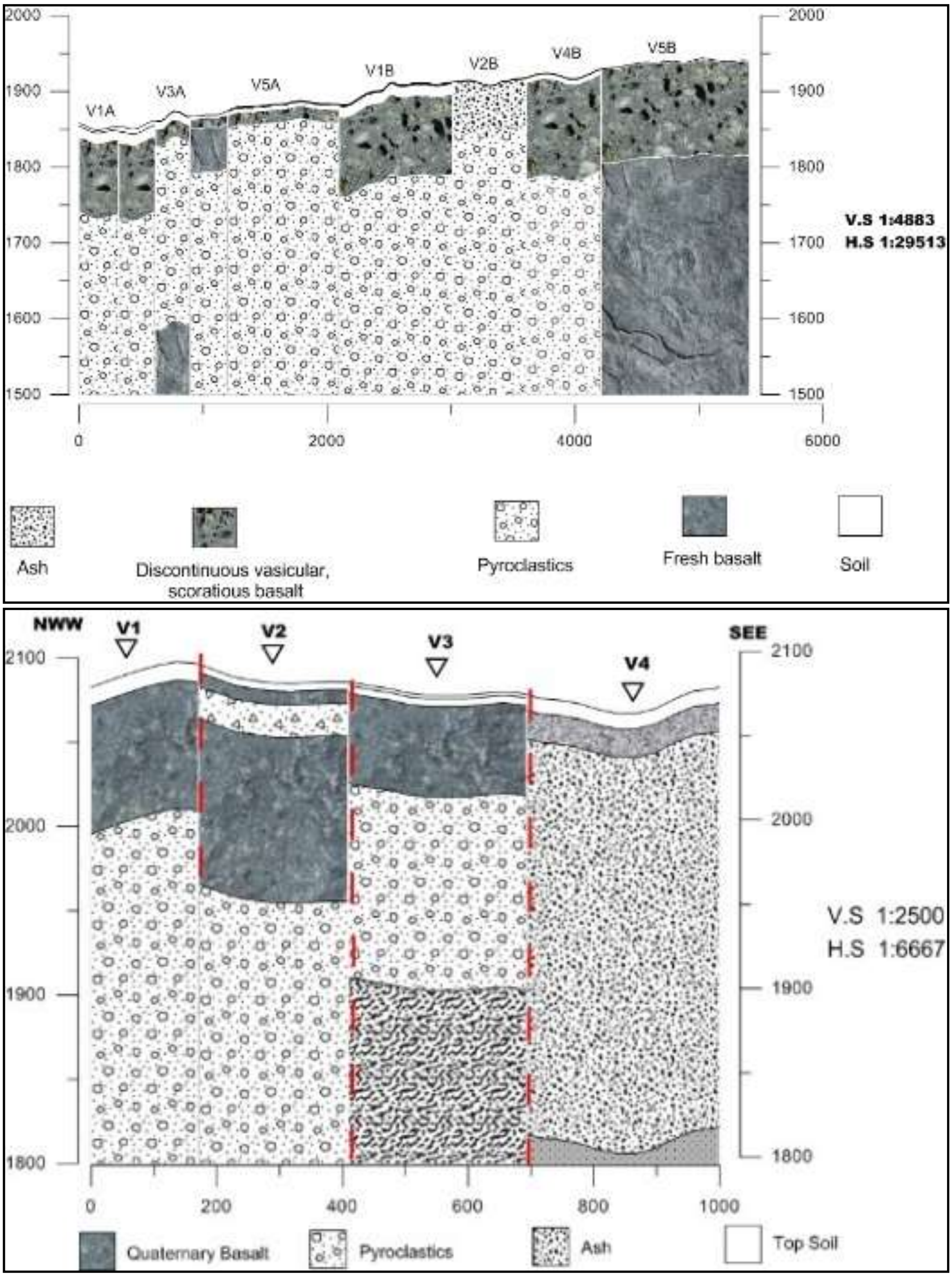

Figure 3: Local variations of subsurface geology as represented by geoelectric sections of volcanic and pyroclastic rocks in the study area

Groundwater condition in areas with top soil, regolith, and thin layer of fractured Quaternary basalt such as at southeast of Dangila, and around Merawi

The places seen under this hydrogeological type representation have also similarity with the conditions seen southwest of Chara. But the thickness of the basalt under the soil is usually thin and the vesicular basalt which has local penetrative cooling joints and some micro structures highly impact groundwater storage and movement within the soil and basalt horizon. The underlying fractured and weathered basalt and regolith have higher role for better storage than in the top soil. The locally deposited regolith which overlies the weathered Tertiary basalt under the younger (Quaternary basalt) has some moderate role in water quality and spring flow or dug well water storage and recovery of storage after water abstraction. This effect is higher when it is overlain by fractured basalt. In some places where the regolith has direct contact with the top soil underlain by thin layer of fractured basalt, the flow of springs and the amount of water abstracted from dug wells is seen to be much higher. Some of the springs around Gayita kebele of Dangila wereda are good examples. The water quality is also good in most cases.

The deep groundwater storage is more controlled by the fracture penetration, morphologic setting and the geologic stratification. The newly drilled wells in the fault lands of Gayita and some of the old wells fitted with hand pump such as the well close to Military camp clearly indicate this.

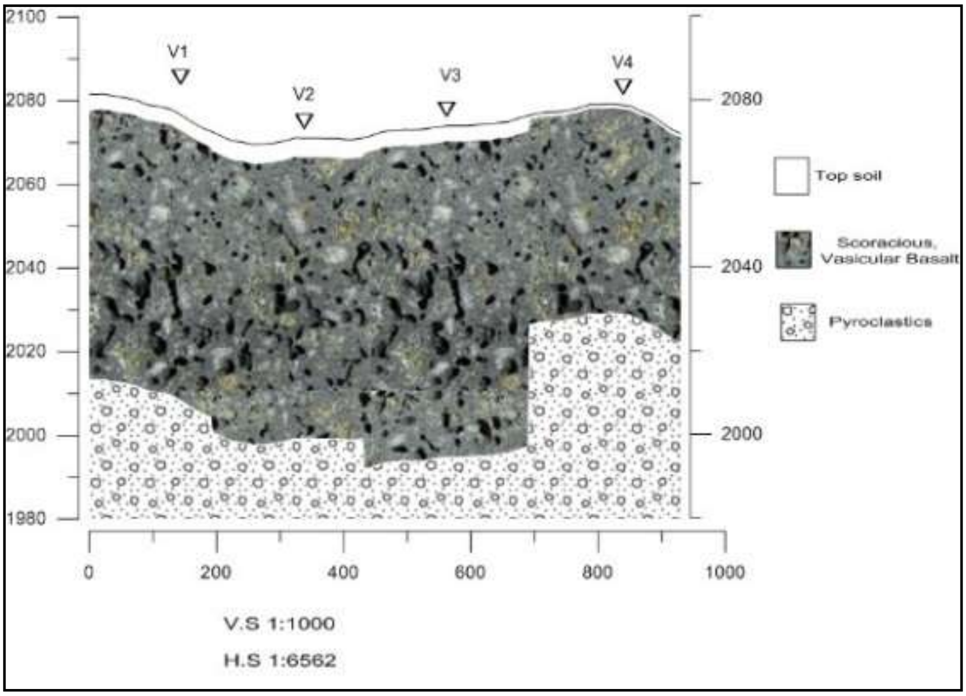

Figure 4: thickness variation of rocks in some of the study areas that impacts water availability at different depths.

<u>Hydrogeological condition in areas with top soil cover and underlying Quaternary basalt or pyroclastic material cover (Merawi Area type aquifers)</u>

Areas with this type of soil/rock stratification are found only in limited areas around Merawi and its surroundings for the shallow aquifers and in some localities southwest of Addis Kidam for the deeper aquifer. The water bearing property of the rocks in such areas is better compared to other volcanic hosted aquifers, and springs with yield between 12 to 20 l/sec are seen in such places. The spring NW of Merawi (holy water) is a good example of this type of geological stratification. On the other hand the fractured Quaternary basalt underneath the soil has a very good potential especially along fractured zones and cumulative spring yield reaches up to 50 l/sec in a few cases. The newly developed spring for Merawi town supply is a good example for localized high yield of fractured and vesiculated Quaternary basalt hosted aquifers.

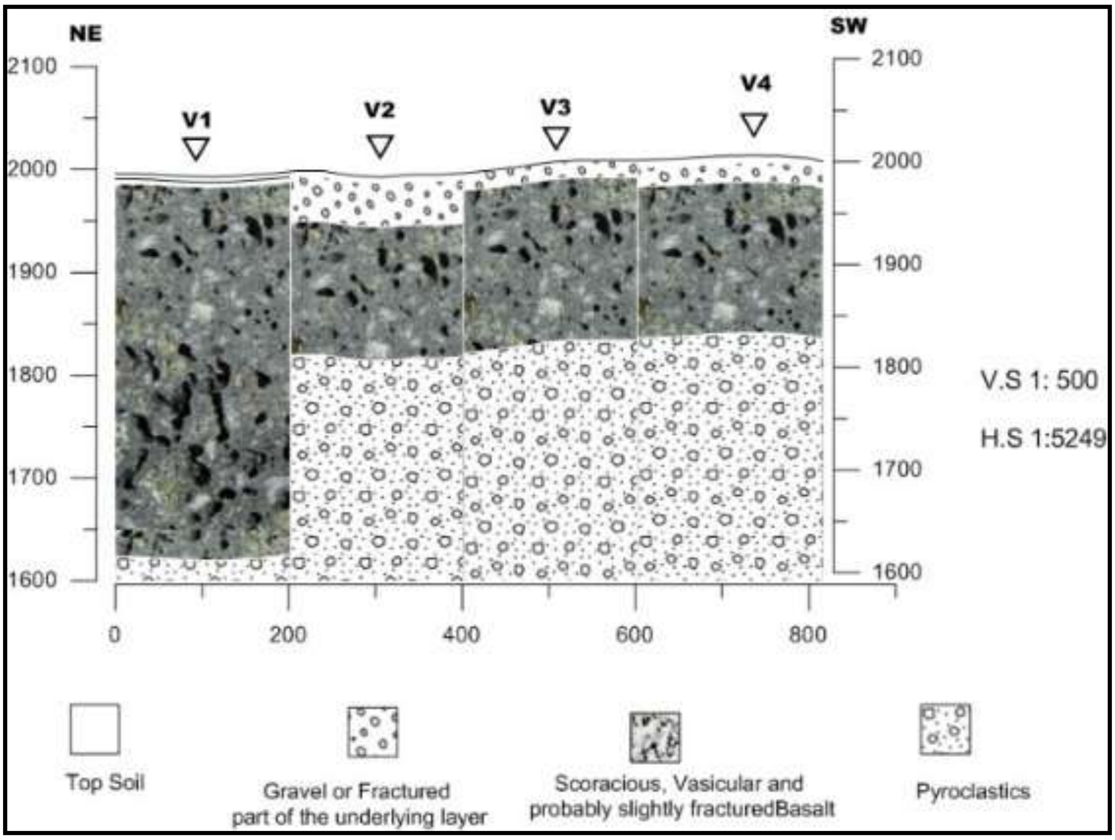

Figure 5: Thickness variation of rocks in some of the study areas that impacts water availability at different depths and better shallow storage variations.

Hydrogeological condition of weathered and fractured Tertiary basalts with variegated color of weathering (local compositional variations)

The water bearing property of Tertiary basalts in the area has significant variation sometimes irrespective of weathering depth and topographic suitability. The micro-fractures especially in the elevated areas have significant role for groundwater flow and storage within the Tertiary basalts. The yield measured or estimated in many places is low to very low due to the shallow nature of the fractures. However, in places where there are deep seated fractures the well yield from stratified rocks of the deeper aquifer is seen to be good though there is significant well yield drop after some years of pumping. The groundwater potential in the Tertiary basalts has significant yield variation after pumping the wells for some years, and variable storage depending on other factors such as topographic variation, nature of the stratified rocks, vertical hydraulic connectivity, and rainfall distribution variation.

The water quality stored in most highlands within the weathered and fractured Tertiary volcanics is good quality and with low electrical conductivity as we go higher in elevation with in the study area. However, the storage is heterogeneous due to significant local variation in depth of weathering, and in some cases due to the presence of massive layers that are less fractured which doesn't store water except along the limited fracture zones especially for the shallow groundwater storage.

The contact zones and near by areas with the Quaternary basalt are better saturated and wetlands are formed in some cases possibly due to shallow groundwater lateral movement from the highly fractured and vesiculated Quaternary basalt towards the weathered Tertiary basalts, and better recharge in the vesiculated Quaternary basalt and faster flow towards the topopgraphically low areas covered by weathered Tertiary basalts.

Fractures (mostly NW and NS and rarely the EW) have significant impact on water storage and flow especially in highland plateau areas where topography is controlled either by fracture, river incision or volcanism.

The yield of deep wells reaches up to 22 l/sec but a significant yield drop is reported (from 22 l/sec to 12 l/sec in three years of pumping) in many of the wells drilled in the Tertiary basalts. The shallow dug well yield is below 0.5 l/sec in most cases.

Hydrogeological condition in Tertiary volcanics covering the highlands

The areas around Dimsa, around Nefas Eyesus of Dangila woreda and areas east and southeast of Rim in Mecha wereda, and highlands NW and NS of Kunzila woreda where depth of weathering in the highland is relatively good but groundwater storage is limited are discussed under this morphologic category.

The storage and flow is either controlled by microfractures, mainly the NS, N30W and sometimes the EW or by redeposited alluvial/colluvial material deposited at the foot of hills or along major depressions that are partly related to faulting, volcanism, or river incision and redeposition. The highland local depressions have also limited storage of shallow groundwater but depending on slope angle, local morphological variation, and size of catchment area, wells dug in the highland have limited storage in the dry season or dry wells are encountered after digging to the depth of 25 to 28m depth in most cases. The morphology favours runoff or lateral shallow groundwater flow to low lying depressions or flat lands in most cases. However, some of the slopes before the flat land or mid of ridges are emergence points of springs depending on top geologic and fracture condition though flow in the springs has significant seasonal variation as reported by local people in most cases.

Hydrogeological condition in soil and alluvial material

The areas with this type of material are found in limited areas in the flat land or relatively low lying plains. The water stored in such areas has relatively shallow depth, and continuous supply for most dug wells from such places. But at some of the alluvial covered swampy areas, the water quality is not promising for drinking due to its odour and most people prefer to use spring water (springs that emerge from margins of the swamps) than dug well water dug within the wet land or close by the periphery of the wet land. The taste of the dug well water is reported to change after two to three years of pumping and especially in the wet season. The soil thickness is relatively deep reaching up to 12m in rare cases as reported by well diggers and users. The colour of the soil changes from loamy reddish brown clay at the top to black loamy soil before the weathered section. In such stratification condition the water storage and flow is from the black loamy clay soil layer before the weathered section and the water supply is better in most cases as reported by users and the local people who know the history of the dug well.

Areas that are found close to the boundary of Dangila woreda and Achefer are best representation of such alluvial hosted shallow aquifer underlain by stratified aquifer in fractured and weathered basalt.

Hydrogeological condition in mixed alluvial and Quaternary basalt aquifers

The water storage and flow in such localized aquifers has high yield variation between the wet and dry season but generally have good storage with yield of springs up to 12 l/sec. When such alluvial aquifers are connected to upland fractured aquifers the yield is much higher. The area around Werkmeda is a good example of mixed alluvial soil and jointed thin layers of Quaternary basalt above the Tertiary basalt which at places is also deeply fractured and supplies good water as seen around Workmeda. Some of the localities around Merawi have a similar condition although the thickness of the Quaternary basalt seems thicker around Merawi and most perennial springs have some contribution from thin regolith between the top soil and the underlying Quaternary basalt in the latter case.

Hydrogeological condition in trachytes and local rhyolites

The water stored within these rocks is limited to only fractured sections that seem to have vertical and lateral connectivity and aquiclude in most massive and compacted sections.

Most places covered by these types of volcanics have very limited storage, few of the springs are seepage type of flow especially in dry season, or dry seasonally. The yields estimated from users are as low as below 0.01 l/sec especially in relatively elevated parts.

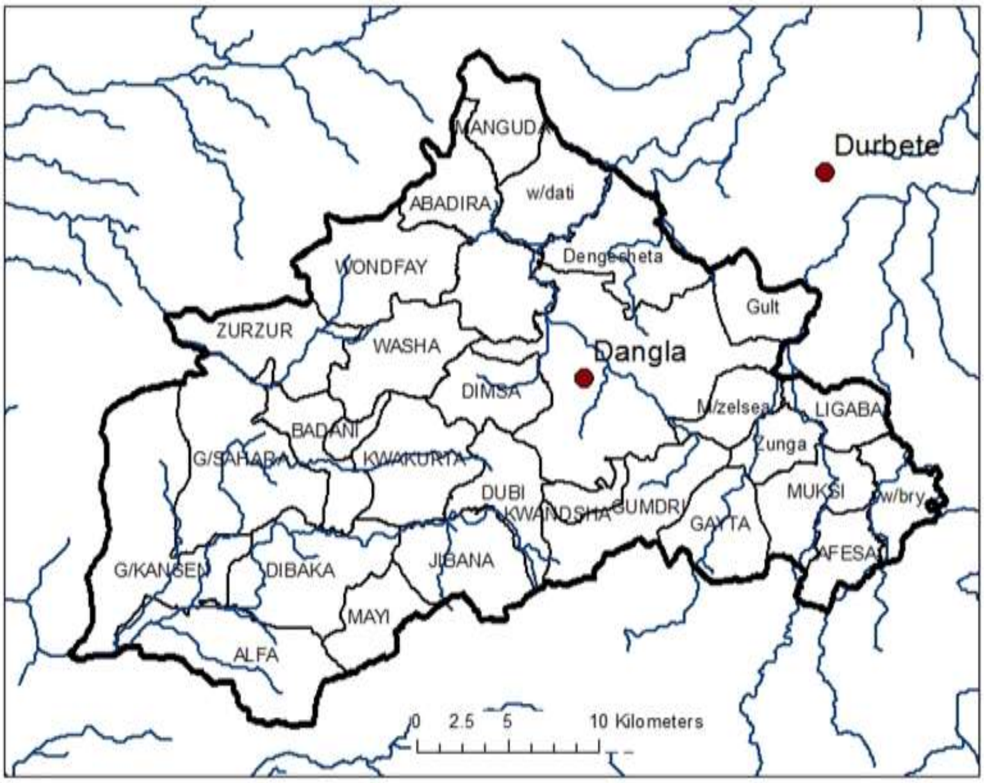

Figure 6: Location map for hydrogeological investigation