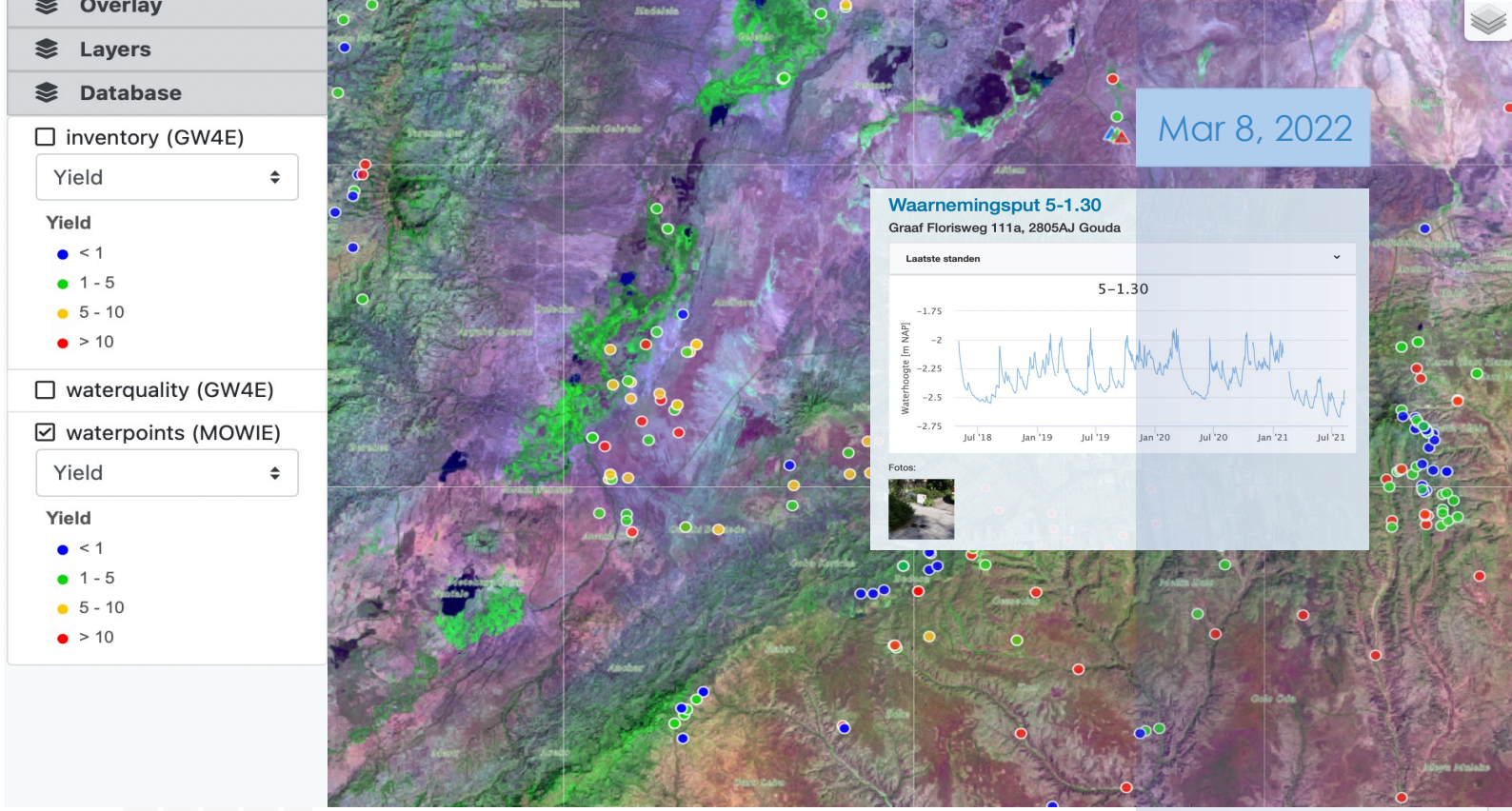

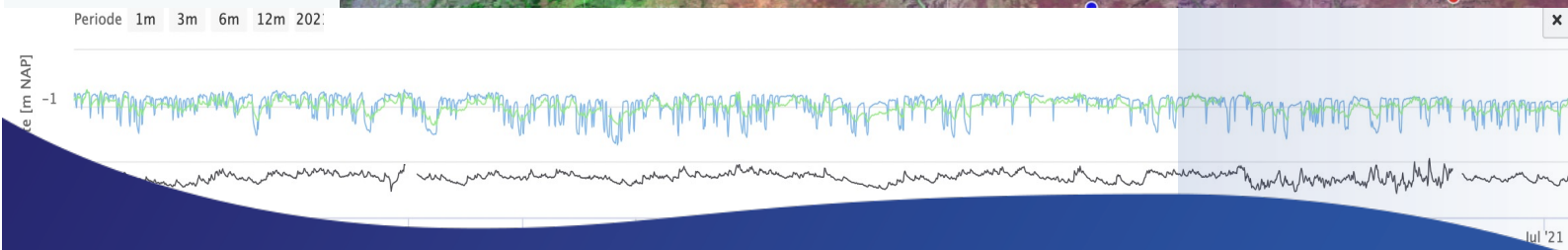

Hydrogeological mapping for Climate Resilient WASH in Ethiopia – LOT 5

Report Phase 2 – Final BDA/ICB/GW01/2021




Foreign, Commonwealth & Development Office

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Introduction

Drought is the major natural disaster affecting the livelihood of Ethiopians, resulting in water insecurity which in turn causes disruption of livelihoods and loss of life. A significant proportion of the Ethiopian population still lacks access to clean water, even though Ethiopia successfully achieved the Millennium Development Goal (MDG) target of halving the number of people without access to improved drinking water. At the national level, 60 to 80 per cent of communicable diseases are attributed to limited access to safe water, and inadequate sanitation and hygiene services.

The UK Department for International Development (DFID) supports the Government of Ethiopia to improve water security through the One Wash National Programme (OWNP) and other longer-term development and emergency activities. Yet, whilst emergency support is critical, it is also vitally important that resilient WASH development programming takes place in water insecure areas to break the cycle of emergencies. The challenges are greatest in the lowland parts of Ethiopia due to the complex geology and hydrogeology of the areas, which provide challenges to the development of productive groundwater sources. In addition, most regions of Ethiopia lack detailed hydrogeological maps that can be used as a quick reference for siting water wells. As a result, the drilling of dry or low-yielding wells is the main challenge in groundwater development.

Current national mapping is very broad-scale and focuses primarily on depth to water and geology. Although an excellent starting point, this level of mapping appears to focus on irrigation, and does not necessarily tie in well with development potential, or range of borehole yields. With accurate borehole attribute data and accurate geological mapping, hydrogeological characterization and mapping can provide the basis for efficient field verification of groundwater.

The Ministry of Water and Energy (MoWE) has received funding from DFID for a three-year project entitled Delivering Climate Resilient Water, Sanitation and Hygiene in Ethiopia (DCRW). As agreed by an MOU between DFID and the Government of Ethiopia work stream, two of the four programme areas are being implemented by MoWE.

This project, which ends on the 31st of March 2022, is part of the UK Government's aid strategy to support the poorest people in adapting to climate change, specifically on building climate resilience in water and sanitation services that contributes to achieving Sustainable Development Goal (SDG) 6. The project complements DFID and Ethiopia's significant programming on water and sanitation and supports effective delivery of the Government of Ethiopia's strategy for sustainable water supply in drought affected areas. A key feature of this program involves funding for groundwater mapping and improvement of groundwater data management.

1.1 Objectives

The project has been subdivided into 5 lots. Lots 1, 2, 3 and 4 cover 53 selected woredas in the regions Tigray, Amhara, Afar, Gambela, Oromia, Somali and SNNPR (Figure 1). Lot 5 deals with data management and dissemination.

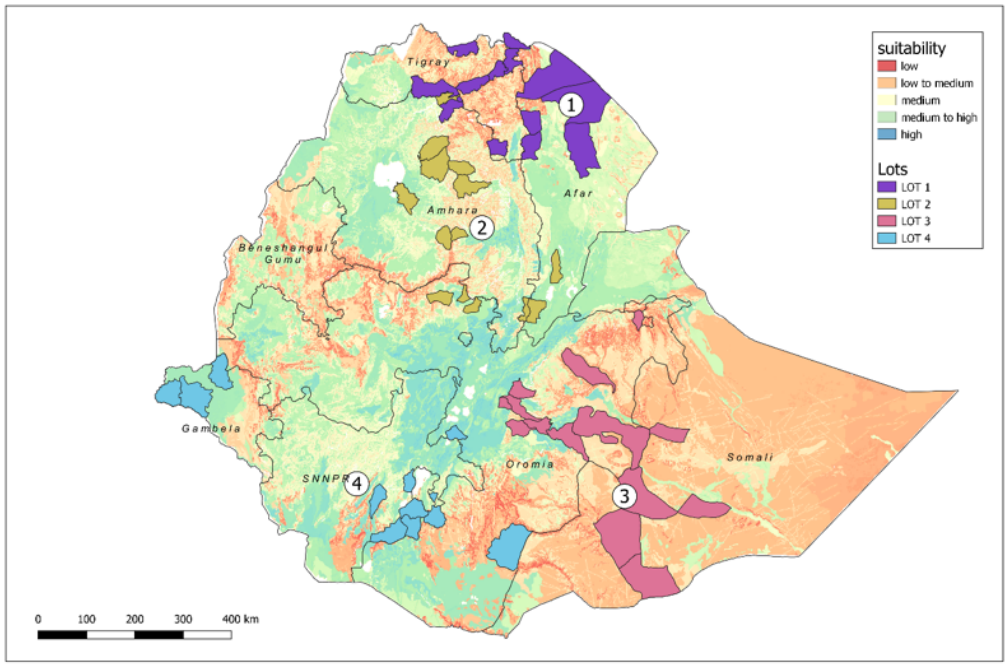

Figure 1 Project area, with the different lots (coloured polygons) displayed on the groundwater suitability map.

1.1.1 Overall objective

The objective of this project is to increase access to safe and sustainably used water for the people in drought affected regions by producing hydrogeological maps at woreda level and recommending drilling sites, which the Government of Ethiopia and other partners can use for developing groundwater resources.

1.1.2 Specific objectives

Lots 1, 2, 3, and 4

- Create detailed groundwater potential maps for each Woreda.
- Identify one optimal drilling site and one alternative (optional) drilling site per Woreda using these maps and geophysical field investigation.
- Recommend the type of drilling methodology to be employed.
- Build the capacity of WDC, MoWE, Regional governments, and NGOs to use overlay analysis techniques for groundwater potential mapping in Ethiopia.

Lot 5

- Conduct a detailed assessment and review of the status and configuration of the existing Ethiopian national groundwater information system.
- Identify the most effective platform for storage and presentation of the digital data.
- Develop a web-based platform for two-way information flow and test its operation and access to data.

1.2 Activities specified for Lot 5

For Lot 5 the following activities have been specified in the Terms of Reference:

- Review of the existing Groundwater Information System;
- Establishment of a central database;

- Migration of existing data into that database;
- Development of an online platform for dissemination, analysis, and data acquisition;
- Liaise with the Regional Water Bureaus;
- Capacity building at BDA on usage of the system and database operation and maintenance.

1.3 Lot deliverables

For Lots 1, 2, 3 and 4 the following tangible outputs have been defined:

- Collation of relevant maps, reports, and data;
- Conceptual hydrogeological models;
- Water point inventories;
- Demographic data and maps;
- Hydrogeological maps;
- Groundwater potential maps per woreda;
- Drilling site maps.

The deliverables for Lot-5 are:

- A central Groundwater Database;
- Migrated data;
- Online platform for groundwater data;
- Capacity built at MoWE.

Groundwater database aspects

1.4 Existing databases

In the past, the Ministry has used two software packages for storage, retrieval, and analysis of groundwater data, *i.e.* ENGDA (USGS) and ENGWIS (Schlumberger Water Services). Both packages are outdated and dysfunctional. The data stored in ENGDA were rescued, but the data from ENGWIS could not be retrieved because the license had expired and was never renewed. Moreover, the software runs on outdated versions of Microsoft Windows and Internet Explorer (Windows XP, IE 5.0). Currently, groundwater data are stored on different computers at the Ministry and in different formats (Excel, Word, PDF).

1.4.1 ENGDA

ENGDA has been developed by USGS in 2004-2007. It uses Microsoft Access as database engine and contains information about the following topics listed in Table 1.

Table 1. Topics and data included in ENGDA.

Topic	Number of records
Boreholes	2983
Springs	796
Well construction	662
Pumps	57
Lithological logs	398
Aquifer tests	32
Water use	14
Discharge	988
Water levels	1413
Water samples	1902
Drilling	32
Well development	69

After analysing the structure and database fields it was felt that the structure of the ENGDA database was well suited for management of groundwater resources by the Ministry. It could therefore serve as a basis for further development of a new groundwater data management system. Detailed information about the structure and field definitions of the ENGDA database can be found online at http://pubs.er.usgs.gov/publication/ofr20071099. The main advantage of ENGDA is a clear database structure, that addresses the groundwater management needs of the Ministry. Disadvantages of ENGDA are the outdated database software (MS Access), a lack of GIS support and interoperability functionality.

1.4.2 ENGWIS

ENGWIS uses Microsoft SQL server 2005 as database backend and consists of three main packages, all with commercial licenses.

Hydro Geo Analyst

Hydro Geo Analyst is an information management system for managing groundwater and environmental data. It provides database utilities, borehole logging / reporting, 2D mapping and cross sections and 3D visualisation.

Aquifer Test Pro

Aquifer Test Pro is designed for graphical analysis and reporting of pumping and slug test data, offers the tools necessary to calculate an aquifer's hydraulic properties including hydraulic conductivity, transmissivity, and storativity values.

AquaChem

AquaChem is used for the management, analysis, and reporting of water quality data. It includes the geochemical reaction model PHREEQC. This software suite targets professionals in the field of groundwater research, development, and management. It contains a collection of advanced tools to support the groundwater professional in daily work and can interface with external modelling software such as MODFLOW and PHREEQC.

The Microsoft SQL database backend stores information about the following topics:

- Site description;
- Well construction;
- Well history;
- Geological descriptions;
- Geophysics;
- Monitoring data.

The number of records and quality of the data stored could not be determined because the system is not functional anymore and data cannot be accessed. The design of the underlying database is somewhat different than that of ENDGA, but it contains similar database fields.

The advantages of ENGWIS are the flexible template system that allows users to define or modify the database fields and tables, and the strong linkage with postprocessing and modelling software. The latter, however, can also be viewed as a disadvantage because the linkage is only with a predefined set of (advanced) software tools. These tools include AquaChem, Aquifer Test pro, PHREEQC and MODFLOW and require high levels of specific hydrogeological knowledge and experience. Another disadvantage is the closed system that relies on proprietary, licensed software running on a single computer, not in a shared environment.

1.4.3 Other data sources

The Ministry keeps groundwater data in many files and formats on different desktop computers and laptops. These files contain database dumps of ENGDA, ENGWIS, and WASH inventories, well completion reports and other project related documents. It is envisaged that a start will be made with the import of this data during phase 3 of this project. Before importing, the data needs to be thoroughly analysed and validated to ensure that the data in the database is of high-quality. Data validation, cleaning, and importing procedures form an integral part of the training that will take place at the start of phase 3 (January 2022).

In addition to data stored at MoWE, public domain data sources with well inventories and water quality data exist, such as those available at CSA, UNICEF and the Waterpoint Data Exchange platform (WPdx).

Another important resource for groundwater data is the scientific community. Scientist at Ethiopian and foreign universities have collected and analysed groundwater data for decades and for many research projects. Unfortunately, these data are often not easily accessible.

1.4.4 Lessons learnt

The main lessons learnt from the previous experiences with database systems and groundwater data management at the Ministry are:

- Database tables contain unvalidated data and duplicates;
- Accessibility challenges (only accessible through computer at the Ministry);
- No backup/restore system in place;
- No formal database management procedures;
- Many (redundant) tables with limited data;
- Complex support and postprocessing software;
- Monitoring data (quality, levels, discharges) are missing, and databases contain mainly inventory data.

1.5 Data system design principles

1.5.1 Background

Previously, the database systems were installed on computers at the Ministry. The database software (Microsoft Access and Microsoft SQL server) was at the time of installation a logical choice. The systems could still be functional because the underlying database systems are still supported and maintained. Microsoft Access however is not designed for remote access, and installation in a client-server environment is discouraged because of security and performance issues. ENGWIS' database system (Microsoft SQL Server) is better suited in these environments. The main disadvantage of ENGWIS is the user interface and support software that was supplied by SWS. This is proprietary software that is subject to license fees and does not run on current operating systems versions without (costly) upgrades.

1.5.2 A modern data management system

Based on the lessons learnt, we have designed a web-based client-server system, based on open-source software. Its main purpose is to store groundwater data in a structured manner and provide data entry, validation, and querying/display functionality. The database tables and fields have been designed in such a way that most existing data can easily be migrated (no data lost).

Because the system is web-based, there are no installation, hardware, or software requirements for the end-users and data integrity is guaranteed though automatic backups in the cloud. Accessibility is greatly improved when compared to ENGDA or ENGWIS. Users can access the system (with appropriate credentials) on any device using any major internet browser, such as Edge, Chrome, Firefox, Safari and Opera. The system can also be accessed through a REpresentational State Transfer (REST) application programming interface (API) to facilitate linkage/exchange with third party systems, such as external databases and sensor platforms.

Finally, the proposed data management system provides web services (WFS and WMS) to enable online linkage with GIS packages and (online) mapping applications.

The basic data management system design is visualised in Figure 2.

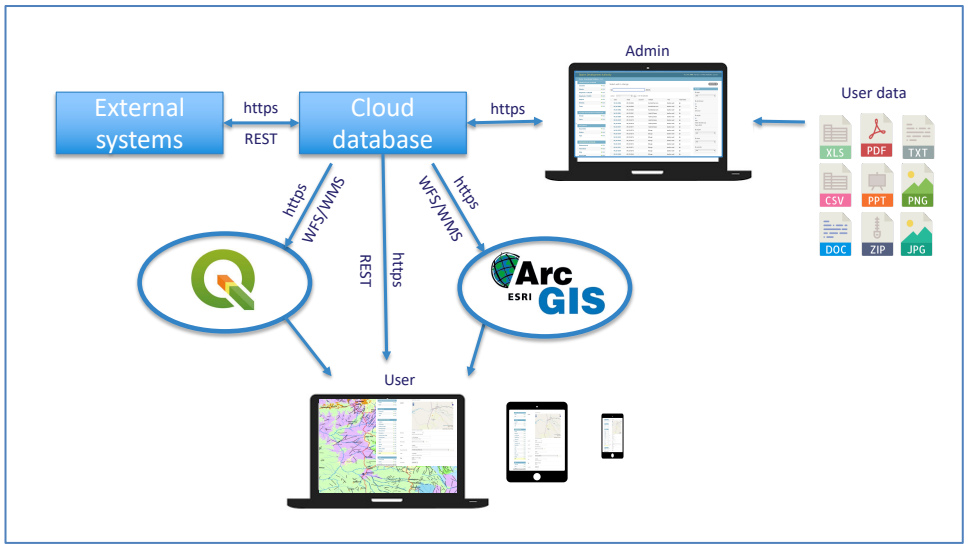

Figure 2 Schematic structure of the proposed modern data management system

1.5.3 Software aspects

PostgreSQL is used as software for the database backend. PostgreSQL is a powerful, open-source object-relational database system with over 30 years of active development that has earned it a strong reputation for reliability, feature robustness, and performance. It is one of the most used open-source database systems and has excellent performance, security, and support.

The backend has been created using Django and the Django REST Framework (https://www.djangoproject.com). Django is a high-level Python web framework that encourages rapid development and clean, pragmatic design. Built by experienced developers, it takes care of much of the hassle of web development. It is free and open source. Django REST framework is a powerful and flexible toolkit for building Web APIs.

The font-end has been created using Django, Leaflet, HTML, CSS, and JavaScript. All these software components are expected to be supported and developed further for many years to come.

1.5.4 System security and access rights

To avoid compromising the integrity of the system and prohibit unauthorized access, all access to the system is channelled through secure, encrypted SSL connections. Users are assigned a role that defines their access rights. Currently, roles have been assigned for administrators, MoWE staff, consultants (for Lot 1, 2, 3 and 4) and the public. The roles and related authorizations can be modified by the database administrator.

1.5.5 Location and hardware

During the development phase we have used a dedicated server from our service provider in the Netherlands (https://mowe.acaciadata.com). When both a domain name (subdomain of .gov.et) and a service provider in Ethiopia become available, the system can be transferred to the new server and data can be migrated. Backups of the data system are maintained in the cloud but can also be physically stored at the Ministry, if preferred.

1.6 Data management platform design

1.6.1 Design of the backend

The database structures of ENGDA and ENGWIS have been used as starting points for the design of the backend. In addition to groundwater data, the backend stores documents and maps, as well as the configuration of the map viewer and map servers.

Groundwater data

The groundwater data are subdivided into four main classes:

- Waterpoint data (inventory data);
- Well construction data;
    - Casing arrangements;
    - Screen setting;
    - Pump details ;
- Groundwater data (timeseries of quality and quantity);
    - Well logs (driller's logs, lithological and geophysical logs);
    - Water samples and analyses, and
- Pumping tests.

Additional resources

The backend is also a datastore for other data such as:

- Documents, spreadsheets, pictures, GIS files, etc.;
- Administrative divisions (CSA, 2007);
- Map sheet numbering (1:250,000 and 1:50,000);
- Map compositions for the map viewer;
- Details about 3rd party GIS servers.

The data are stored in a single PostgreSQL database. For this project, both database and front-end are located on the same server. Because of the modular design of the system, the storage location of the database can also be different from that of the front-end.

A complete list of data tables, Entity Relation Diagrams have been provided in Annex 1, whereas field definitions were listed in Annex 2.

1.6.2 Front-end design

The frontend design is based on the dissemination tool developed during the UNICEF project "Groundwater Mapping for Climate Resilient WASH in Ethiopia", tailored to the needs of the current project and extended with some additional database functionalities. The frontend contains three main modules:

1. A database interface module;
2. A document repository module;
3. A Map viewer module.

Database interface

Authorized users may use this interface for data entry and querying. The interface has been built upon Django's Admin Interface, was customized for MoWE and provides functionality for management, data entry and querying of:

- Authentication and authorization;
- Documents;
- Groundwater data;
- Import template definitions;
- Validation rules;
- Map viewer configuration;

- Administrative divisions, river basins and map sheets.

A sample interface is show in Figure 3.

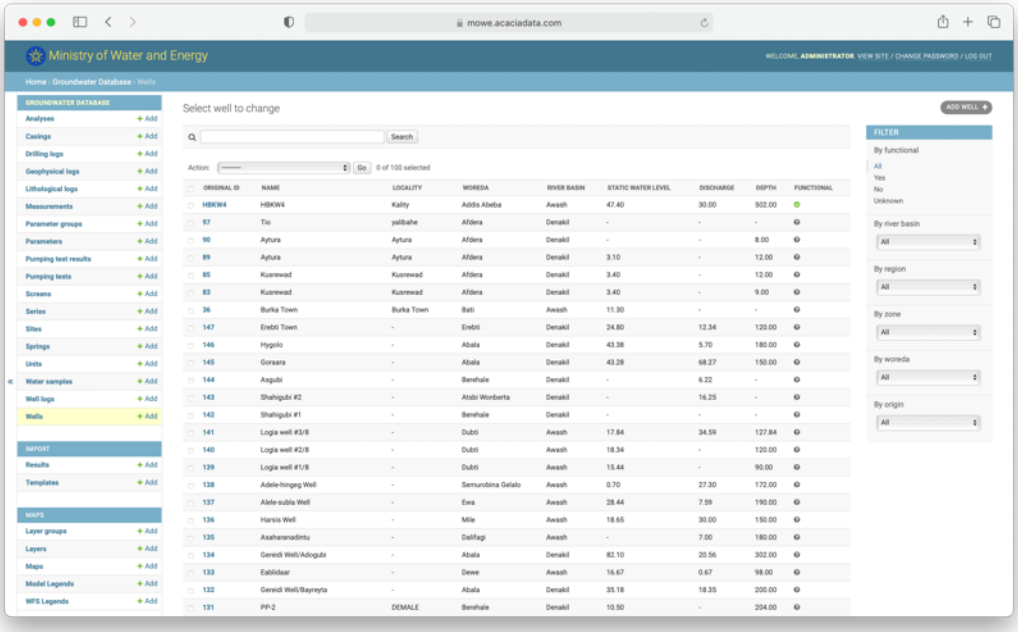

Figure 3 Image showing the administrator's interface of the groundwater data management platform.

1.1 User manual development

A user manual will be developed, also based on the experiences with the groundwater database management system in the capacity building workshop. The user manual will be added as Annex 5 in the final report.

Document repository

The document repository resides in the same database as the groundwater data. It contains documents and maps related to this project (deliverables), as well as other relevant documents related to groundwater in Ethiopia.

The repository interface lets the user browse through the documents, such as reports, maps, and data files. Authorized users can preview or download the documents and maps directly from the portal. A sample screenshot of the document repository is shown in Figure 4. The documents can be tagged, and linked to most database entries, like wells, water samples or pumping tests. This facilitates querying and retrieval of related documents, such as well completion reports, well logs or pumping tests.

The project deliverables are also stored in the document repository, organized by project Lot number. The deliverables are:

Maps:

- Hydrogeological map 1:1,000,000;
- Socio-economic map 1:1,000,000;
- Groundwater potential maps per woreda (1:100,000);
- Conceptual models per woreda;
- Hydrogeological maps per target area (1:50,000);
- Hydrogeological cross sections per target area;
- Geophysical survey maps with proposed sites (1:5,000).

Reports:

- Inception report;
- Phase 2 report;
- Final report;
- Risk Mitigation Strategy document.

Database administrators can modify or extend the repository structure to add other project related documents, such as minutes of workshops, progress reports, training manuals, etc.
For this project, the repository structure has been organised into project lots (Lot 1,2,3 and 4). After completion of the project, the structure could be modified by the database administrator to reflect an alternative setup, such as river basin or administrative division.

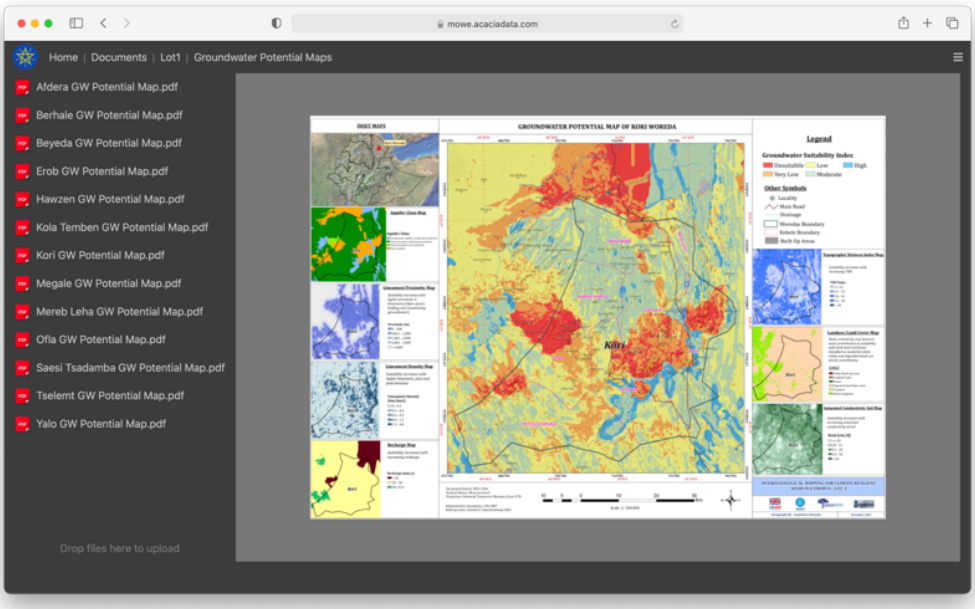

Figure 4 Example of the document repository interface of the groundwater data management platform.

Map Viewer

The Map Viewer allows the user to open a map with a predefined set of layers (Figure 5). Map compositions (layer order, visibility, opacity, legends etc) are configured by the system administrator and stored in the backend. Only the configurations (compositions) are stored, the actual maps are served from external webservers. For this project we have created a dedicated web service to serve the groundwater layers directly from the database, and specific project related layers such as satellite imagery and hydrogeological maps from a QGIS server (gis.acaciadata.com).

1.2 Map Layers

The following map layers have been included by default, and cover the entire country of Ethiopia:

- Administrative boundaries (CSA);
- Annual precipitation (CHIRPS);
- True colour composite (Landsat-8);
- False colour composite (Landsat-8);
- Elevation (SRTM);
- Road network (OSM);
- Stream network (CSA);
- Land cover (ESA);
- Soil class (Soilgrids.org).

The above list of standard map layers can be customized by the database administrator.

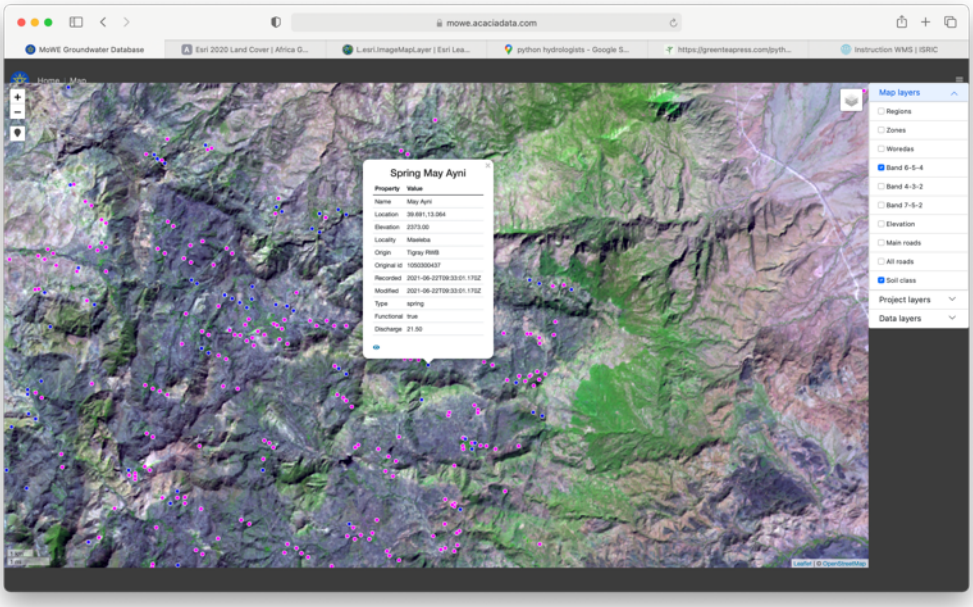

Figure 5 Example of the map viewer interface of the groundwater data management platform.

1.3 Project Layers

Besides the standard map layers, the map viewer also includes project specific layers like administrative boundaries of the project woredas, groundwater potential, lineaments, recharge, wetness index, lithology, land use, soil and slope. The project layers for Lot 1 have been added to the map composition, the layers for the other lots will be added by the consultants during Phase 3 of the project.

1.4 Data Layers

The third group of layers included by the viewer are the data layers.
The data layers are served directly from the database and include:

- Inventory data (wells and springs);
- Water samples (sites with water quality data);
- Water levels (sites with water levels);
- Well logs (sites with a well log, and/or construction details);
- Pumping tests.

Capacity building aspects

1.5 Training

At the start of Phase 3, immediately after the phase 2 validation workshop (Annex 3), a 4-day training workshop will be held in Addis Ababa. The training targets MoWE staff, RWB's and consultants of Lot 1, 2, 3 and 4. Participants should have a background in hydrogeology. A working knowledge of GIS and Excel is preferred. The workshop schedule is provided in Table 2

Table 2 Training programme schedule

Day	Time	Subject
1	Morning	Introduction to the groundwater database
	Afternoon	Documents and Maps / Map viewer
2	Morning	Data cleaning and validation
	Afternoon	Data entry and querying
3	Morning	Data migration and bulk transfer
	Afternoon	Interoperability: REST API and webservices
4	Morning	Uploading documents and project deliverables
	Afternoon	GIS server

More details on the training programme are provided in Annex 4. The latest version of the manuals, sample data and other information will be made available online at the digital learning platform of the Acacia Water Academy (awa2.acaciadata.com).

1.6 Migration

Publicly available datasets from CSA, UNICEF and WPDx (Water Point Data exchange) have already been migrated to the database. The available data at MoWE, Regional Water Bureaus and at Woreda offices (not public domain) have not been migrated yet. MoWE staff will receive training in data cleaning, validation and import during the training. After the training, the project team will be available for assistance with the migration.

Van Hogendorpplein 4
2805 BM Gouda
The Netherlands

Tel: (+31)182 – 686424
www.acaciawater.com
info@acaciawater.com