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ACEWATER2 Regional database: hydro-climatology data-analysis

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Background

Widely recognized by the diplomatic dialogue between EC-AUC, the need of research on Transboundary water resources management, integrated water resources management, and conflict prevention is grounded in the 2018 Foreign Affairs Council Conclusions on Water Diplomacy.

In particular, one of the key limitations to a harmonious development and management of water resources in Africa is the lack of human and institutional capacity to assimilate the modern advances in science and technology necessary to deal with the complex interactions between the hydrological cycle and the societal needs, while conserving the environment.

At present, research and development in the water resource sector in Africa is highly dependent on developed countries' expertise both in terms of knowledge and human resources. African countries can, however, find innovative solutions for sustainable development if and when they mobilize and direct their different capacities towards common research and development challenges.

Within its strategy, the Commission supports different continental institutions in the water sector, including the AU (African Union) and its water arm, AMCOW (African Ministers' Council on Water), and ANBO (African Network of Basin Organisations).

In particular, the "Joint Africa-EU Strategy Roadmap 2014-2017" established at the 4th EU-Africa Summit, held in Brussels on 2-3 April 2014, by the Heads of State and Government of the EU and Africa, the President of the European Council, the President of the European Commission, the President of the AU and the Chairperson of the AUC explicitly stated:

a. The need for the EU to support the development of the Centers of Excellence in Africa in the framework of priority area 3 "Human development";
b. The need to include water amongst the strategic priorities for cooperation and urged actions in the water sector to ensure, through institutional strengthening, sustainable and efficient management of water resources, contributing to growth, peace and security in the framework of priority area 4 "Sustainable and inclusive development and growth and continental integration";
c. The will to strengthen African capacity to monitor environment in the framework of priority area 5 "Global and emerging issues" including water resources through the GMES/MESA (Global Monitoring for Environment and Security / Monitoring for Environment and Security in Africa) EU programmes.

EuropeAid launched the pilot project "Support to the New Partnership for Africa's Development (NEPAD) Centres of Excellence (CoEs) in Water Sciences and Technologies". The pilot phase of the project (2011-13) was implemented by the Joint Research Centre on the European Commission's behalf. This pilot initiative aimed at fostering the capacity development and the ownership of south to south networking and cooperation in water science in the African high education, training, research, advocacy, and consultancy communities, in line with the principles of the multi-stakeholder participatory approach fostered by the European Union cooperation policies. The EU Commission supported these CoEs, identified by NEPAD and organized in three networks: the NEPAD Southern African Water Centres of Excellence (SANWATCE coordinated by the University of Stellenbosch), the NEPAD Western African Water Centres of Excellence (WANWATCE coordinated by University of Cheick Anta Diop of Dakar) and the NEPAD Central and Eastern African Water Centers of Excellence (CEANWATCE, coordinated by the Water Resources Center of the University of Khartoum)

By scaling up method and approach of the pilot phase, the “NEPAD African Network of Centers of Excellence on Water Sciences and Technology (II phase) 2016-2020“, thereafter “ACEWATER2” project, is aimed at fostering the network of NEPAD Water CoEs in their development of a collaborative approach improving their capacities and strengthening their role in supporting water sector development. This action focuses on higher education and scientific research in the water sector.

The target groups include a range of different users/beneficiaries:

- the students as users of the Centres of Excellence;
- the continental institutions such as NEPAD and AMCOW;
- the RECs (Regional Economic Communities) and in particular ECOWAS (Economic COmmunity of West African States), IGAD (InterGovernmental Authority on Development) and SADC (Southern African Development Community);
- the RBOs (River Basin Organizations) and in particular OMVS (Organisation pour la mise en valeur du fleuve Sénégal), ZAMCOM (Zambezi Watercourse Commission), NBA (Niger Basin Authority) and NBI (Nile Basin Initiative);
- other african and international Institutions, as development and cooperation agencies, governments, water users, local authorities, NGOs, etc.

One of the most relevant objectives of the ACEWATER2 initiative, is to strengthen institutional networking and improving research support to policy making in the water sector. Currently, the project is implementing a policy-driven dialogue with relevant River Basin Organizations in Africa (ZAMCOM, OMVS and NBA) leading to the implementation of research and technical activities to support decision making processes. In particular, the three different networks of CoEs in Western, Eastern and Southern Africa (WANWATCE, CEANWATCE and SANWATCE) are currently developing innovative research projects in pilot river basins, selected for their relevance at regional level (the Senegal, the Niger, the Nile, and the Zambezi respectively). Within these projects, the WEFE nexus as well as the climate change/variability assessments are performed, according to the needs and priorities as set up by the relevant regional policy and decision makers.

In this framework, available transdisciplinary data useful for collaborative research are collected, relevant to, among others, environmental and resource sustainability assessment, climate variability impact analysis, water resource security related to water/energy/food security nexus, as well as the development of the regional African Atlas of Water Cooperation (Farinosi et al, 2017).

Abstract

The report presents the implementation, in the framework of the ACEWATER2 project, of a regional hydro-climatology information system. The information system is aimed at sharing metadata and data relevant to the scientific undertakings of the CoEs (Centers of Excellence), including both freely available large and regional data sources, as well as databases submitted by the CoEs themselves as part of their scientific undertakings.

The information system builds upon the JRC knowledge sharing platform Aquaknow (https://aquaknow.jrc.ec.europa.eu/), including:

- at the system core, a relational database: its schema has been designed to store both detailed metadata and, where relevant (avoiding duplication of information otherwise accessible) data themselves. Metadata include, among others, datasets' extended description, spatial extent, temporal frequency, reference Institutions/authors, credits and limitations, web links to access original data and/or any further documentation. Data can be stored as public or private, depending upon confidentiality and sharing policies. At the lower level, datasets are organized in the file system, based on a logical structure.
- user friendly facilities, supporting the end user in efficiently browsing, querying, uploading and downloading information (metadata and data). System access is limited to accredited audience, via password authentication. Dedicated groups for the three ACEWATER CoE networks (Western, Southern and Central-Eastern Africa) have been setup and scientists invited to register. Currently the system is operational, CoE databases documented and, depending upon confidentiality and authorization constrains, also uploaded.

The information system is conceived to efficiently manage complex datasets. Still, as the authorized users can upload their own datasets, the control over their consistency mainly remains under the responsibility of a centralized review. No specific constrain is enforced, both in terms of data formats and/or structure. Massive and/or regular data update, as is it would be the case for data collection at monitoring networks and/or analyses at laboratory facilities, demands for the adoption of more advanced technological paradigms. Although not implemented at this stage, the solution relies upon spatial databases. Hence the report also includes a brief review of existing options and delineates a proposal on the way forward.

A general review and classification of freely available information at continenal, regional and local scale, of relevance to ACEWATER2 project, has been conducted. Metadata and, where relevant, data themselves have been stored in the information system database. Information submitted by the CoE, as part of the continuous scientific research process, is migrated to the database as well, depending upon sharing authorization or limitations, focusing on the selected study areas (Senegal, Gambia, and Niger; Zambezi; Blue Nile and Lake Victoria).

The report also documents the ongoing scientific research at JRC on Climate Variability (CV) analysis based on L-Moments statistics. Estimated precipitation deficit for different return periods and heat waves maps at the river basin scale for the areas of interest are presented in this report and included in the database. The analysis complements the contributions on CV from few leading CoEs, namely Botswana Un. and UCAD, respectively for the Zambezi and the Senegal-Gambia river basins. Introduction

Current document presents the hydro-climatology information system developed in the framework of the ACEWATER2 project, in order to effectively support scientific undertakings.

Actually the hydro-climatology information system encompasses different components:

- A GUI (Graphical User-friendly Interface), developed in the framework of an existing Knowledge sharing platform named Aquaknow, facilitating the end user in querying, accessing and downloading stored data, further to uploading new datasets organized within dedicated protected working groups;
- A spatio-temporal database, providing both metadata and (where relevant) data themselves, covering both freely available continental and regional scale datasets, and data compiled by CoE in the framework of their scientific undertakings.

The design and implementation of the information system and related database is rooted upon the evidences emerged and documented during a previous analysis phase (Crestaz et al., 2017). Datasets, documented and partly collected at that stage, have been updated and properly integrated, in the light of newly available free datasets and outcomes of ongoing scientific research activities implemented by the CoE.

The database organizes information (metadata) (Figure 1) on a wide spectrum of data, based on a rough classification accounting for the following categories: agriculture, climate, demography, geology, ecosystem, energy, hazards, health, hydrology, land, infrastructure, politics, socio-economy, soil, topography and transport.

Metadata contains detailed information as, among others: short dataset description, spatial and temporal coverage, web links from where data can be accessed, copyright and confidentiality issues. Metadata typically provide an entry-point to the original data sources, in order to avoid any unnecessary duplication on the Aquaknow servers.

Still, where relevant, data themselves can be stored within the information system; this typically applies to:

- Freely available datasets, whose access by end user is facilitated through the facilities provided by Aquaknow, compared to the original web sources;
- Data provided by the CoEs, namely for the Zambezi, Senegal, Gambia, Niger, and Nile (Blue Nile, Victoria lake) river basins.

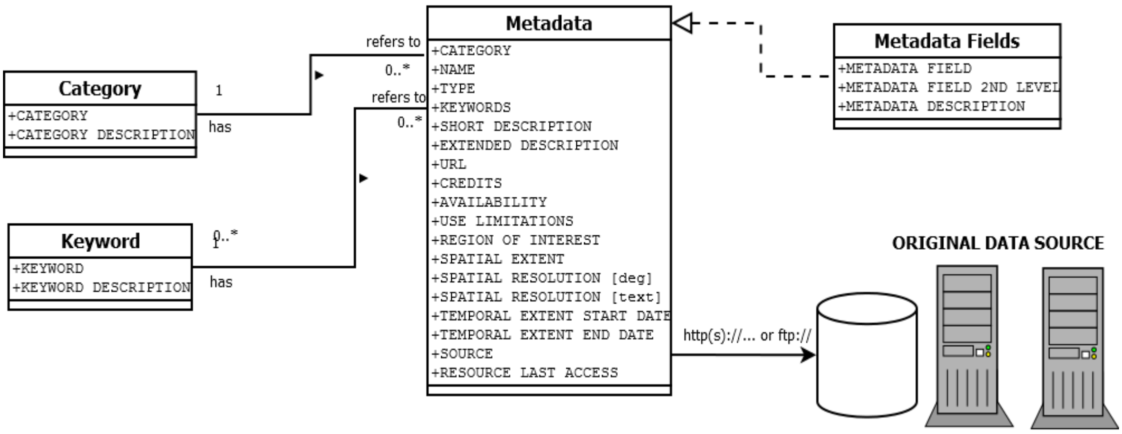

Figure 1 Conceptual schema of metadata organization

Following chapters address:

- Information system, database architecture and implementation, further to a review of key spatial databases concepts and options;
- Database contents;

- Climate variability and heat waves analysis for the river basins under consideration;
- Conclusions and the way forward.

1 Information system architecture

1.1 Aquaknow knowledge sharing platform

AquaKnow (Figure 2) is a tool designed and implemented in the framework of a European Union Water Initiative (EUWI) managed by the Joint Research Centre.

It is a collaborative workspace and CMS (Content Management System) dedicated to sharing technical and scientific documents, data, tools and knowledge relevant to the sustainable development of the water sector.

The GUI, developed using a responsive design, is simple, easy to use and fast, granting access from both desktop and mobile devices. Contents are easily manageable, searchable and usable, also thanks to the multi language support, providing automatic translation for the three currently supported languages: English, French, and Spanish. Users can easily select the language through the drop down menu in the GUI top right corner.

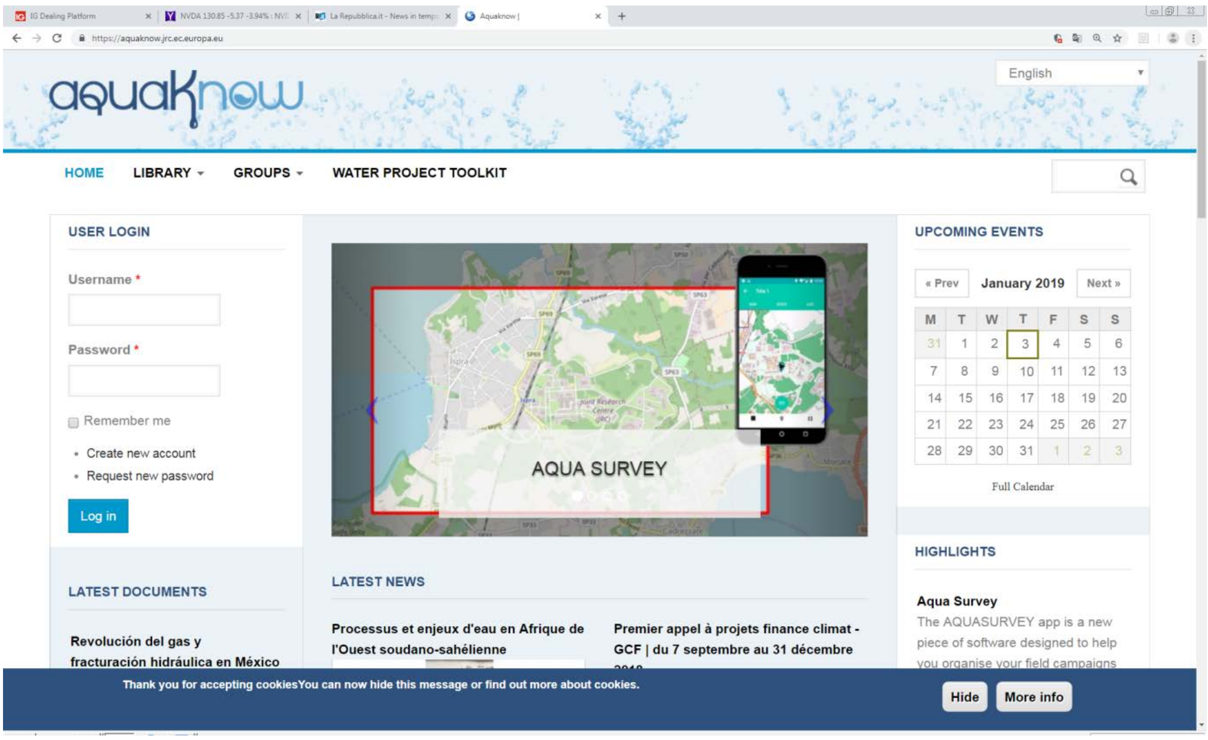

Figure 2 Aquaknow GUI

Facilities were implemented to support the management of system users, who can be roughly classified in the two distinct categories of anonymous and registered users.

Anonymous users do not need any registration, they have access only to the public contents and cannot post their own contents online.

On the other hand, the registered users are permitted to post their own contents and can create and access private contents, explicitly limited to the authorized group(s). Users can register by simply filling the forms below (Figure 3; Figure 4; Figure 5); registration is activated subject to the approval of the system administrator.

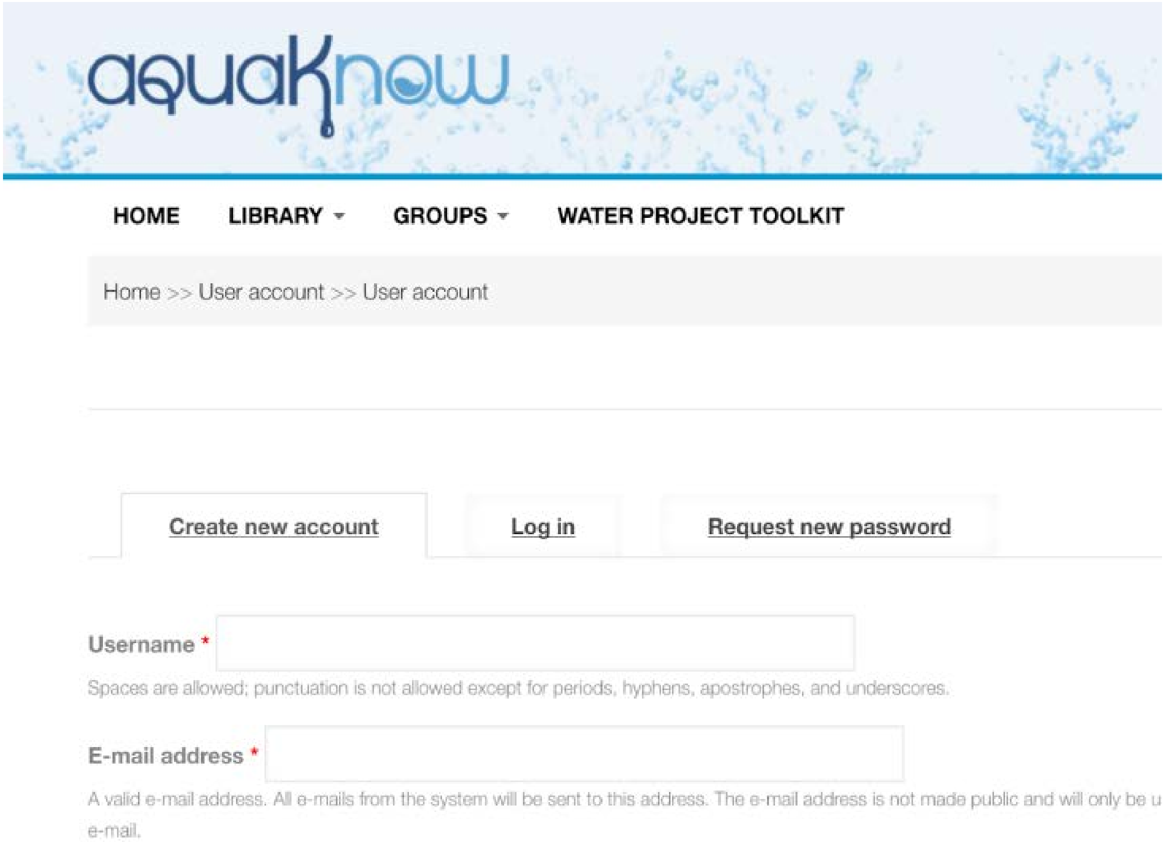

Figure 3 Aquaknow user registration: new account window creation

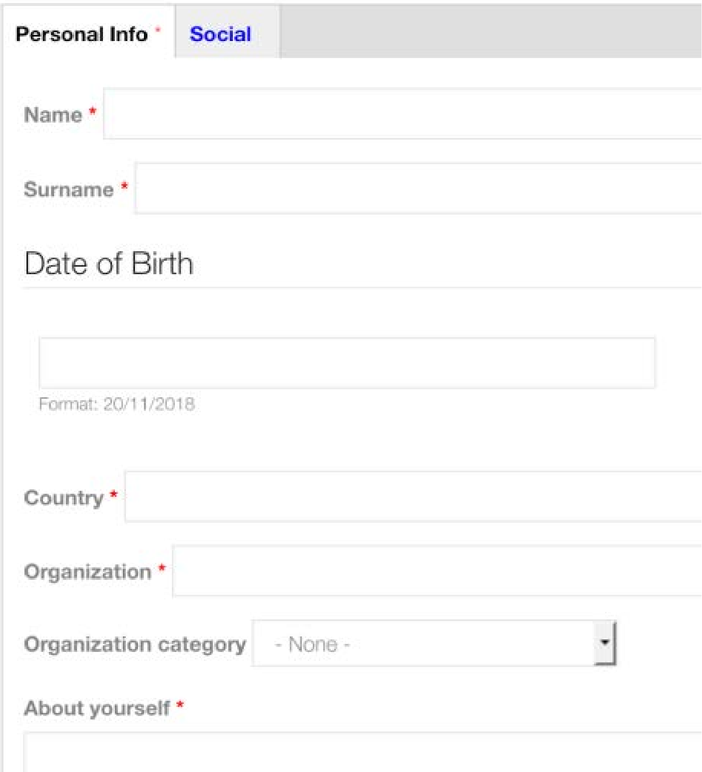

Figure 4 Aquaknow user registration: personal Info

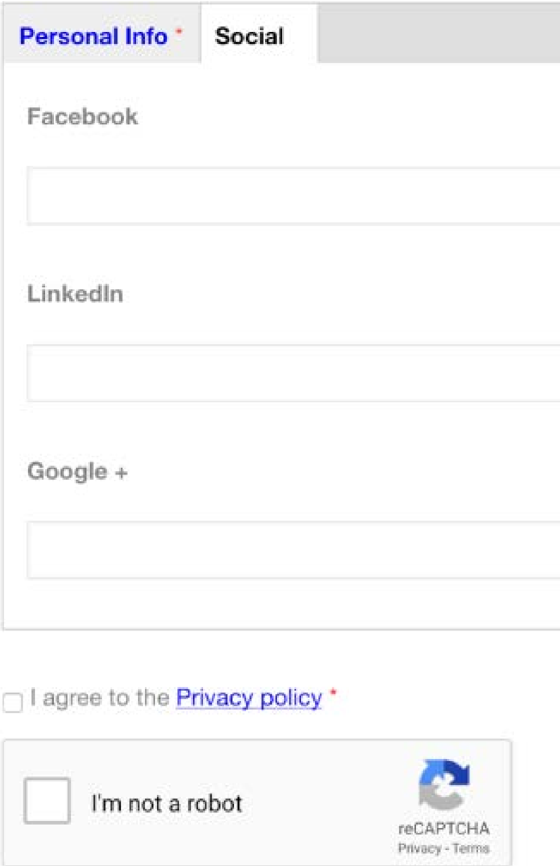

Figure 5 Aquaknow user registration: social networks links

Registered users can login into Aquaknow web platform, post their own contents and access authorized contents. They have two distinct options:

Contents can be shared publicy or privately, if they need to be protected. Two distinct strategies can be adopted:

Operationally, registered users login into Aquaknow, access authorized contents and post their own contents, publicy or privately.

Publicy shared contents are available to any user, including anonymous ones.

Privately shared concents are accessible to a restricted group of users only.

When posting public contents, different trail can be followed:

1. create public content as document, news, event, etc., on the main pages of Aquaknow (i.e. https://aquaknow.jrc.ec.europa.eu/news); posted content will be accessible to every users, even the anonymous ones.
2. create, or subscribe to, a public working group (WG), that's a public web space whose contents can be restricted to its members only. Once a public WG group is created, users can be sent a membership request or they can be added by the group creator.

When posting private contents, two distinct pathways can be followed:

1. create shared content ("share content" action) and identify registered Aquaknow user(s) to whom the contents are expected to be made available;

once the process is completed, the targeted audience is notified by email and can access the content through the platform;

2. create, or subscribe to, a private working group (WG), that's a web space whose access is restricted to its members only. Once a private WG group is created, users can be added by the group creator only, on an invitation basis, mainly for privacy and contents protection reasons.

Both options above benefit from the Aquaknow advanced data protection features, one of the main reasons for which the platform has been selected in the framework of the ACEWATER2 project.

Posting users declare their ownership or the right to use and to share uploaded contents, the action being entirely under their responsibility.

In the framework of ACEWATER2, a custom content type has been designed and developed. In the context of Aquaknow it is named "dataset" and its concept referring to both data and related metadata.

Users posting datasets are expected to compile full metadata, including, among others, information on the group audience, meant as the working group for which contents are made accessible, in case these are available and could be disseminated. A full list of requested information and related descriptions is summarized in the following table (Table 1).

Field	**Description**
TITLE	Title of the dataset appeared, as it shows up on Group page
CATEGORY	Category of the data set
NAME	Identification Name of the dataset
TYPE	Type of the data set (if specified) (e.g. raster, vector)
FORMAT	Format of the data files to be downloaded (e.g. tif,shp,txt,xls,zip,...)
KEYWORDS	Keywords of the data set
SHORT DESCRIPTION	Dataset short description
EXTENDED DESCRIPTION	Dataset extended description
URL	Data set web page URL
CREDITS	Credits and references to peer-reviewed publication where the dataset was published.
AVAILABILITY	Brief summary on the availability of the data set (i.e. «FREE», «REGISTRATION REQUIRED», «PRIVATE»,«PAID ACCESS» or «NOT ACTUALLY AVAILABLE»)

USE LIMITATIONS	Terms and conditions of use of the data set
REGION OF INTEREST	Textual description of the area covered by the data set (spatial extent) (e.g. «Africa», «Southern Africa», «Africa and Europe» ,«World»)
DATASET SPATIAL EXTENT [deg]	Area covered by the data set expressed as a geospatial extent with longitude and latitude coordinates (for instance .«-180, 180, -90, 90 (xmin, xmax, ymin, ymax)(W,E,S,N)» if the region of interest is «World») . The coordinate reference system is EPSG 4326 (+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs)
SPATIAL RESOLUTION [deg]	Spatial resolution expressed in degrees (deg) when available
SPATIAL RESOLUTION DESCRIPTION [text]	Human-readable textual description of the spatial resolution
TEMPORAL EXTENT - START DATE	Temporal extent – start date of the data set (if the data set is dynamic). Date format must be in ISO 8601
TEMPORAL EXTENT - END DATE	Temporal extent – end date of the data set (if the data set is dynamic). Date must be in ISO 8601 standard format
TEMPORAL FREQUENCY	Temporal resolution of the data set (i.e. «static», «none», «not specified» «multi-year», «yearly», «multi-month» , «monthly», «multi-day», «daily», «sub-daily»)
SOURCE	Source of the dataset (in most cases it is the URL of the web page from which the dataset can be directly downloaded)
RESOURCE LAST ACCESS	Latest day when the dataset URL was visited and verified.
GROUPS AUDIENCE	The name of the group of users that can access the dataset (e.g. NEPAD SANWATCE, NEPAD WANWATCE and NEPAD CEANWATCE)
DATASET FILE	Compress archive file for the dataset containing all data and related metadata
DATASET IMAGE	Symbolic image used as a dataset icon within Aquaknow.

Table 1 Datasets metadata

1.2 Information system design and implementation

The Aquaknow knowledge platform has been developed using Drupal 7, the open source PHP standard framework adopted by the European Commission to build web applications.

Drupal is a content management software; it has great standard features, like easy content authoring, reliable performance, and excellent security. But what sets it apart is its flexibility, modularity being one of its core principles. Its tools help to build the versatile, structured content that dynamic web experience demands for.

It's also a great choice for creating integrated digital frameworks. You can extend it, thanks to thousands of available add-ons. Modules expand Drupal's functionality. Themes let you customize your content's presentation. No other content management software is so powerful and scalable.

Drupal is an open source software. Anyone can download, use, work on, and share it with others, for free, no licensing fees being due. It's built on principles like collaboration, globalism, and innovation. It's distributed under the terms of the GNU General Public License (GPL).

Drupal uses databases to store the contents and platform configurations and therefore requires software such as MySQL or PostgreSQL.

In the specific case, datasets are managed through a set of MySQL tables, following the Drupal standard organisation. The relational schema is organized around a series of tables, listed here below and splitted in order to improve the readability, (Figure 6, Figure 7,Figure 8 and Figure 9 .

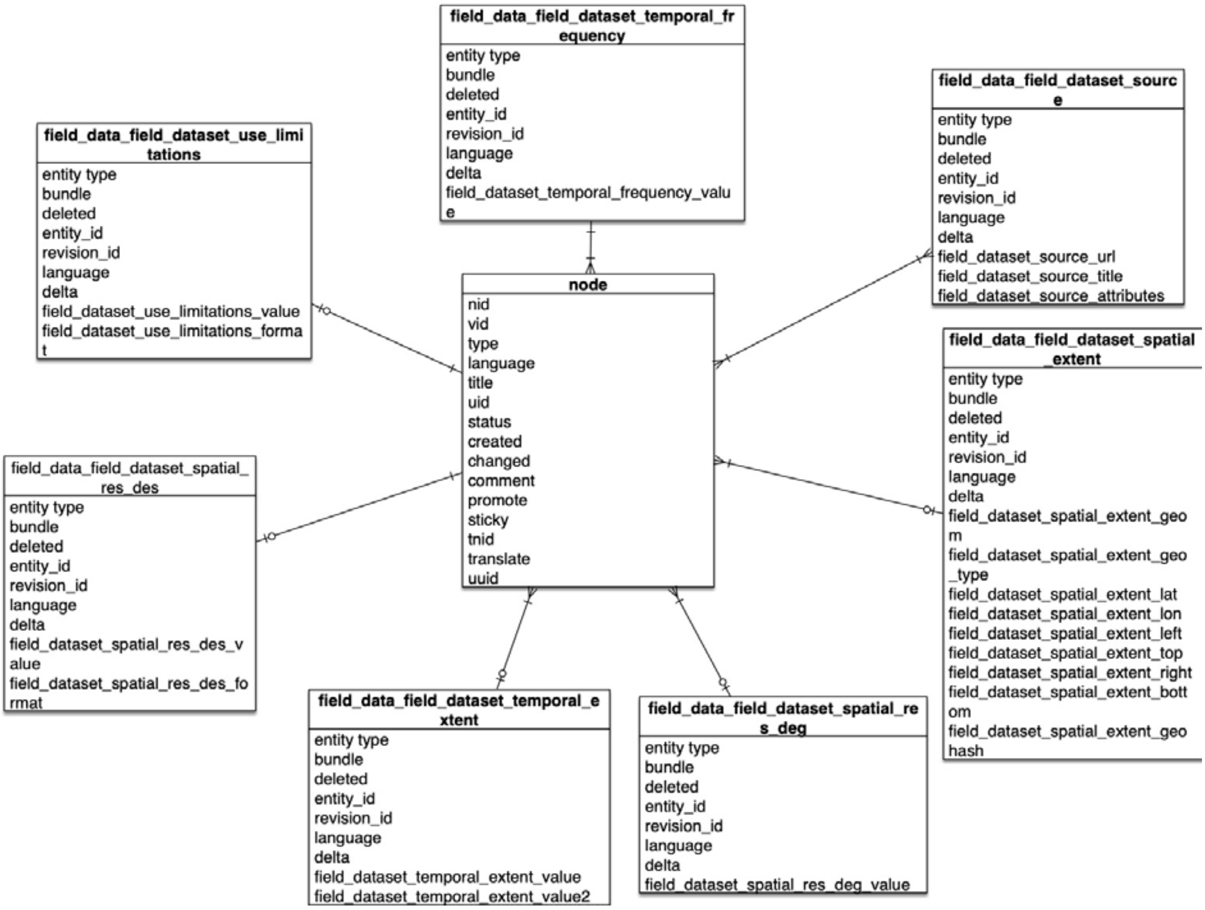

Figure 6 MySQL Metadata Fields relational tables (1/4)

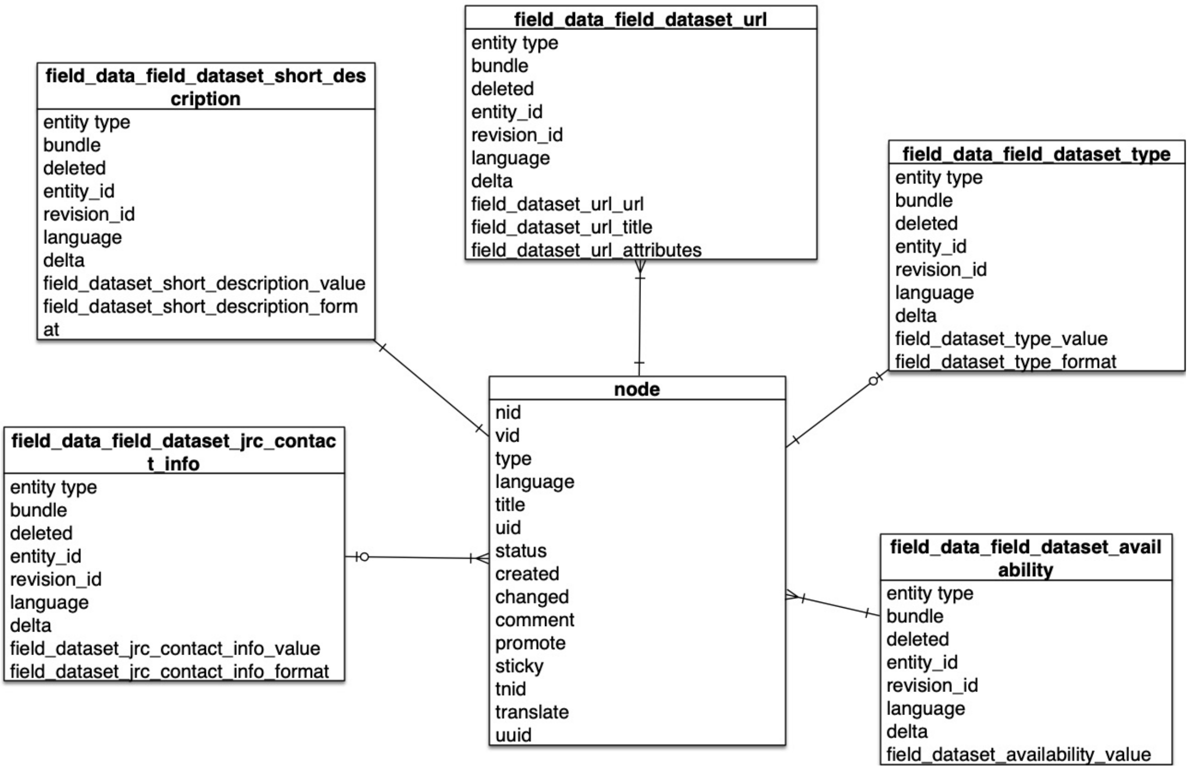

Figure 7 MySQL Metadata Fields relational tables (2/4)

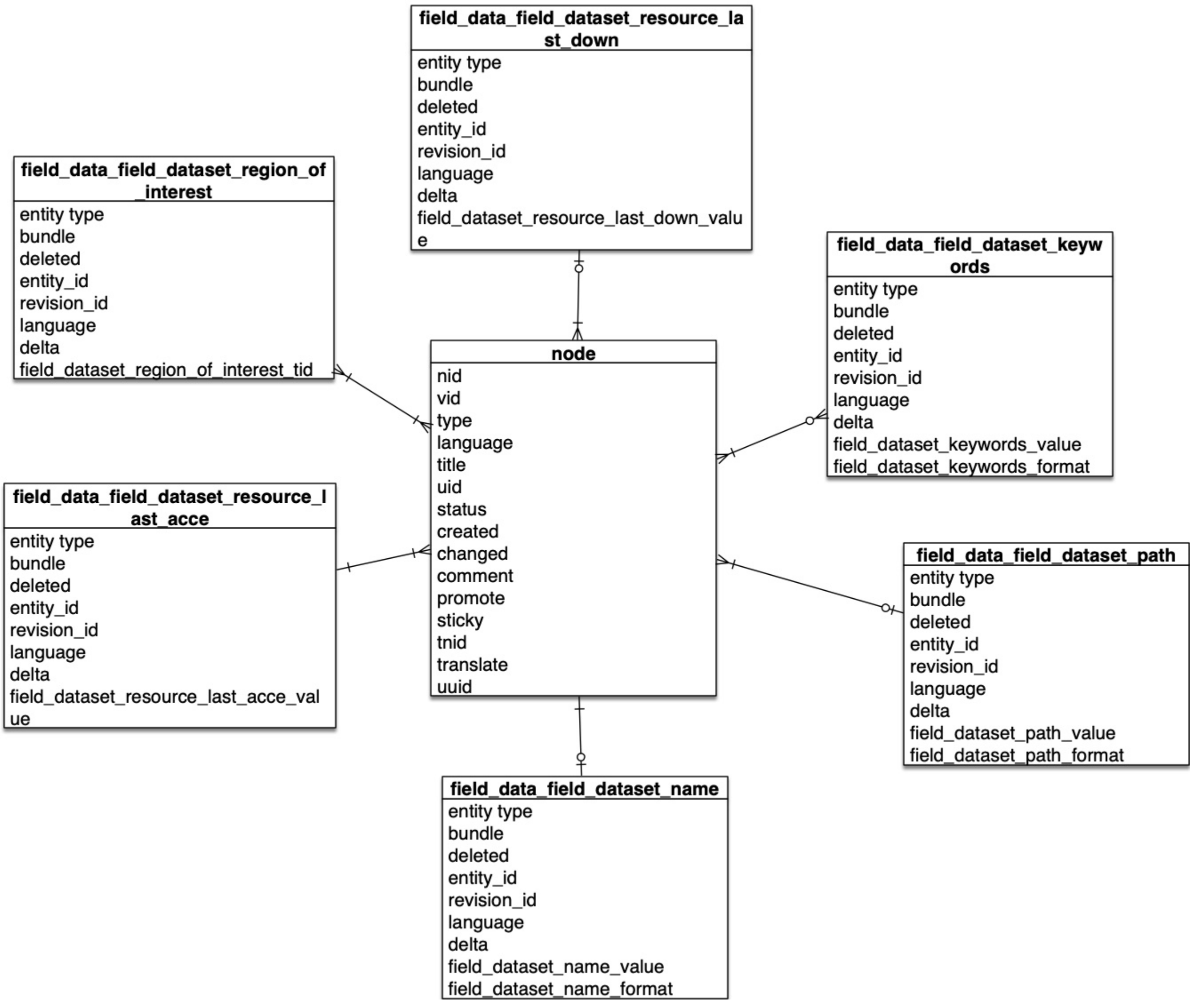

Figure 8 MySQL Metadata Fields relational tables (3/4)

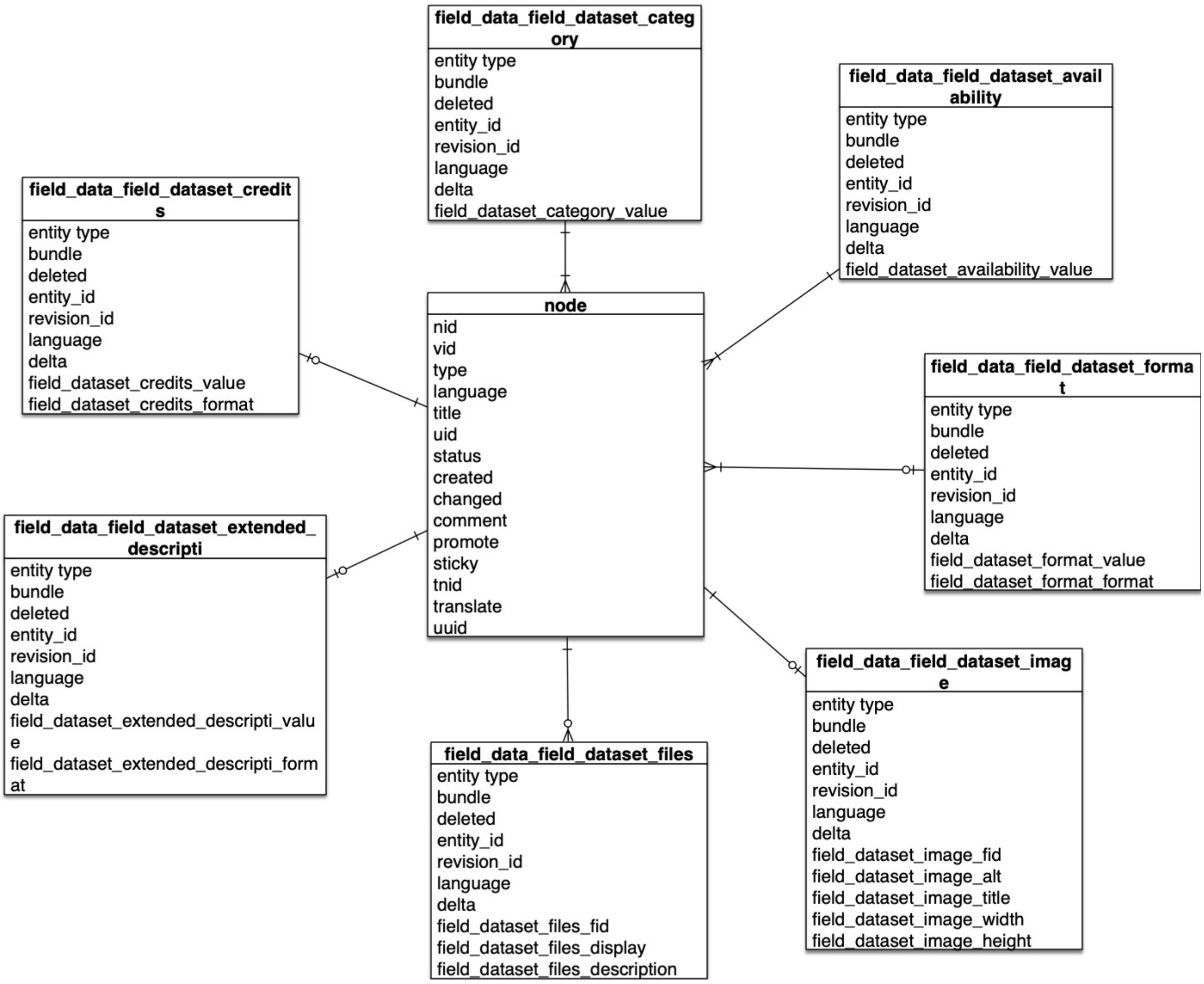

Figure 9 MySQL Metadata Fields relational tables (4/4)

ACEWATER2 members can access the database to view and/or download the shared datasets, consistently with the permissions originally granted by the owner.

Anonymous users accessing Aquaknow are allowed to perform the following actions (Figure 10):

- Viewing public Working Group dataset list;
- Searching public datasets, if any;
- Viewing public dataset;
- Downloading public datasets, if allowed by the dataset use conditions.

Hence anonymous users are not granted the access to private groups contents, nor to any other user's owned content, if not explicitly authorized.

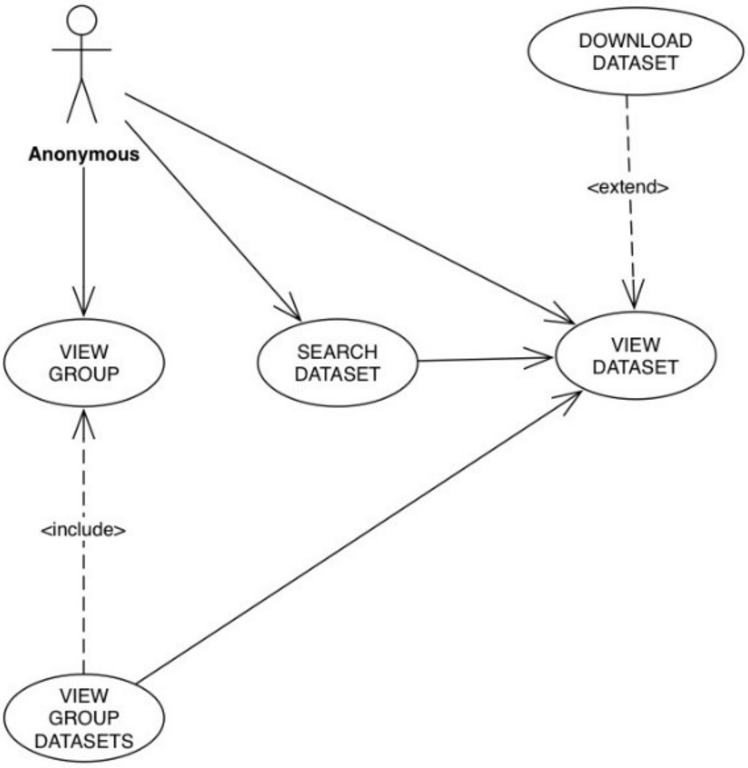

Figure 10 Anonymous User actions

Three private groups have been set up for the Western, Southern and Central-Eastern Africa. Logged users can perform the following actions (Figure 11):

- Viewing public Working Groups or groups in which he/she has the membership;
- Viewing Working Group dataset list;
- Searching dataset for which the user has the visualisation permissions, e.g. the datasets of his/her group(s) and public datasets, if any;
- Viewing datasets;
- Downloading the datasets;
- Leaving a comment on the Datasets' page.

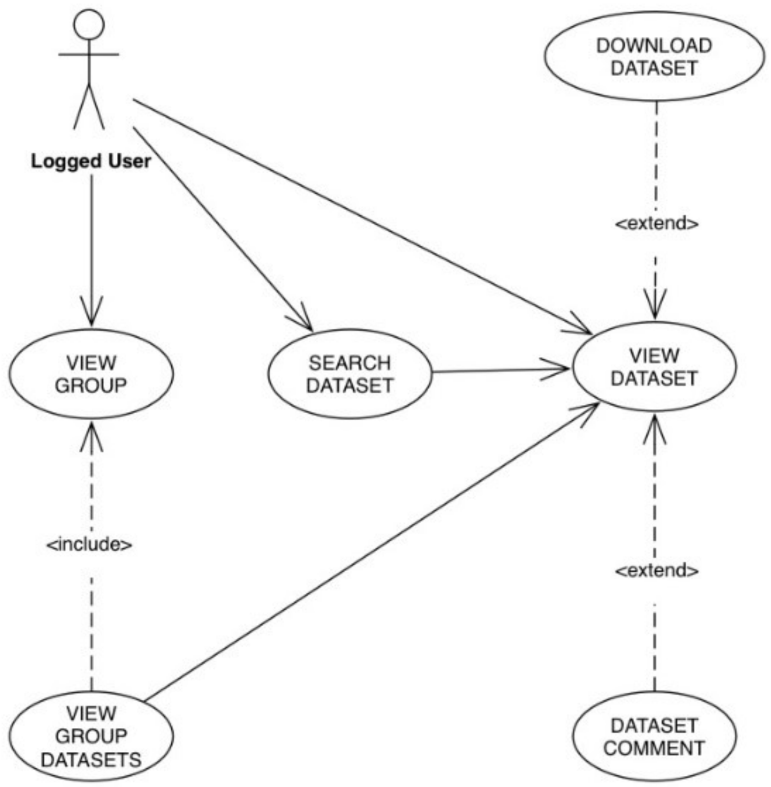

Figure 11 Logged User actions

Users posting datasets become the content owners and they can perform the following actions (Figure 12):

- Viewing public Working Groups or groups of which they have the membership;
- Viewing Working Group dataset list;
- Searching datasets for which the users have the visualisation permissions, e.g. the datasets of his/her group(s) and public datasets, if any;
- Viewing such datasets;
- Creating their own datasets
- Editing/Deleting their own datasets, this means that they can always correct or update the metadata and the dataset archive file; additionally they can set which groups can access their own dataset;

- Downloading all datasets of their group, for which they have been granted the viewing permission (including the owned datasets);
- Leaving a comment to such datasets.

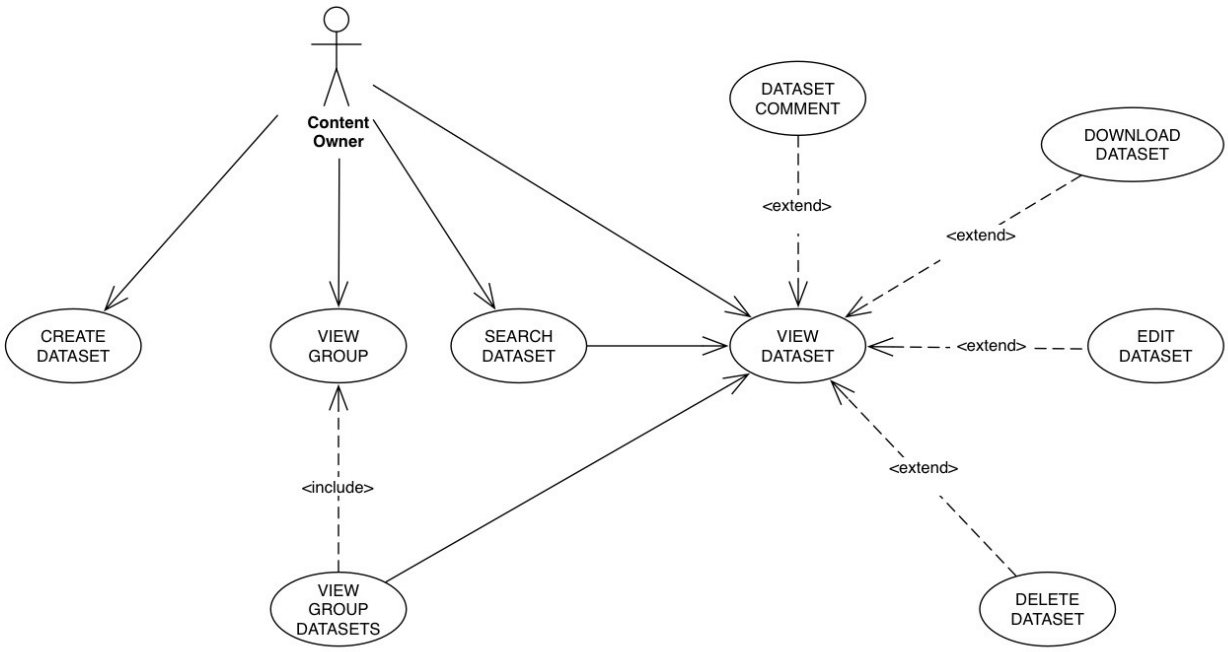

Figure 12 Content owner User actions

Dataset permissions are managed by Aquaknow in accordance with the agreed conditions. ACEWATER2 datasets are private and shared only among the NEPAD SANWATCE, WANWATCE, and CEANWATCE working groups. All members of one of these three groups can view and use shared data for his/her research activities. Metadata of publicly available global datasets are shared through all the three groups.

Aquaknow screenshots documenting the process of dataset adding are provided here below (Figure 13, Figure 14 ,Figure 15 , Figure 16, Figure 17, Figure 18).

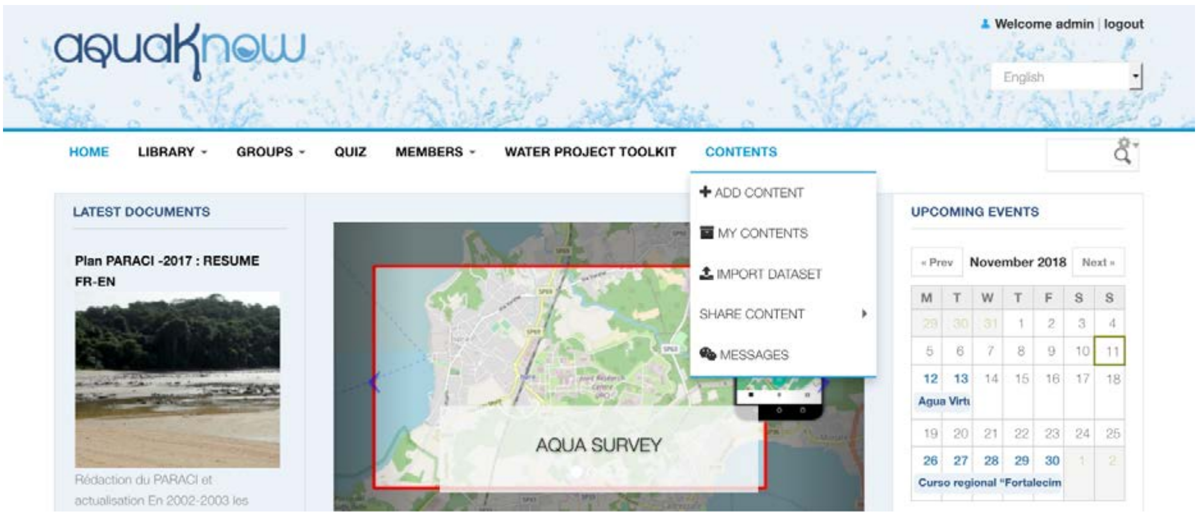

Figure 13 Aquaknow: dataset adding (1/6)

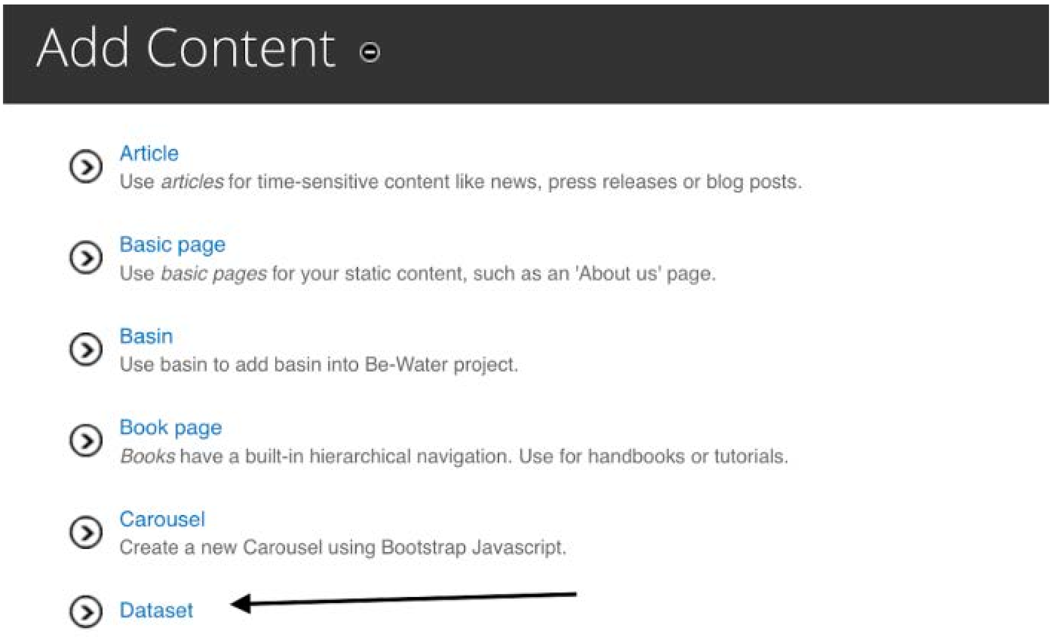

Figure 14 Aquaknow: dataset adding (2/6)

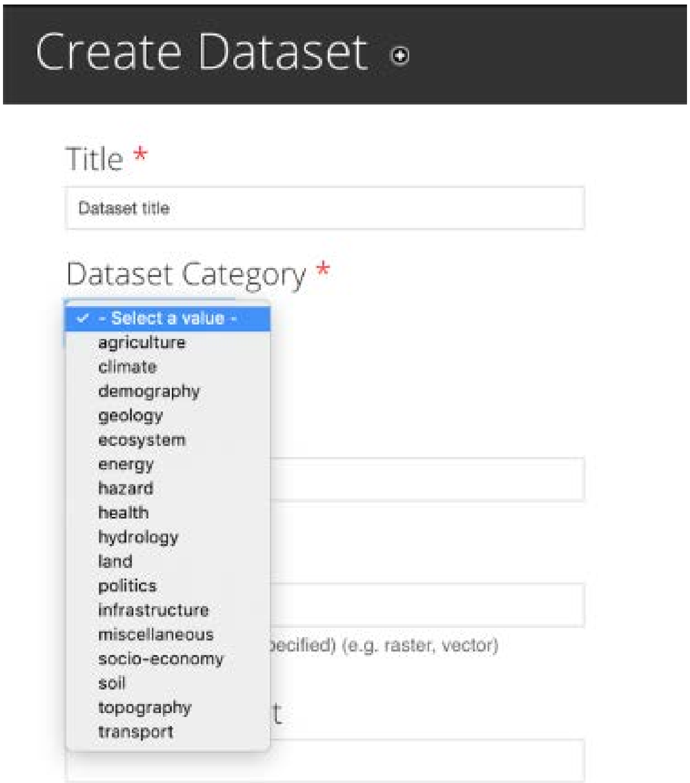

Figure 15 Aquaknow: dataset adding (3/6)

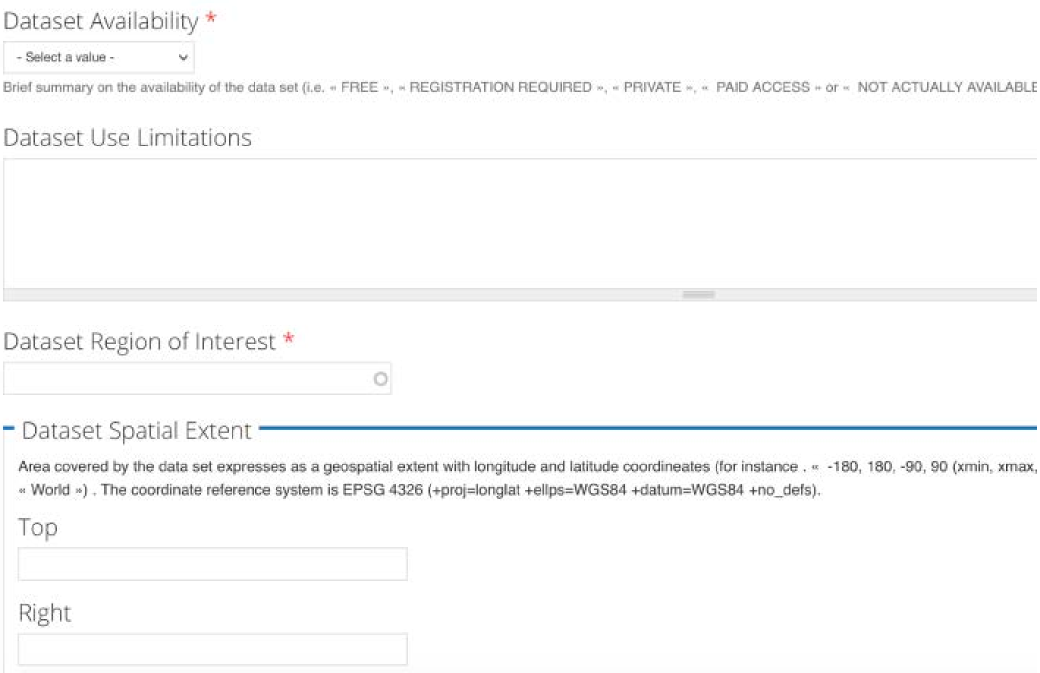

Figure 16 Aquaknow: dataset adding (4/6)

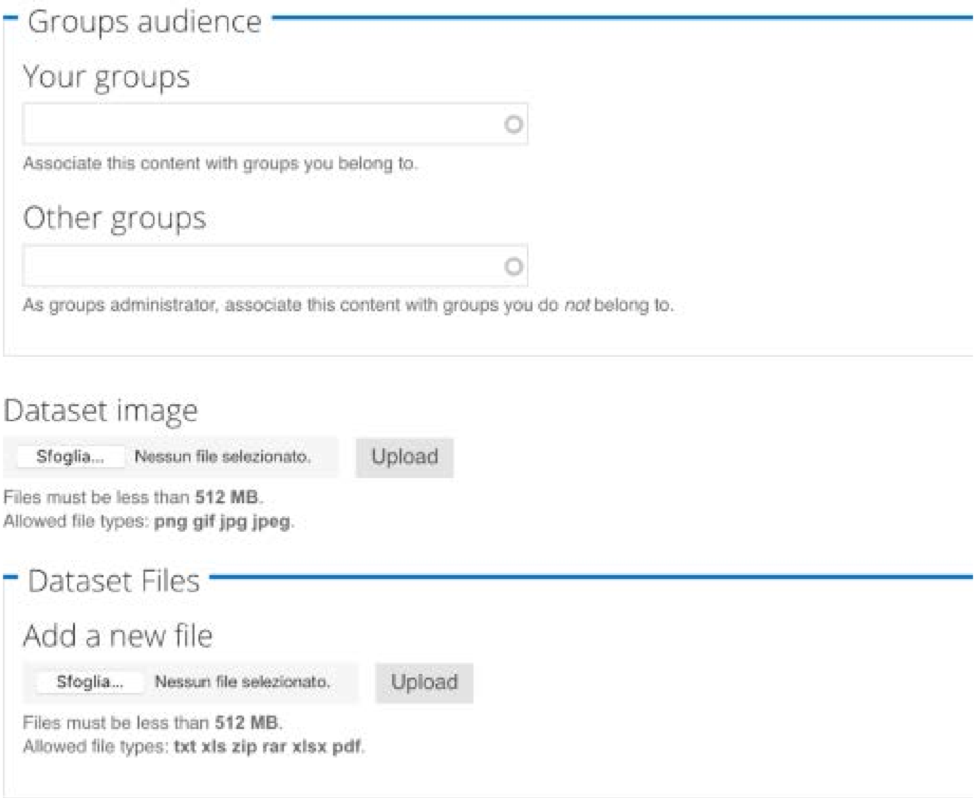

Figure 17 Aquaknow: dataset adding (5/6)

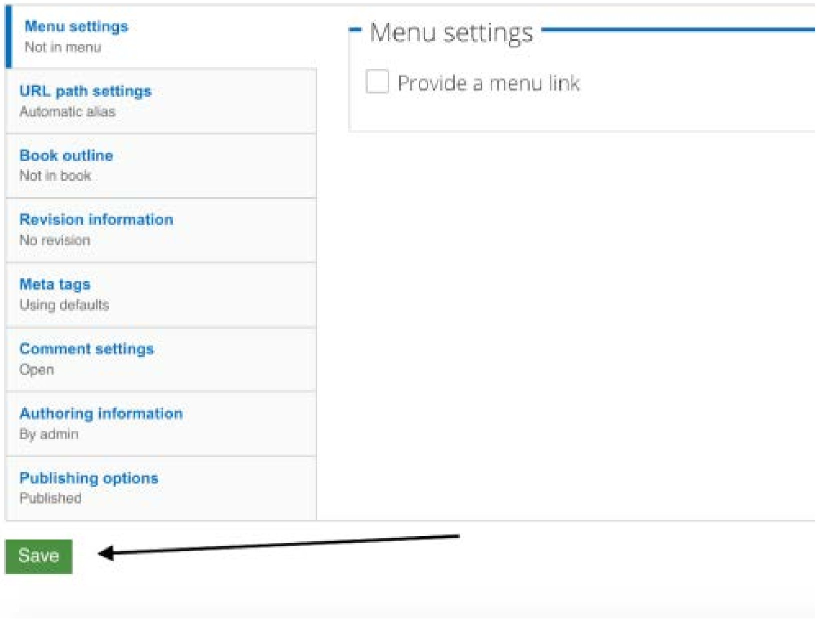

Figure 18 Aquaknow: dataset adding (6/6)

A snapshot of the system user interface reporting datasets information is provided here below (Figure 19). The example refers to monthly CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) (Funk et al, 2015) precipitation datasets. A map viewer captures the dataset geographical extent, worldwide between -50S and 50 N degrees).

climate::chirps::Monthly CHIRPS Precipitation Dataset

By admin 0 Comments

Dataset Category:
climate
Dataset name:
chirps
Dataset Type:
raster
Dataset Format:
geotiff
Dataset Keywords:
RAIN
Dataset Short Description:
Monthly CHIRPS Precipitation Dataset
Dataset Extended Description:
Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 30+ year quasi-global rainfall dataset. Spanning 50°S-50°N (and all longitudes), starting in 1981 to near-present, CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.
Dataset URL:
http://chg.geog.ucsb.edu/data/chirps/
Dataset Credits:
Funk, Chris, Pete Peterson, Martin Landsfeld, Diego Pedreros, James Verdin, Shraddhanand Shukla, Gregory Husak, James Rowland, Laura Harrison, Andrew Hoell & Joel Michaelsen. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Scientific Data 2, 150066. doi:10.1038/sdata.2015.66 2015. http://chg.geog.ucsb.edu /data/chirps/index.html
Dataset Availability:
FREE
Dataset Spatial Extent:

Dataset Region of Interest:
World
Dataset Spatial Resolution Description:
about 5 km
Dataset Spatial Resolution Degree:
0.0500000000
Dataset Temporal Extent:
Thursday, 1 January, 1981 to Tuesday, 31 January, 2017
Dataset temporal frequency:
monthly
Dataset Source:
ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/global_monthly/tifs/
Dataset Last Access:
Friday, 25 August, 2017
Dataset JRC Contact Info:
cesar.carmona-moreno@ec.europa.eu
Dataset Path:
climate/CHIRS/data/montlhly/tif
Groups audience:
ACEWATER2_JRC
NEPAD SANWATCE
NEPAD CEANWATCE
NEPAD WANWATCE

Figure 19 Example of Aquaknow Dataset content, e.g. Monthly CHIRPS Precipitation Dataset.

In the framework of the ACEWATER2 project, NEPAD CoE have been registered as Aquaknow users (Crestaz et al, 2018), being members of one of the three different groups:

- "NEPAD SANWATCE", for Southern Africa CoEs;
- "NEPAD WANWATCE", for Western Africa CoEs;
- "NEPAD CEANWATCE", for Central and Eastern Africa CoEs.

A list of people being granted access to each network group is maintained centrally by the system administrator. New system access requests can be submitted to JRC; upon approval, the system administrator will update the proper authorization list[1].

1.3 Spatial databases

1.3.1 General framework

Current Aquaknow datasets organization in the file system by category (directory) perfectly fits the needs and requirements of a large and highly variable data collection. No integrity rules are enforced, hence the maintenance of the database integrity largely relies upon consistency checks performed by both system users, before dataset uploading, and system adminstrator(s), in the framework of centralized control policies.

Regarding the future perspectives, specific data management needs are likely to emerge, as for the support to continuous update of data regularly collected by the monitoring networks or provided by laboratory analyses. This is an operational perspective, demanding for additional efforts towards the design and implementation of dedicated spatial database and services (e.g for data cleaning and tidying tasks).

Hence, aside of the implementation activities in the Aquaknow Knowledge sharing platform, a review of different spatio-temporal database options was conducted. A spatio-temporal database enables the storage, uploading and querying of vector spatial data and related time series. Typically based upon a relational database engine (Codd, 1970; Connolly and Begg, 2010) and, ideally, a spatial engine (Obe and Hsu, 2011), such a system supports effective geographic information management, further to enforcing classic data integrity rules to limit risks of data consistency and duplication failure.

An assessment of the different existing options has lead to the identification of two main groups, namely:

- database proprietary infrastructures;
- native spatial databases.

Major outcomes of this analysis are summarized in the following sub-sections.

1.3.2 Database proprietary infrastructures

The category of proprietary spatial databases cover a wide spectrum of options, still one of the most well known being the ESRI geodatabase.

Basically, the ESRI geodatabase is a concept and a generalized architecture framework, rather than a unique database implementation. Geodatabases are tight coupled with the classical ESRI GIS tools, as ArcCatalog and ArcMap. Their implementation rely upon different underlying database engines, ranging from single user solutions, as the MsAccess (Personal geodatabase in the ESRI jargon), to multi-user concurrent enterprise databases, as Oracle and PostgreSQL. The geodatabase concept extends even beyond, with the data being stored to the file system in an alternative single user configuration (file geodatabase), to address the traditional 2GB storage limitation of the personal geodatabase.

[1] Aquaknow web site address: https://aquaknow.jrc.ec.europa.eu/ System access request should be submitted to the person referred in the contact information (page following the front page)

The key point with the ESRI geodatabase is that the proprietary GIS tools keep the control over the underlying data storage structure, whether it is the file system or the database engine itself. This implies advantages, mainly that the high level GIS tools on top provide easy to use and fully integrated features to design and build the database, as well as to visualize, query and upload the spatial data. On the other hand, major drawbacks exist as well, the most relevant being the reduced flexibility in freely coupling different tools.

Where licensing costs is a major concern, the above limitations can strongly impact on the architecture scalability at corporate/organization level and definitely limit the wider adoption of geospatial solutions.

Geodatabases' technical specifications were released by ESRI, as well as in the case of the shape file format. Hence, accessing the geodatabase from external tools, as Open Source GIS or analysis environments as QGIS and R, can be performed. Still, the seamless integration based on standards promoted by the Open Geospatial Consortium (OGC, 2018) is not as easy, and native spatial databases look like to be far more promising.

1.3.3 Native spatial databases

The native spatial databases are databases providing their own native spatial data management facilities. From the technical point of view, this means that they can be implemented indipendently from any GIS tools on top. They can be generally accessed through the commonly used GIS tools, as ArcGIS and QGIS; sometimes with limitations, as read only permissions in ArcGIS depending upon license, or even with advantages, as is the case for QGIS which has originally been conceived as a GIS interface to the PostgreSQL/PostGIS database engine.

The spatial data management facilities, we referred to above, include:

- support to spatial attributes (geometry, spatial reference system);
- spatial indexing, as RTree algorithms, key to efficient spatial data querying;
- spatial data uploading, as geospatial data transfer from ESRI shape files to the database;
- and, last but not least, support to extended spatial SQL (Standard Query Language).

Most of the time, the extended spatial SQL support, mentioned above, goes far beyond the traditional querying features, providing rich toolsets of geospatial functions addressing both common and advanced geoprocessing tasks, otherwise available only in traditional GIS environments. Among these functions, just to mention few of them, merging, point-in-polygon querying, distance computation, supporting both planar projected and sphreoid coordinates. Thanks to these features, the native spatial databases turn to be powerful geospatial analysis environments, largely overlapping with the traditional GISs.

Leading proprietary and Open Source database systems, as Oracle and PostgreSQL/PostGIS, candidate as the most advanced native spatial database platforms available. As you may notice, which by the way is somehow confusing for not database audience, the same databases can alternatively be used as relational engines controlled by proprietary systems, as is the case for the ESRI GIS platform above, or as native spatial databases on thei own.

The choice to adopt native spatial databases instead of proprietary database architectures, as the ESRI geodatabase, has many complex implications, ranging from the issue of licensing costs/availability, specific expertise at hand, maintenance costs and geospatial solution desired/expected flexibility.

Indipendently from the selection of underlying database engine, various and efficient spatio-temporal database schemas have been designed for water and environmental data management. Among them, the Hydro data model (Figure 20), jointly designed by ESRI and Austin Un (TX, USA) (Maidment, 2002) and implemented within the proprietary ArcGIS platform, turns to be an optimal candidate for spatio-temporal data management. The hydro data model is relatively easy to implement in an Open Source framework (Crestaz, 2014; EAR diagram in Crestaz et al., 2015; Figure 21).

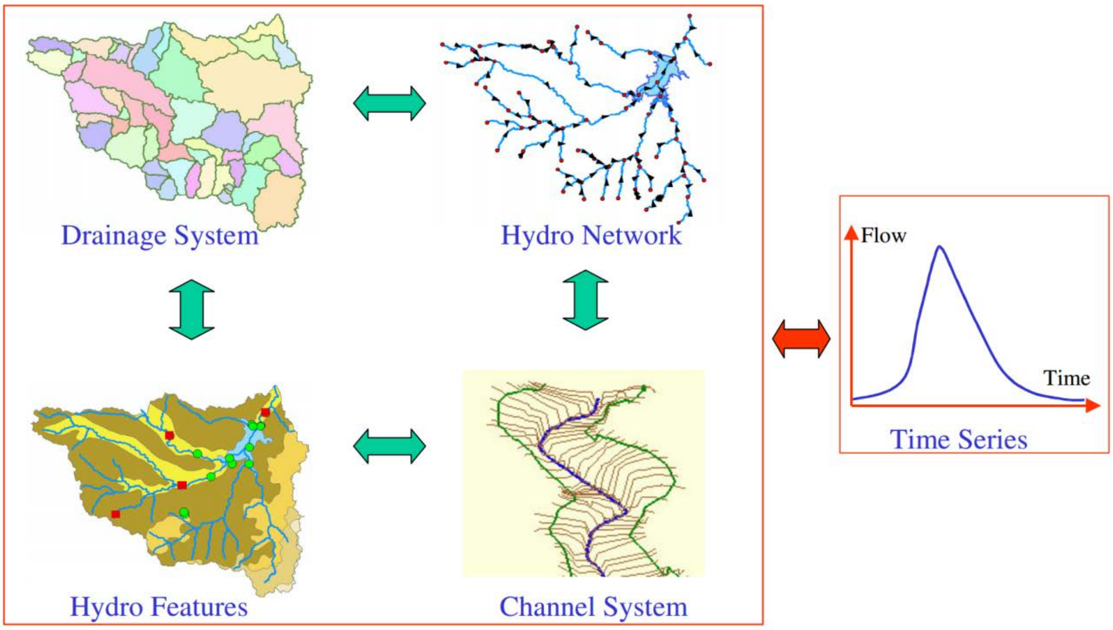

Figure 20- Hydro data model conceptual framework (Maidment, 2002)

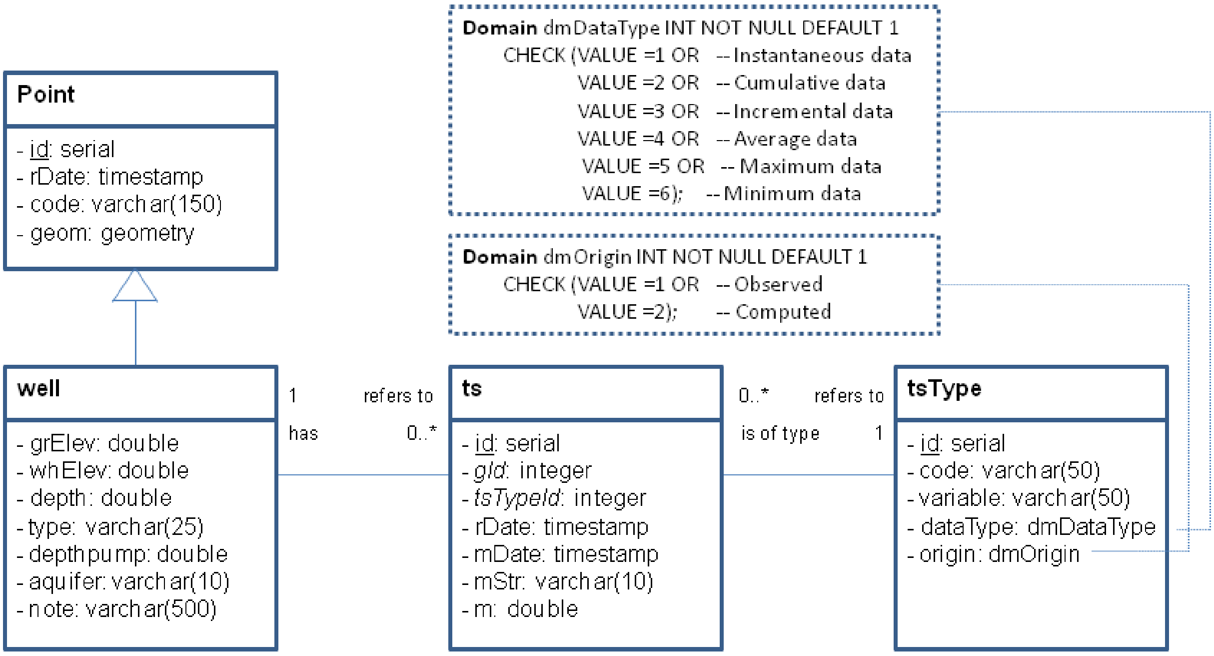

Figure 21 - Spatio-temporal monitoring database EAR schema (Crestaz et al., 2015)

Definitely a spatio-temporal database, designed after the hydro data model schema and implemented in an open source tool as the PostgreSQL/PostGIS, can be considered as a complementary facility to the traditional datasets organization in the file system.

A native spatio-temporal database represents a major shift paradigm from an application centered perspective, as is the case of GIS proprietary systems as ESRI ArcGIS, towards a database centered perspective. The different applications support flexible uploading, editing, accessing and geovisualizing database contents, without keeping control of the database. The users can continue to have direct access to the database and even perform advanced geospatial analysis tasks (Figure 22).

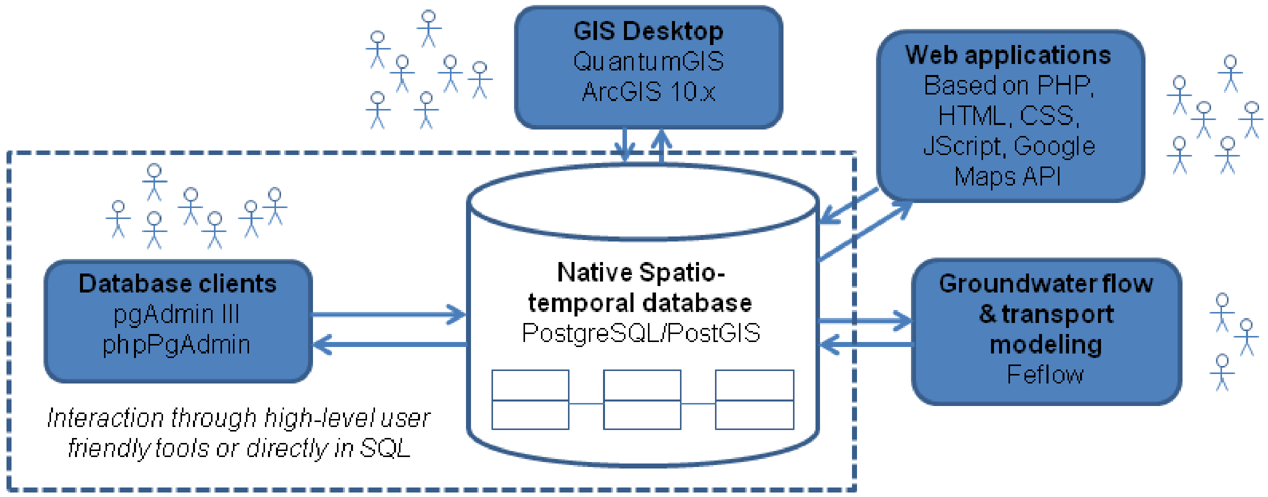

Figure 22 - A native spatio-temporal database from a database centric applications perspective (Crestaz et al., 2015)

Specialized tools can implement their own OGC compliant facilities to access native spatial databases. An example is provided by the DHI-WASY groundwater flow and transport modelling environment Feflow, as based on an implementation integrated in the standard package since version 6.2 (Figure 23).

Rather than duplicating data in numerical code own formats, the data can be seamlessly integrated by querying the spatial database. The complex settings of both input parameters and flow/transport modelling outcomes are well captured in the 3D visualization of a model implemented at an industrial facility and should make clear the advantages of such an approach to data management (Crestaz et al., 2015;Figure 24).

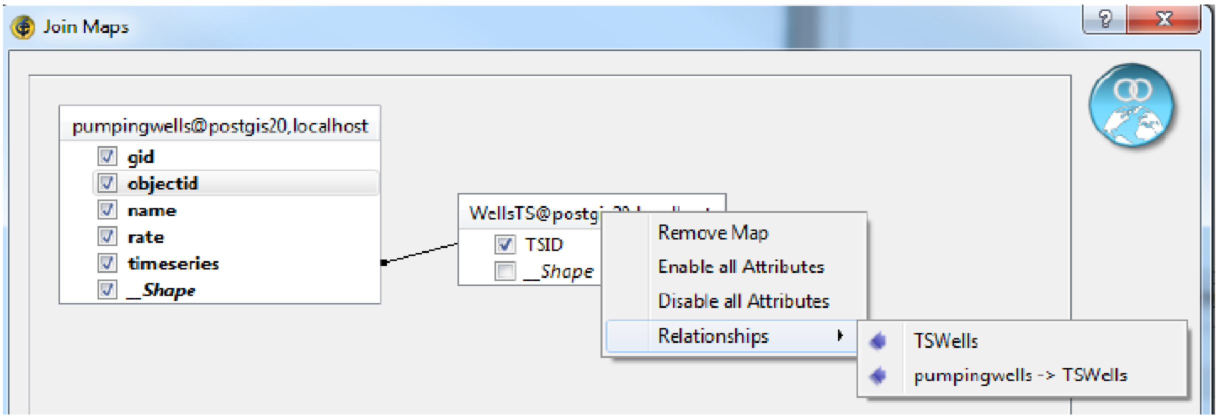

Figure 23 - Management facilities of PostgreSQL/PostGIS data relationships within the DHI-WASY Feflow groundwater modelling system

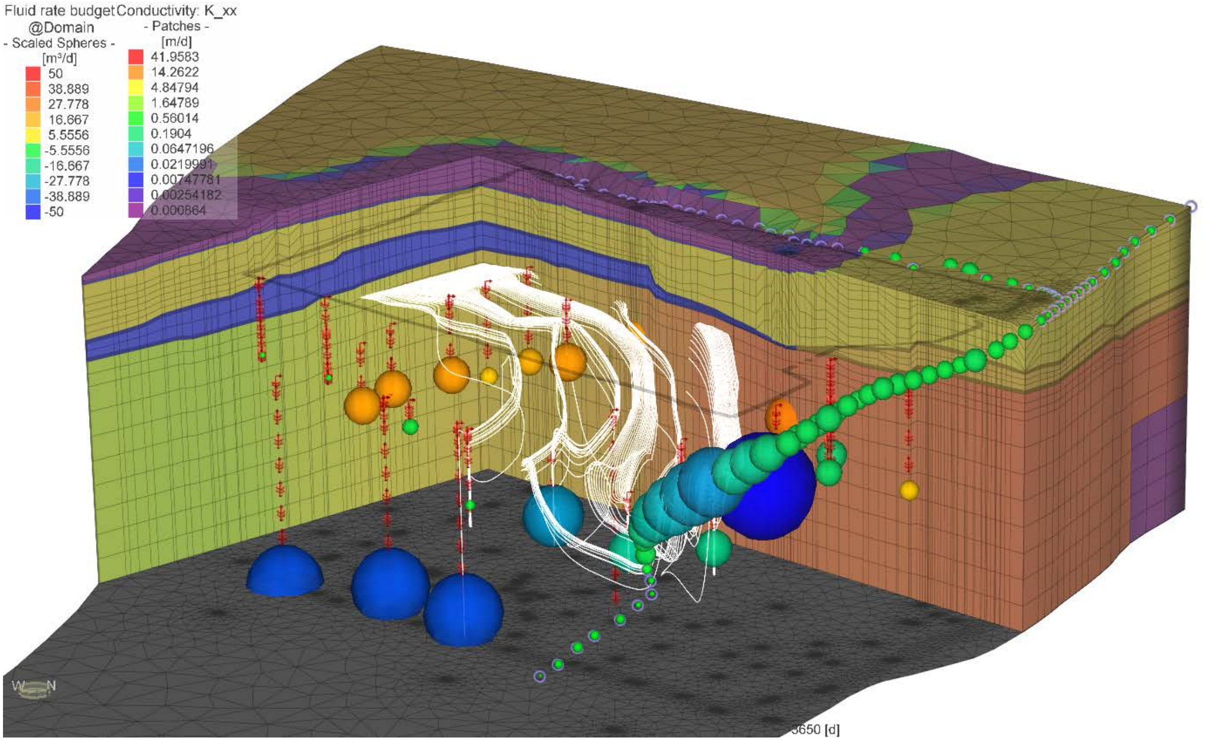

Figure 24 - Parameters and boundary conditions in a Feflow 3D groundwater flow and transport model

1.3.4 Summary of different geospatial database solutions

Above discussion can be summarized as follows:

- storing and organizing entire datasets collections, as is the case of data provided by the CoE or by freely available data sources, is the main task implemented by this activity of the ACEWATER2 project. Checks on data consistency are necessarily demandated to a centralized control, in order, for example, to limit data duplications/overlapping and enforcing data consistency.

  Stakeholders accessing the system have the possibility to upload documented datasets, download data locally, edit, and analyse information making use of their own tools. The availability of web mapping tools will also support the end user in a wide range of tasks, from simple geovisualization to advanced geo-exploratory analysis.

- detailed data flow management, as in the case of monitoring networks data, demands for the adoption of more advanced approaches and tools. The need for controlling consistency among monitoring stations spatial location, variable types, which can be quite large (e.g. analytical parameters for environmental quality monitoring) and observed datasets (e.g. raw field data, lab analyses) must be granted.

  Face to the challenges above, a spatial database, whether proprietary or native, must be made available. Standardization of electronic data file formats for transfer to the database must be setup, and facilities for data cleaning/tidying, validation and database uploading implemented. Examples of file formats standardization are easily available on the web, as in the case of the EPA standard EDD (Electronic Data Deliverable) formats (USG EPA, 2018). A feature similar to the EDP (EDD Data Processing) applications, aimed at reporting errors or inconsistencies in input raw data to be fixed by the end user should be implemented as well.

  Users accessing the system are expected to have access to software facilities to clean, harmonize, validate data, as well as to upload data to the spatial database. They will theoretically have both the options to download data locally or visualize the data through web mapping tools, enabling data browsing and querying data in both space and time.

  Web mapping front end visualization tools and classic GIS platforms (e.g. QGIS, ArcGIS) can definitely grant the access to the spatial database. The option to embed these visualization tools within the Aquaknow platform can also be considered.

Both the systems above can be integrated with or complement existing water information systems, as ZAMWIS from ZAMCOM, or Information Systems run at NBA and AGRHYMET.

For the moment being, a follow up to the analysis of the different options, as detailed above, was focused on the design and implementation of a preliminary test platform combining:

- A spatial database, designed on the basis of the Hydro Data Model, using the Open Source native spatial database PostgreSQL/PostGIS platform;
- An EDP application, implemented in R and Python, aimed at supporting end user in data cleaning/tidying tasks and further data uploading to the database.

No results are presented at this stage, being still an ongoing work. Also the issue of integrating such functionalities within the Aquaknow platform is still an open issue, which deserves further analysis.

2 Information system contents

2.1 Global and continental datasets

The hydro-climatological database covers a wide range of topics related to water, at global, continental and river basin scale. The datasets, organized by distinct categories, integrate a former collection (Crestaz et al., 2018) with new datasets, both freely available and submitted by the project partners, as related to groundwater hydrology, water quality, geology and ecosystems.

2.1.1 Agriculture

This category covers datasets addressing the following variables:

- Crop production statistics;
- Irrigation;
- Livestock production statistics;
- Freshwater fishery activities.

The listed datasets are:

a. MAP Spatial Production Allocation Model (MapSPAM) (IFPRI and IIASA, 2017; Wood-Sichra et al., 2016) - Global spatially-disaggregated crop production statistics data, including cultivated and irrigated areas, for 2005.

b. Global Map of Irrigated Areas (GMIA), version 5 (Siebert et al, 2013) - Areas equipped for irrigation for the year 2005, including details on irrigation by groundwater, surface water or non-conventional water sources (e.g. from desalination, industrial waste water reuse).

c. Historical Irrigation Dataset (HID) (Siebert et al, 2015) –Extent of areas equipped for irrigation from 1900 to 2005 at a 5-arc second resolution based on the former dataset GMIA.

d. Gridded Livestock of the World (GLW) (Robinson et al., 2014) – Livestock production statistics**.**

e. FAO Fisheries and Aquaculture Department Dataset (http://www.fao.org/fishery/topic/16140/en) - Global fresh water aquaculture activities and production.

2.1.2 Climate

This category covers datasets of both observed and estimated (past and future scenarios) meteo-climatic information, including, among others:

- Ground observed data (e.g. precipitation and temperature time series from meteorological stations);
- Estimated historical data, i.e. based on models or analysis of remote sensed images with possible integration with data collected at ground stations;
- Maps deriving from climate variability analysis and/or future climate change projections/scenarios.

The listed datasets are:

a. Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (Funk et al, 2015) - A quasi-global (50N-50S, 180W-180E) gridded precipitation distribution, based on integrated analysis of remote sensed data sources and in-situ ground stations, with spatial resolution of about 5 km (at equator), starting from 1981, at, among others, daily and monthly temporal frequency. CHIRPS are of high interest due to both spatial coverage/resolution and temporal frequency and the implicit cross validation against ground observations. Examples of studies recently conducted at JRC making use of CHIRPS include climate variability assessment in South America and West Africa (Ceccherini et al, 2015).
b. Multi-Source Weighted-Ensemble Precipitation (MSWEP) (Beck et al, 2017) - A global gridded precipitation dataset, based on integrated analysis of remote sensed data sources and in-situ ground stations with corrections for orographic effects and gauge under-check, with spatial resolution of about 25 km (at equator), starting from 1981 to 2015, and 3-hourly frequency. MSWEP is of interest for the potential use in distributed hydrological modelling, due to its 3-hourly frequency (see LISFLOOD output on “Hydrology” category subsection).
c. ECMWF Re-Analysis-Interim (ERA-Interim) (Dee et al, 2011) - A global atmospheric (temperature, precipitation, evapotranspiration, other turbulent fluxes, etc.) gridded distribution with spatial resolution of about 80 km (at equator), starting from 1979, at a sub-daily frequency (6 hours). The product is the outcome of a reanalysis process based on remote sensed images, continuously updated in real time.
d. Global Summary Of the Day (GSOD) - A global network of ground weather-climate stations, operated by NOAA, reporting daily observed time series of, among others, precipitation, temperature, relative humidity, wind speed and direction.
e. GLDAS (Global Land Data Assimilitation System; Rodell et al, 2004) and PGF (Princeton Global meteorological Forcing database) (Sheffield et al, 2006) - Two global spatially gridded coverages of re-analysed weather variables, respectively starting from 1948 and 1901, relevant to distributed land surface modelling.
f. NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) (Thrasher et al, 2012) - Downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs).

2.1.3 **Demography**

This category covers demographic datasets, namely:

- Spatio-temporal distribution of population and population density (historical data and future projections), often derived by census data;
- Data containing information on ethnic groups.

Listed demography datasets are:

a. Gridded Population of the World, version 4 (GPW4) (CIESIN, 2016) - A global spatially gridded coverage of population density provided by NASA for the period 2000-2020 (extrapolated) ;

b. Global Human Settlement (GHS) (JRC and Columbia Un., 2015) - A global spatially gridded coverage of population density,downscaling the GPW v4 (see above), covering from 1975 to 2015;

c. World population (WorldPop) (Pezzulo et al,2017, Tejedor-Garavi et al.,2017, Thomson et al,2017, Weber et al,2017, http://www.worldpop.org.uk) - A web portal containing population distribution data, widely used in the literature;

d. GEOcoded Ethnic Power Relations (GEOEPR) (Vogt et al,2015, Wucherpfennig et al, 2011), a spatially global coverage of the ethnic groups.

2.1.4 Geology

This category covers geological datasets, currently only one being listed:

a. OneGeology (http://portal.onegeology.org/OnegeologyGlobal/) - An international initiative promoting collaboration among national geological surveys around the world. This ground-breaking project launched in 2007 contains a collection of global maps of geological units.

2.1.5 Ecosystem

This category covers a wide range of topics:

- Protected areas;
- Endangered species;
- Water pollution data;
- Ecological data;
- Ecosystem services.

Listed datasets include:

a. Biofresh Altas (Global Freshwater Biodiversity Atlas) (Oberdorff et al, 2017) - Acollection of published and open access maps on freshwaters, reporting links to publications and data sources related to biodiversity at the global, continental and local scale.

b. Global wetland dataset (Gumbricht et al, 2017) – Initiative promoted by CIFOR (Center for International Forestry Research), collecting information on tropical wetlands.

2.1.6 Energy

This category covers datasets at basin or country scale related to energy production, including:

- Renewal Energy Production;
- Hydropower;
- Biomass.

The only listed web portal is:

a. ECOWAS Observatory for Renewable Energy and Energy Efficiency (ECOWREX) (http://www.ecowrex.org/) - A portal containing energy production/consumption at country level for the Western African region. It also provides access to a webgis focused on thermal and renewable energy power plants in Western Africa.

b. the U.S. Energy Information Administration (https://www.eia.gov/beta/international/) - Time series of energy production and consumption from all over the world.

2.1.7 Health

This category covers the following topics:

- Health Indices;
- Spatio-Temporal distribution of parasite and main diseases.

The only listed dataset is:

a. MAP (Malaria Atlas Project) (Bhatt et al, 2015) - A web portal containing mapping of P.vivax global endemical areas referred to 2010.

2.1.8 Hydrology

This category covers hydrological data as:

- Observed data, as river gauging stations, groundwater piezometric networks and related time series;
- Interpreted remote sensed data, i.e. mapping of surface water occurrence;
- Hydrological models outcomes, as simulation outputs from numerical models.

Listed datasets include:

a. Global Runoff Data Centre (GRDC) from WMO–UNFCC) (GRDC, 2017; Poméon et al, 2017; Schneider et al, 2017) - A global network of river discharge gauges, reporting observations and estimations from 1979 to 2012, at both daily and monthly frequency;

b. Water Level, discharges and dams' releases data provided by HCB (Hidroelectrica de Cahora Bassa), DNA (Direcção Nacional da Água) and Ara Zambeze (Administracao Regional de Aguas do Zambeze) (Ronco et al, 2010; Nones et al, 2012) - Daily time series from 1946 to 2005 in 3 sites in Zambezi River Basin (Revubue in Chingoze; Zambezi in Zumbo and in Tete,Mozambique)

c. LISFLOOD (Burek et al, 2013) - A spatially distributed hydrological model, simulating the catchment hydrological processes; applied to Africa, model outputs are available as spatially gridded maps of discharge values from 1979 to 2012 at daily frequency;

d. Global Surface Water (GSW) (Pekel et al, 2017) - A global spatially-gridded dataset of surface water occurrence, based on remoted sensed datasources analysis, from 1984 to 2015;

e. World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) (www.whymap.org) - A web portal funded by UNESCO, reporting global maps of groundwater resources;

f. BGS (British Geological Survey) (MacDonald et al. ,2012) - A spatially gridded coverage of groundwater productivity, storage and depth of Africa at a 5 km spatial resolution (at equator).;

g. Gravity Recovery and Climate Experiment (GRACE), from a collaboration of the US and German space agencies, NASA (National Aeronautics and Space Administration) and DLR (Deutsches Zentrum für Luft- und Raumfahrt - German Aerospace Center))(https://grace.jpl.nasa.gov/) – Global spatio-temporally gridded coverage of groundwater storage variation obtained by the GRACE twin satellites, measuring earth gravity, since 2002,;

h. Water Table Depth (WTD) (Fan et al, 2013) – Global observations of water table depth compiled from government archives and literature;

i. GLobal HYdrogeology MaPS (GLHYMPS) (Gleeson et al, 2014) – Global aquifers' maps, including main properties as permeability and porosity;

j. Global Lakes and Wetlands Database (GLWD), compiled by the WWF and the Center for Environmental Systems Research, University of Kassel, Germany (https://www.worldwildlife.org/pages/global-lakes-and-wetlands-database) – Global maps of lakes and wetlands.

Among the above datasets, key resources are:

- GRDC, is for the analysis of river discharge and calibration of hydrological models;
- BGS atlas, GRACE and WTD for the large scale assessment of groundwater availability/accessibility, reserves estimation and temporal dynamics;
- GSW for the detection of small/medium reservoirs (natural and artificial), often used for irrigation or water supply.

2.1.9 Infrastructure

This category covers water infrastructures, like dams and reservoirs, and mining activities, including location and basic characteristics.

Infrastructure datasets include:

a. The Global Reservoir and Dam (GRanD) (Lehner et al, 2011) - A global database providing the location and main specifications of large global reservoirs and dams with a storage capacity higher than 0.1 km^3, both in point and polygon format;

b. AQUASTAT (Lehner et al,2008) - A portal gathering detailed information about dams and their associated reservoirs; AQUASTAT's data was an important input into the Global Reservoirs and Dams (GRanD) database, especially for African dams;

c. Small dams index (SDD) (Mantel et al,2017) number of small dams per square root of basin area. The index is calculated per each quaternary basin of South Africa, Lesotho and Swaziland.

d. World Register of Dams database (WRD) by the International Commission on Large Dams. (https://www.icold-cigb.org/GB/world_register/world_register_of_dams.asp)

2.1.10 **Land**

This category covers data about land surface, namely:

- land cover (agricultural areas, forested areas, human settlements);
- land use, focusing on the management and modification of natural environment or wilderness into built environment, such as settlements and semi-natural habitats such as arable fields, pastures, and managed woods.

Key land cover/land use datasets include:

a. Globeland30 (http://www.globallandcover.com) (Chen et al., 2014) - A global spatially gridded coverage for land cover, categorized in only 10 classes (water bodies, wetland, artificial surfaces, tundra, permanent snow and ice, grasslands, barren lands, cultivated land, shrub lands and Forest) at a resolution of 30 m ;

b. GlobCover (ESA, 2010) - A global coverage of land cover classes at 300 m resolution (at equator), the product been developed in 2009 by ESA using MERIS (MEdium Resolution Imaging Spectrometer) mosaic;

c. Global Land Cover 2000 Project (GLC2000), developed by JRC (2016) - A global coverage of land cover at a spatial resolution of about 1 km (at equator);

d. Moderate Resolution Imaging Spectroradiometer (MODIS) data, accessible through the portal www.landcover.org (University of Maryland);

e. www.geo-wiki.org, a portal that provides products merging results from GLC2000 and MODIS data, integrated with crowdsourced information (See et al, 2015; the article also illustrates a state-of-art review of land-cover products at the global scale);

f. Recently, a prototype land cover map of Africa v1.0 based on 1 year of Sentinel-2A observations from December 2015 to December 2016 (http://2016africalandcover20m.esrin.esa.int); the map has been produced by the ESA CCI (Climate Change Initiative) land cover team, at a spatial resolution of 20 m, over the entire Africa, reporting 10 generic land use classes;

g. Future land use projections (Hurtt et al. in preparation). Ref. http://luh.umd.edu/ http://luh.umd.edu/data.shtml

2.1.11 **Politics**

This category covers a wide range of administrative, legislative and political datasets as:

- Country and other administrative boundaries;
- Data about international treaties on water;
- Data about civil conflicts;
- Possible criticalities in water management and related issue.

The following datasets are listed:

a. Global ADMnistrative boundaries (GADM) (http://gadm.org/) - A spatial database of the location of the world's administrative areas and boundaries ;

b. Armed Conflict Database from the International Institute for Strategic Studies (IISS) A database containing statistical data, analytical reports and daily timeline updates on the political, military and humanitarian developments in 41 active and 47 archived conflicts, as well as information on selected non-state armed groups and a compilation of annual trends in the ACD Index; (http://acd.iiss.org/en/about/demo)

c. Correlates of War (COW) (Bernauer et al, 2012) - A project seeking to facilitate the collection, dissemination, and use of accurate and reliable quantitative data in international relations; key principles of the project include a commitment to standard scientific principles of replication, data reliability, documentation, review, and the transparency of data collection procedures;

d. Transboundary Freshwater Dispute Database (TFDD) (Wolf et al,2003), developed by the Oregon State University College of Earth, Ocean, and Atmospheric Sciences, in collaboration with the Northwest Alliance for Computational Science and Engineering - The database is conceived to support the process of water conflicts prevention and resolution;

e. International Freshwater Treaties Database (IFTD) (Wolf et al, 2003);

f. International Rivers Cooperation and Conflict (IRCC) - A new event dataset on international river basins cooperation and conflict worldwide for the time-period 1997-2007, reporting water-related events among riparian countries, classified on a scale ranging from -6 (most conflictive) to +6 (most cooperative);

g. Armed Conflict Location and Event Dataset (ACLED) (Raleigh et al., 2010; (https://www.strausscenter.org/strauss-articles/acled-3.html)) – The dataset tracks the actions of opposition groups, governments, and militias across Africa and Asia, specifying the exact location and date of battle events, transfers of military control, headquarter establishment, civilian violence, and rioting;

h. Social Conflict Analysis Database (SCAD) (Salehyan et al, 2012) – A database including protests, riots, strikes, inter-communal conflict, government violence against civilians, and other forms of social conflict not systematically tracked in other conflict datasets; it currently includes information on social conflicts from 1990-2015, covering all Africa, further to Mexico, Central America and the Caribbean; (https://www.strausscenter.org/scad.html)

i. River Basin Organizations (RBOs), in the framework of the TFDD project – It is a web portal supporting search for international treaties on river basin organizations (http://gis.nacse.org/tfdd/rbo_new.php).

2.1.12 Socio-Economic

This category covers socio-economic datasets addressing the following topics:

- Gross Domestic Product (GDP) and other related indicators;
- World Development indicators (WDI);
- Worldwide Governance Indicators (WGI).

Key socio-economic datasets include:

a. World Development Indicators (WDI) from the World Bank Open Data (https://data.worldbank.org/data-catalog/world-development-indicators) - An open data portal providing the WDIs at the country level, covering all the world, per each year from 1960 to 2016;

b. Expanded Gross Domestic Product v. 6.0 (GDP) (Kaufmann et al,2010) - A global dataset with yearly country GDP, from 1950 to 2011;

c. World Governance Indicators (WGI) (Kaufmann et al,2010) - A global dataset of governance indicators at country resolution, from 1996 to 2015.

More recent relevant datasets, still to be added to the database, include those reported by Kummu et al. (2018) and Riahi et al. (2017).

2.1.13 Soil

This category covers soil and pedology data, which are important for agricultural activities assessment and hydrological modelling. In most cases, these data are static and, particularly for Africa, mainly gridded coverages from remotely sensed data sources. They include:

- Information relevant to estimation of current and future land potential productivity, identification of land and water limitations, and assessment of risks of land degradation, particularly soil erosion (e.g. nutrient availability/capacity, rooting conditions, excess salts, toxicity, ...);
- soil characterization variables (e. g. carbon content, nitrogen content, organic matter, soil bulk density, soil depth, soil horizons/profile, soil pH, soil salinity/sodicity, texture, soil water holding capacity, soil erosivity, etc…);

Listed datasets include:

a. Harmonized world soil database HWSD (Fisher et al,2008) - A global spatially gridded coverage of soil nutrient availability, nutrient retention capacity, rooting condition, oxygen availability, excess salts, toxicity and workability;

b. Soil and Terrain database programme (SOTER) (Engelen et al, 2013) - A database focused on Southern Africa, containing soil characterization variables (e. g. carbon content, nitrogen content, organic matter, soil bulk density, soil depth, soil horizons/profile, soil pH, soil salinity/sodicity, texture, soil water holding capacity,…);

c. European Soil Data Centre (ESDAC) (Panagos et al, 2012, 2017; Dewitte et al, 2013) - An atlas of soil data published by JRC for Africa and a globally spatially gridded map of soil erosivity.

2.1.14 **Topography**

This category covers:

- Digital Elevation Model (DEM) or Digital Terrain Models (DTM);
- Geomorphological analysis by-products.

Key data sources are:

a. Shuttle Radar Topography Mission (SRTM) (Reuter et al,2007; Jarvis et al,2008; USGS, 2016) - It is a reference global DTM at a spatial resolution of about 90 m (at equator).

b. SRTM30 (https://lta.cr.usgs.gov/SRTM1Arc) - A more recent version of global SRTM with higher resolution, about 30 m at equator;

c. ASTER (NASA LP DAAC, 2015) - A Global Digital Elevation Model developed jointly by NASA and Japan's Ministry of Economy, Trade, and Industry (METI); it has a spatial resolution of about 30 m (at equator) and is capable of collecting in-track stereo using nadir- and aft-looking near infrared cameras;

d. HYDROSHEDS (Lehner et al, 2013) - A set of geomorphological maps derived from SRTM30 for hydrological applications:

i. Void-filled global digital elevation model, relevant to simulation of hydrological processes; given their widespread use, both Europe and Africa datasets have been downloaded to the Aquaknow database;

ii. Derived maps of river network at 15 second or 30 second resolution;

iii. Hydrobasin, polygon layers that depict watershed boundaries and sub-basin delineations at a global scale and at different hierarchical levels.

2.1.15 **Transport**

This category covers different dataset related to:

- Roads;
- Transport information;
- Travel times estimation;
- Connections among regions and/or with the main points of interest.

The following dataset is reported:

a. Global Accessibility Map (GAM) (Nelson et al,2008), developed by JRC - A global spatially gridded coverage at 1 km resolution of estimated travel times to the nearest major cities, based upon; the algorithm is based on a friction-surface raster map, estimated as a function of roads/channels.

2.1.16 **Miscellaneous**

A miscellaneous category has been introduced to report datasets which do not clearly fit any of the above categories. Currently the following dataset is listed:

a. Water Resources Management Authority (WARMA), reporting water use licenses in Zambia from 2010 to 2014 for domestic, agricultural, industrial or hydro-power targets. Data are disaggregated at the level of permit holders.

2.2 Datasets Provided by CoEs, Other Key Stakeholders and JRC

Further to the freely available datasets, the Aquaknow Information System also reports local and/or basin scale datasets and related metadata, as submitted by the ACEWATER2 CoE and other stakeholders.

Among others, two major information systems are referred, respectively mantained by ZAMCOM (ZAMWIS, ZAMCOM Water Information System) and the SADC-GMI (SADC-Groundwater Management Institute) groundwater database.

2.2.1 **SADC-GMI Hydrogeological database**

A web Groundwater Information Portal, hereafter referenced as SADC-GIP[2] provides access to the SADC-GMI (Groundwater Management Institute) hydrogeological database (Figure 25). The scope of the portal is to make relevant hydrogeological information accessible to managers, practitioners and researchers, promoting the use of modern

[2] http://sadc-gmi.org/hydrogeological-maps/; https://apps.geodan.nl/igrac/ggis-viewer/viewer/sadcgip/public/default

technologies, including smartphone applications. Hydrogeological and hydrochemistry maps can be downloaded at high resolution in formats compatible with GIS software. The SADC-GIP is developed and maintained by the International Groundwater Resources Assessment Centre (IGRAC), on behalf of SADC-GMI.Contacts with the SADC-GMI have been developed, addressing multi objectives as, primarily, the enforcement of links to promote joint scientific research on groundwater hydrology and granting access to state-of-the-art datasets for the Zambezi river basin. These contacts led to the preparation and signing of a MoU (Memorandum of Understanding), granting access to the database for the scientific research scopes.

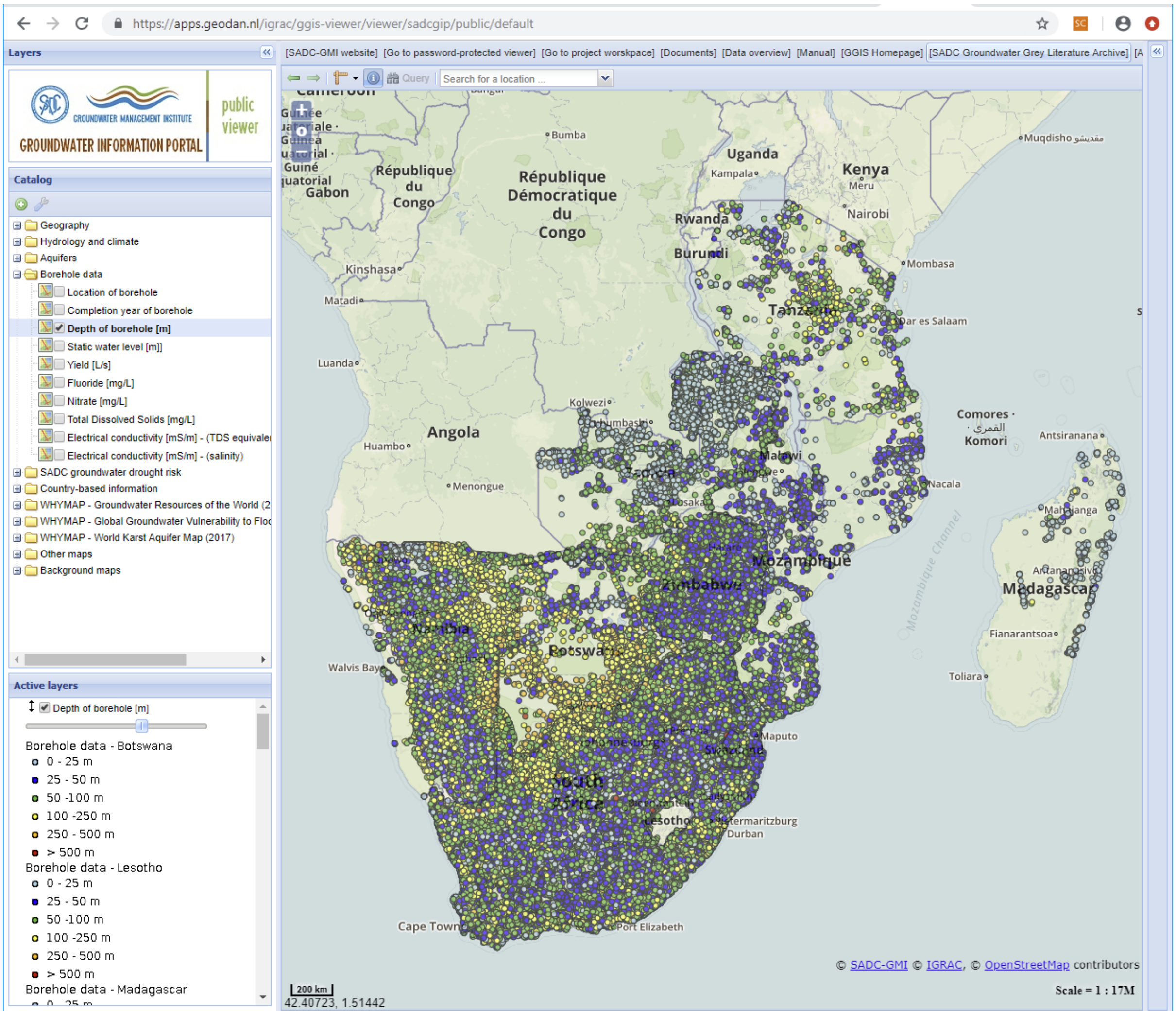

Figure 25 - Screenshot from the SADC-GMI portal (https://apps.geodan.nl/igrac/ggis-viewer/viewer/sadcgip/public/default)

2.2.2 ZAMWIS (ZAMbezi Water resources Information System)

ZAMWIS (ZAMbezi Water resources Information System) (Figure 26 is an interactive, web-based portal, promoted and implemented by ZAMCOM. It provides access to hydrological data, including time series, remote sensed data and maps relevant to the Zambezi river basin.

The system is operational, promoting basin wide collaboration among riparian countries towards routinely sharing data and information. A Decision Support System (DSS) is currently under development and will be integrated within the ZAMWIS to support planning, operations, monitoring and, more generally, effective river basin management.

Contacts with ZAMCOM have been developed, based on the recognition that Organization objectives and main priorities should have led the scientific research framework to be setup for the Zambezi river basin. Of course, multi objectives have been pursued as, primarily, the enforcement of links to promote joint scientific research on basin hydrology and granting access to the state-of-the-art ZAMWIS-hosted datasets.

These contacts led to the preparation and signing of a MoU, stating common technical and research objectives and granting access to the ZAMWIS database for the scientific research scopes over the Zambezi river basin. At the time of writing, NDA (Non Disclosure Agreement) have been signed by the CoE that need to access ZAMWIS; still ZAMWIS data access has not been granted yet by ZAMCOM.

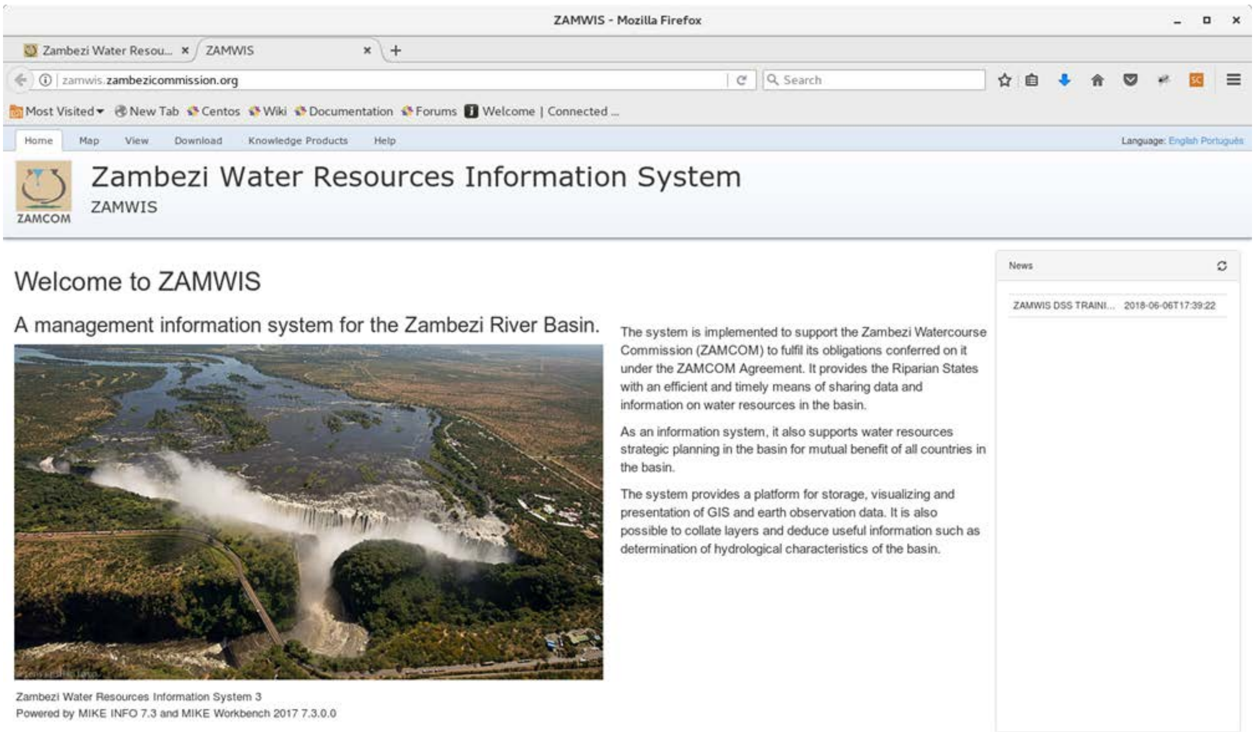

Figure 26 - Screenshot from the ZAMWIS - ZAMbezi Water Information System (http://zamwis.zambezicommission.org/)

2.2.3 Hydrogeological database of Zambia

It is a collection of hydrogeological and groundwater quality data and derived maps., compiled by Dr. Banda K. from the Zambia Un. and geographically focused on the Zambia country scale. The Zambia Un. is one of the ACEWATER2 CoE focusing on the groundwater hydrology and quality topic.

The database contains geographical information on:

- Aquifers;
- Catchment borders and geomorphology;
- Pivots;
- Basement;
- Lithology;
- Boreholes;

- Springs
- Mining.

The conditions of use are restricted and limited to specific partners of SANWATCE CoEs.

2.2.4 Zambezi river basin hydrogeological database (Western Cape University)

The Zambezi river basin database has been compiled by Dr. Mengistu H. of the Un. of Western Cape/South Africa, based upon freely available data sources and data submitted by the other CoE collaborating in the framework of the groundwater hydrology and quality cluster. The database contains different geological and hydrogeological raw data and processed by-products, including:

- Aquifer map (Figure 27);
- Geological map and cross-sections;
- Demographic map;
- Aquifer productivity (Figure 28) and irrigation maps;
- Salinity map;
- Topographic reference map (Figure 29).

The database compiles data from different public domain freely available data sources.

a. Regional and national geological maps, aquifer type and yield data;
b. Digital elevation data from HydroSheds (www.hydrosheds.org);
c. Primary and secondary River shapefiles from Waterbase (www.waterbase.org).

Other confidentail datasets, to be used only for the activities related with the ACEWATER2 project, include:

a. Zambia Water quality data, Zambia shapefiles on tailings lakes, mines, tailings dams and hotspots: University of Zambia;
b. Geological Map of Zimbabwe: Surveyor General of Zimbabwe;
c. SADC transboundary aquifer map shapefiles: Council for Geoscience.

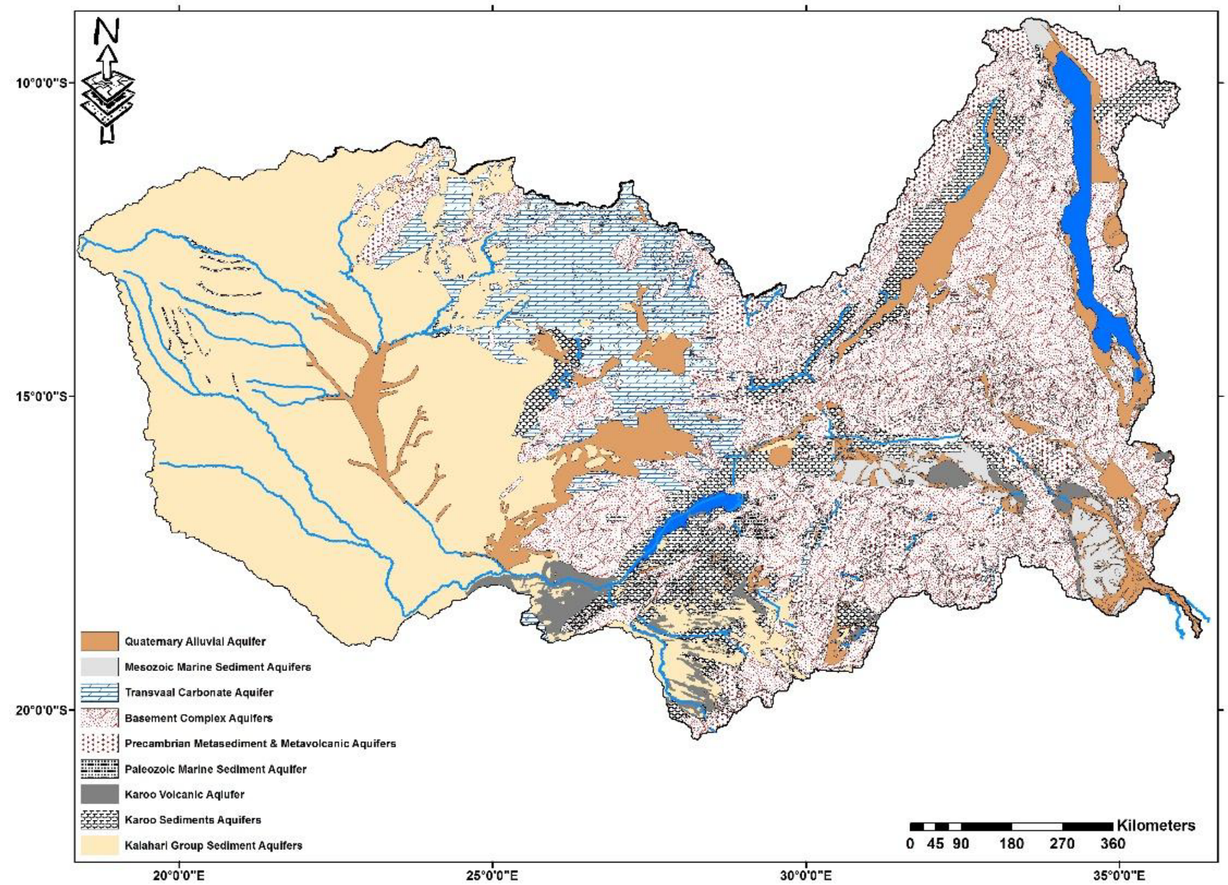

Figure 27 - Complete Aquifer Map (from Western Cape University Zambezi River Basin database)

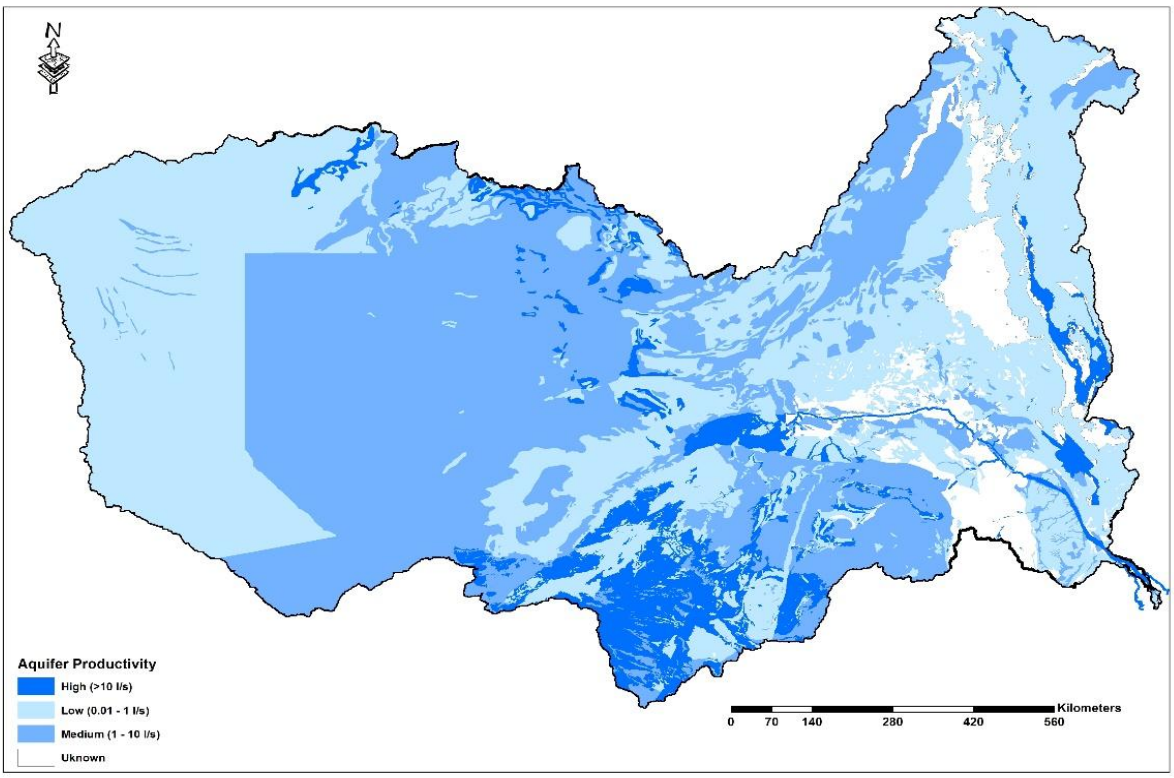

Figure 28 - Aquifer Productivity Map (from Western Cape University Zambezi River Basin database)

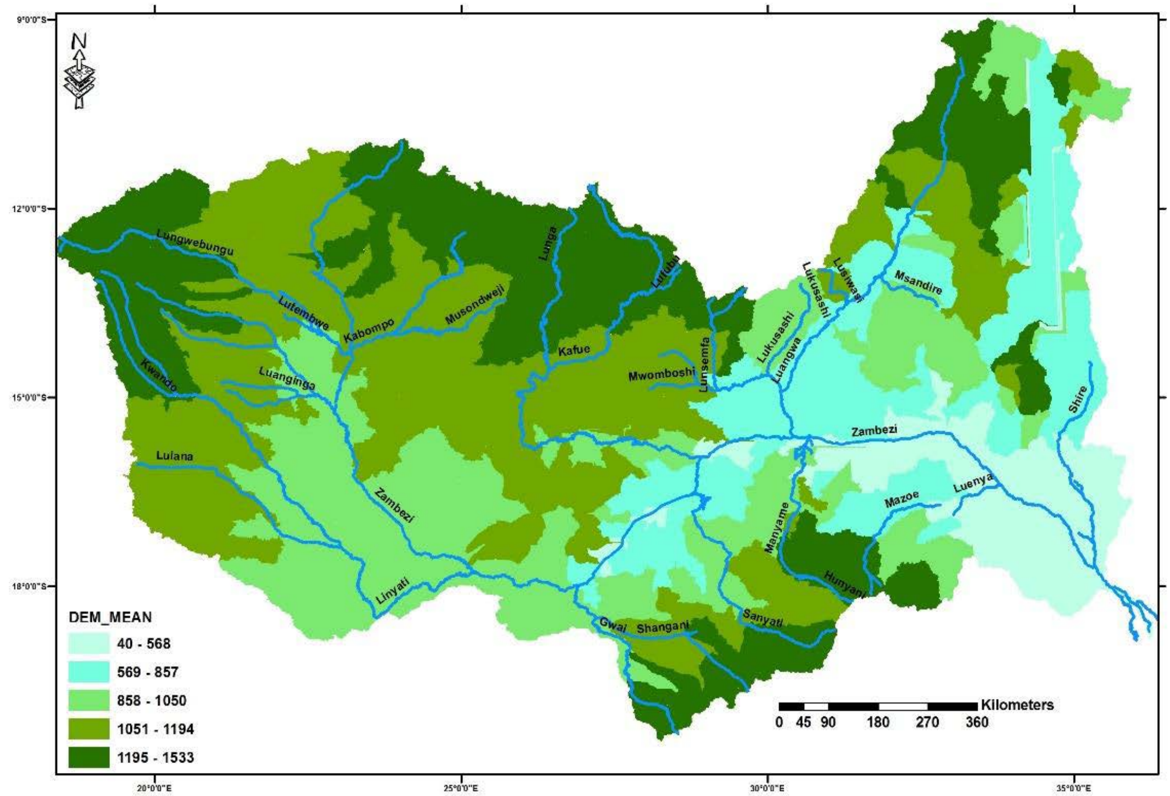

Figure 29 - Terrain Elevation (from Western Cape University Zambezi River Basin database)

2.2.5 Precipitation variability analysis maps

Precipitation variability analysis, implemented in the framework of ACEWATER project on the basis of CHIRPS dataset (Funk et al, 2017), led to the preparation of deficit precipitation maps for different return periods, up to 50 years.

The maps are available for the river basins under investigation (Niger, Nile, Senegal and Zambezi) per each month of the year with 5, 10, 20, 50 year return periods. Maps are developed by JRC.

More details on both the methodoloy and the products in the next chapter "*Climate variability analysis*".

3 Climate variability analysis

3.1 Background

Climate variability refers to the way climatic variables, as precipitation and temperature, fluctuate yearly, above or below a reference average value, typically computed on the basis of a long term data series of at least three decades. The climate variability analysis isbased on the statistical analysis of the time series data.

Climate variability affects socio-economic activities. The assessment of probability of given events, as estimated after the climate variability analysis, supports stakeholders in taking appropriate measures to reduce risks and impacts.

Climate variabiliy clearly differs from the climate change, that refers to the numerical simulation of long-term climate dynamics based on RCPs (Representative Concentration Pathways) scenarios (i.e. climate projections).

Traditional statistical methods can be used to perform the climate variability analysis. Still in this framework the L-moment method was preferred, being less susceptible to outliers. Details on the methology are provided in the following paragraph.

3.2 Precipitation deficit (drought)

L-moments statistics have been used to study precipitation and extreme events. The Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) was used at the monthly scale for the period 1981-2017. CHIRPS is a gridded 30+ year quasi global rainfall dataset with a resolution of 0.05 degrees (Funk et al., 2014).

The L-moments are combinations of probability weighted moments, based on difference of expected values (means) of sub-samples. Their interpretation is similar to other statistical moments, but with the advantage of being less susceptible to the presence of outliers and performing better with smaller samples (Hosking and Wallis, 1997).

The 1st L-moment (L-mean) corresponds to the conventional statistical mean. The 2nd L-moment (L-cv) measures random variable’s dispersion. The 3rd and 4th L-moments (L-skewness and L-kurtosis) are measures relating to the shape of the sample distribution. The L-skewness quantifies the asymmetry of the sample distribution, and the L-kurtosis measures whether the samples are peaked or flat relative to a normal distribution. A detailed mathematical formalization of L-Moments is discussed by Hosking and Wallis, 1997.

The analysis of rainfall CHIRPS estimates has been implemented for the four river basins selected as case studies in the framework of the ACEWATER2 project (Niger, Nile, Senegal and Zambezi; digital terrain elevation maps in Figure 30, Figure 31 and Figure 32).

L-Moments were calculated for the full time window of CHIRPS dataset (Hosking, 2017, 2017b; Cordano, 2018, 2018b). Based on L-moments derived maps, the probability associated to specific rainfall amount is estimated by fitting a parametric statistical distribution. A Pearson-III probability distribution resulted to be the optimal solution for the monthly datasets.

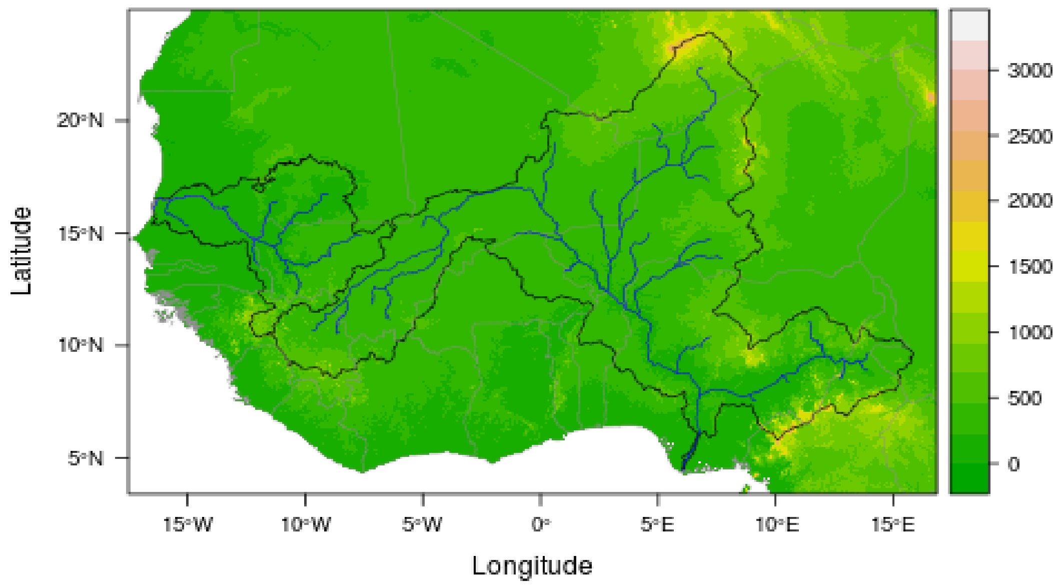

Figure 30 - Digital Elevation Model (SRTM) of the area including Niger and Senal river basins

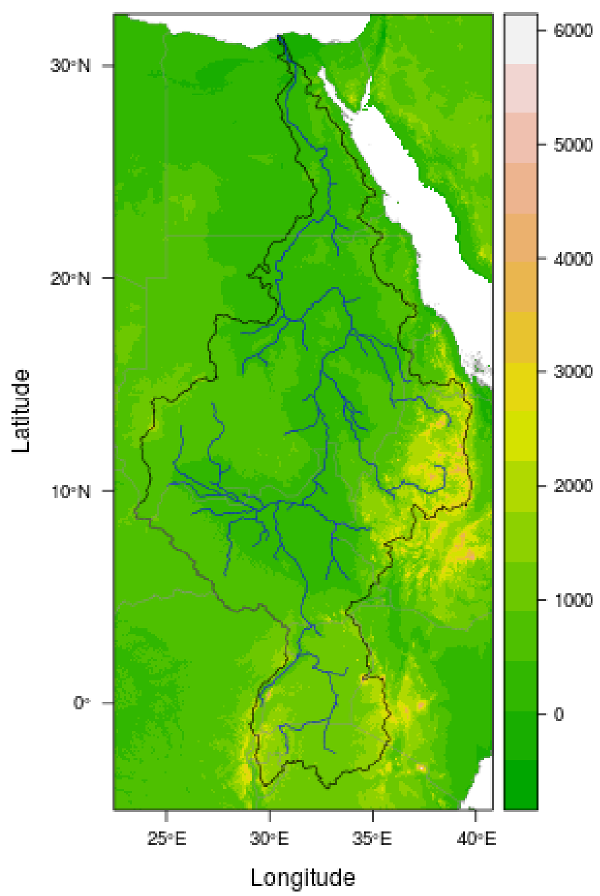

Figure 31 - Digital Elevation Model (SRTM) of the area including Nile river basin

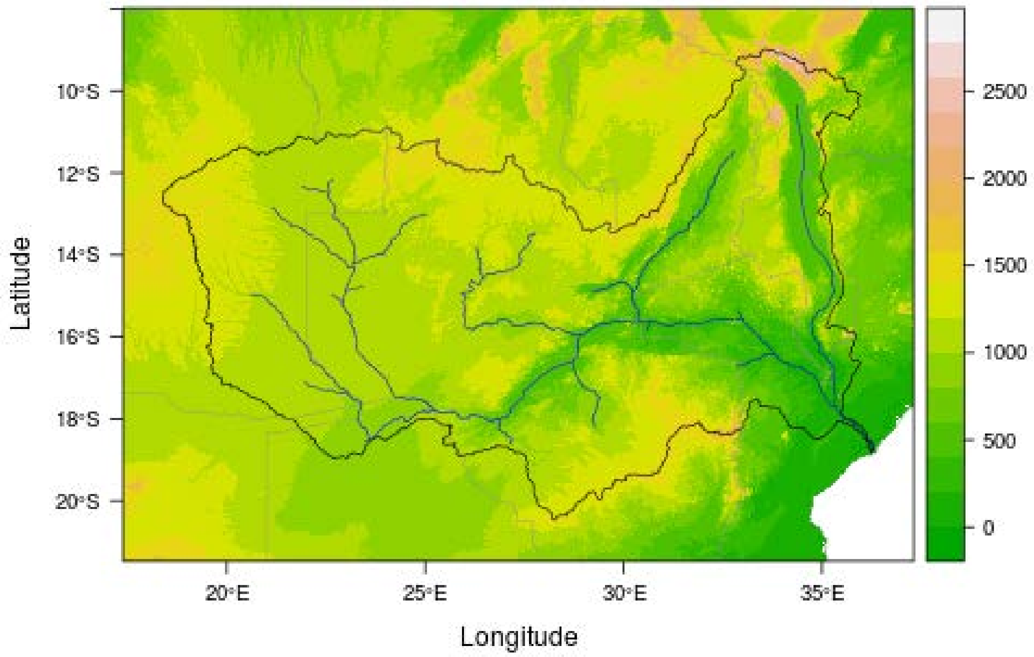

Figure 32 - Digital Elevation Model (SRTM) of the area including Zambezi river basin

Based on estimated probability function of monthly precipitation at each pixel, various deficit/excess indexes and return periods can be mapped.The deficit/excess indices highlight the divergence with respect to mean climatology. In particular, the relative deficit, that's the deficit rescaled to the mean, is defined as (1):

$$D = \frac{E[P]-P}{E[P]} \quad (1)$$

where P is the precipitation and $E[P]$ is the mean or expected value of precipitation. Relative excess is the opposite of relative deficit. Deficit increases as precipitation decreases.

The L-Moments analysis, based on the CHIRPS dataset, focused on the computation of the mean precipitation and the relative deficit associated to different return periods (5, 10, 20 and 50 years), disaggregated on a monthly basis.

Deficit values for different return periods depend on the shape of probability distribution. The return periods depend on precipitation/deficit cumulative probability and correspond to the average time, expressed in years, between two events with the same magnitude (or higher).

Return periods of deficit provide an indication on the variability of precipitation, with reference to current climate conditions. Whereas events with higher return periods (i.e. 50 years) are to be considered as extremes, events with lower return periods (i.e. 5-10 years) turn to be a powerful indicator of relatively short term precipitation variability with high likelihood to occur.

For example, let's assume the case of a 60% deficit being associated to a return period of 5 years, this is associated to a 40% decrease in the precipitation with respect to the mean expected value. The occuring of such a condition can be assumed to be relatively frequent. In a significantly different scenario, where the deficit slowly increases with return periods, the precipitation remains close to the average or expected value, being a typical condition of a low variability scenario.

Further to the above, it is worth noting that variability is often highly dependent upon the month or the season, high variability tending to occur in drier periods, which can turn to be the most critical for the agriculture.

The variability of precipitation regime can be useful for further comparison with crop modelling maps in order to investigate the effect of climate variability on agriculture and other WEFE nexus activities.

3.2.1 Niger and Senegal River Basins

Precipitation expected values and deficit values for different return periods are plotted for the Niger and Senegal river basins, extending over the entire Western Africa (Figure 33).

As a general plotting guideline, followed also for the subsequent study areas, the computed average precipitation (1st L-Moment) map is plotted at each month, with the relative deficit maps at increasing return periods (5, 10,20, 50 years) on the same row.

Such a layout permits to better appreciate the information conveyed by relative deficit maps. For example, high to very high relative deficits can have low significance in areas characterized by very low mean precipitation, as is the case for the Sahelian and neighbouring desertic areas. On the other hand, similar relative deficits makes sense in humid areas.

From the above considerations, it comes out that higher deficit variability tends to be concentrated in areas with lower precipitation, as the visual inspection of the maps clearly confirm.

Provided that relative deficit increases with longer return periods indipendently from rainfall amounts, higher increases can be reported in low rainfall areas and also during rainy season. This is a key message, as such a high climate variability impacts on the poorest and driest regions, strongly dependent upon rainfall for both human water supply and rainfed agriculture.

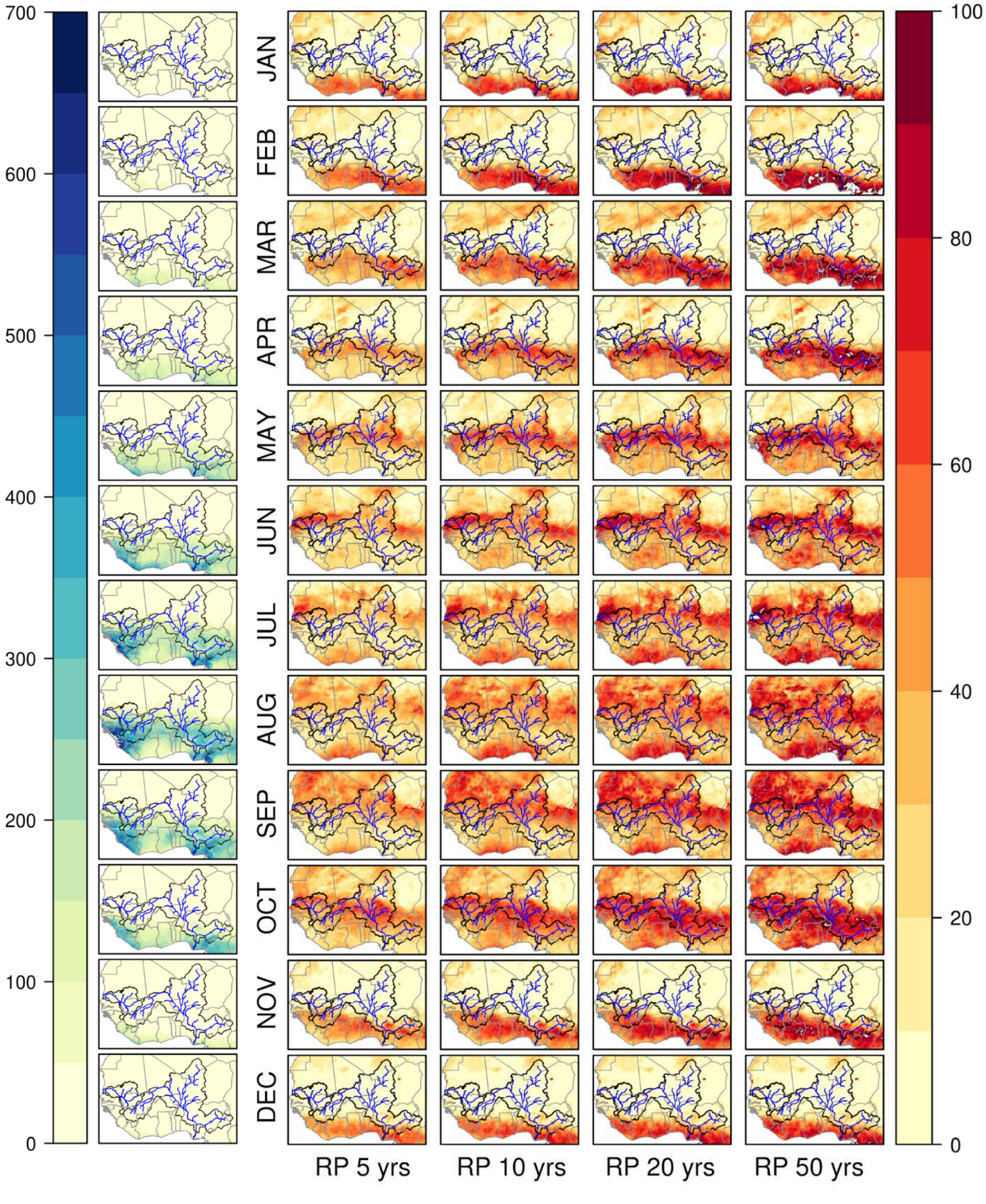

Figure 33 - Monthly mean precipitation [mm](left) and relative deficit values [%] associated to the return periods of 5, 10, 20 and 50 years in Niger and Senegal River basins

3.2.2 Nile River Basin

Precipitation expected values and deficit values for different return periods for Nile river basin are plotted here below (Figure 34; Figure 35).

The basin extends in a south-north direction, partly covering both terrestrial hemispheres. The very dry lower part of the basin, in Egypt, reveals very low variability basically due to negligible rainfall values.As one moves to the south, the distinct rainy seasons patterns on the north and sourth emisphere clearly shows up. The rainy season in the northern hemisphere tropical areas extends over June-September, and over September-June in the southern ones.

Differently from the Western Africa case study, the relationship between higher climate variability and lower precipitation does not appear so evident. Further numerical analysis will be required to confirm this assessment.

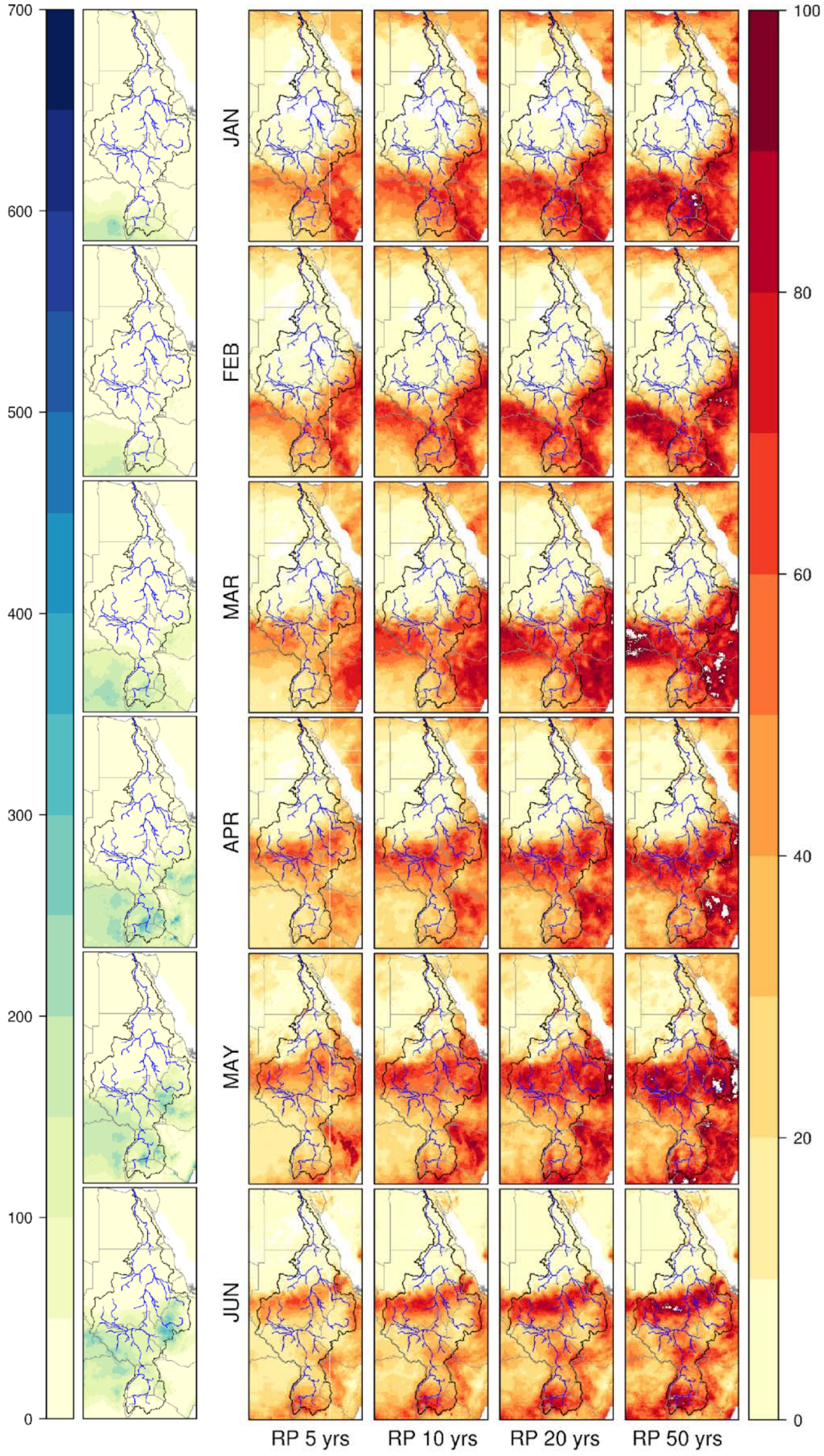

Figure 34 - Monthly mean precipitation [mm](left) and relative deficit values [%] associated to the return periods of 5, 10, 20 and 50 years in Nile River basin (January to June)

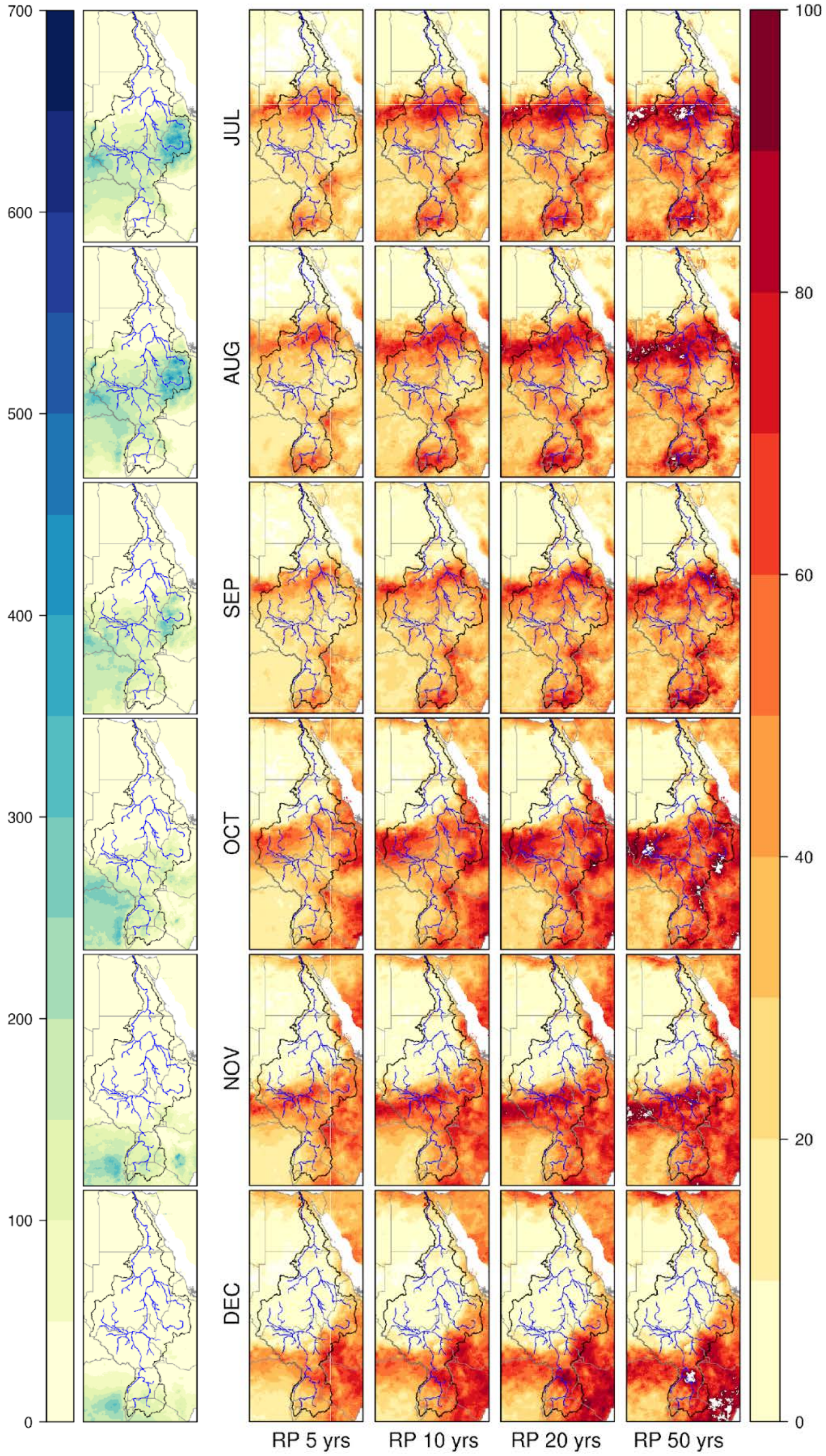

Figure 35 - Monthly mean precipitation [mm](left) and relative deficit values [%] associated to the return periods of 5, 10, 20 and 50 years in Nile River basin (July to December)

3.2.3 Zambezi River Basin

Monthly precipitation average values and deficit values for different return periods for Zambezi river basin are plotted in Figure 36.

The basin is located in Southern Africa, covering different climatic zones with a clear spatial pattern from humid areas along the northern boundary toward the arid-semiarid south-western regions (Okawango inner delta). During the rainy season, extending from December to March, high precipitation rates concentrate in the north, while extending southward.

A preliminary assessment based on the maps suggest the existence of a relationship between climate variability and average precipitation/climate zones. Similarly to patterns observed elsewhere, higher climate variability emerges in the drier souther regions of the basin. It is also worth to note how the precipitation variability reduces in the middle of the dry season, from June to July.

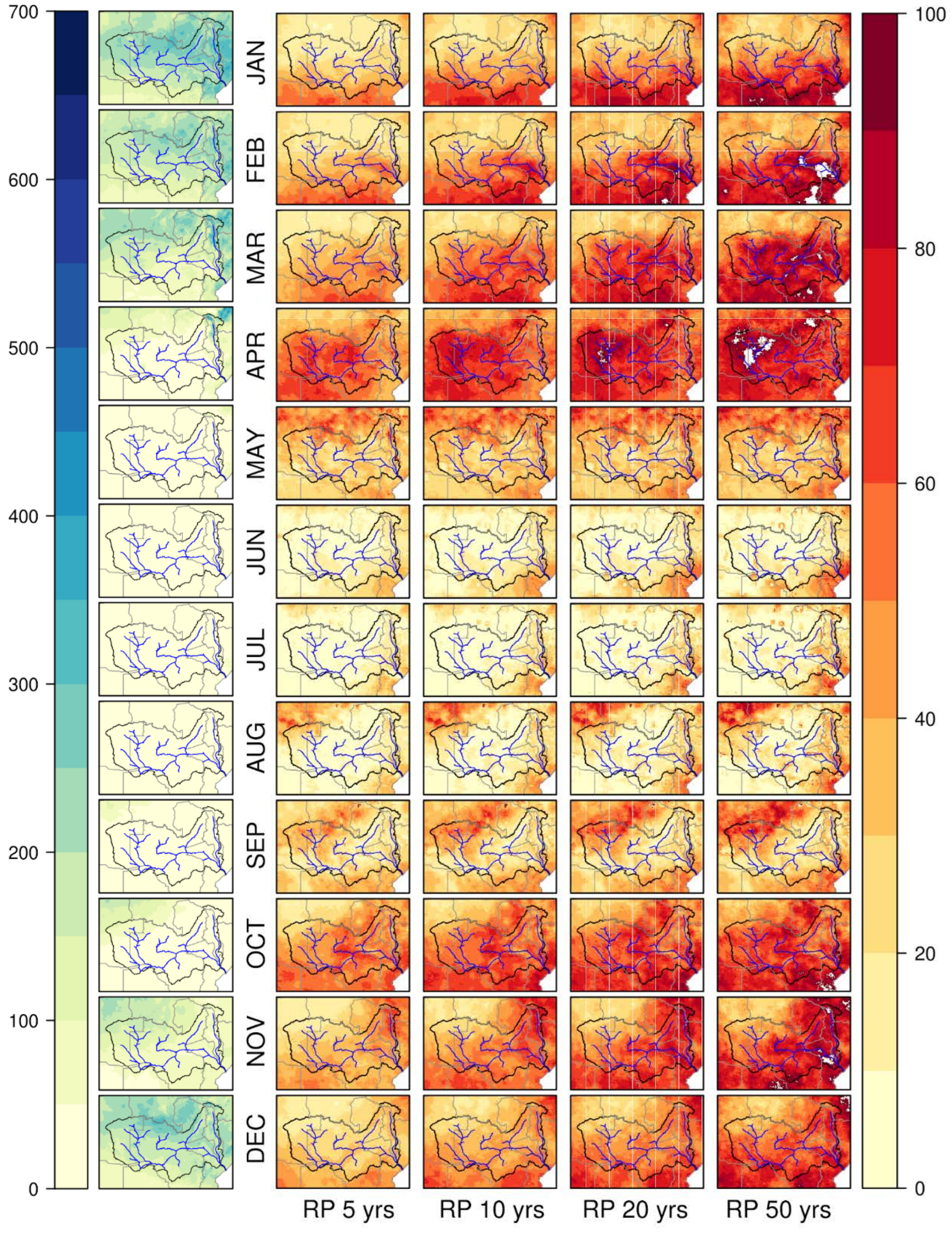

Figure 36 - Monthly mean precipitation [mm](left) and relative deficit values [%] associated to the return periods of 5, 10, 20 and 50 years in Zambezi River basin.

3.3 Heat waves

Heat waves are defined as a period of at least three consecutive days for which daily maximum temperature exceeds a threshold value, which is defined as the 90th percentile of daily maxima temperature, centered on a 31 day window.

Detailed mathematical formulation and possible alternative definitions of the magnitude of a heat wave are discussed in Russo et al. (2015, 2016). Further to this, a magnitude heat wave index has been defined by the authors as the sum of the magnitude of the consecutive days composing a heatwave. Refer to the papers above for the details on computation of daily magnitude.

Spatial gridded datasets of daily temperature can be used to calculate annual heat wave magnitude index, using specific software tools, as the Extremes R PACKAGE (Gilleland and Katz, 2016).

In order to complement the climate variability analysis conducted at the four basins of interest (Niger, Nile, Senegal and Zambezi), heat wave magnitude indices have been computed over the reference period 1981-2017. ERA-INTERIM (Dee et al, 2011) has been used as reference data.

Maps are provided for the four basins (Figure 37; Figure 38; Figure 39), reporting the number of the years over the reference period for which the magnitude heat wave index is greater than 4 (Ceccherini et al,2017). Roughly speaking, the maps can be used to highlight areas characterized by extremely severe hot conditions.

According to Ceccherini et al. (2017), the most impacted areas at continental level include an elongated region spanning through Algeria up to South Sudan, Congo, Angola and Southern Africa. These results find confirmation in current analysis and maps below, where the north-western part of the Niger River Basin; the White Nile area between South Sudan and Congo and the southern part of the Zambezi River Basin are reported as the most critical ones.

Further coupled analysis of heat waves and precipitation deficit is demanded to a future effort, hopefully providing further insight on critical areas. For the moment being, it is worth to stress that spotted heat waves can have relevant impacts on people life and health, hence being particularly critical in densely populated areas.

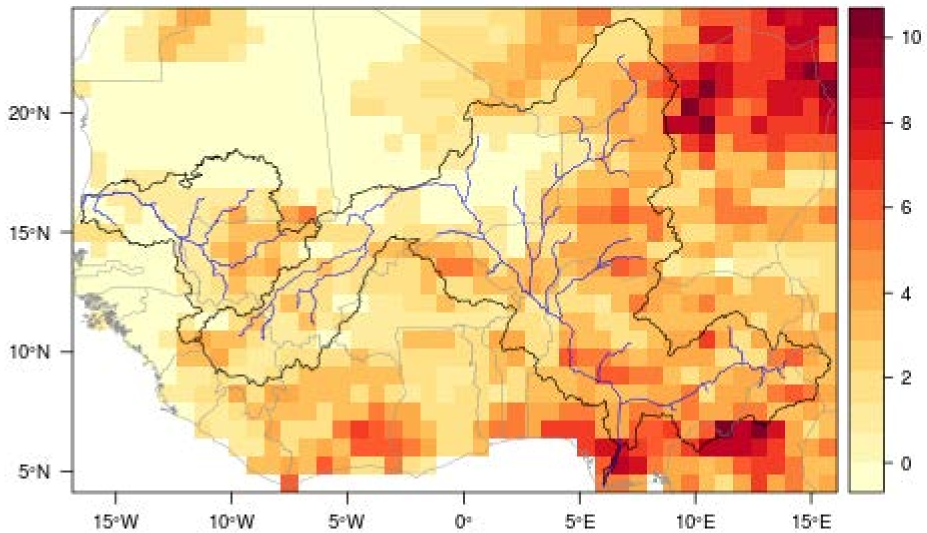

Figure 37 - Number of years with heat magnitude index greater than 4 in Senegal, Gambia, Niger River Basins and Western Africa

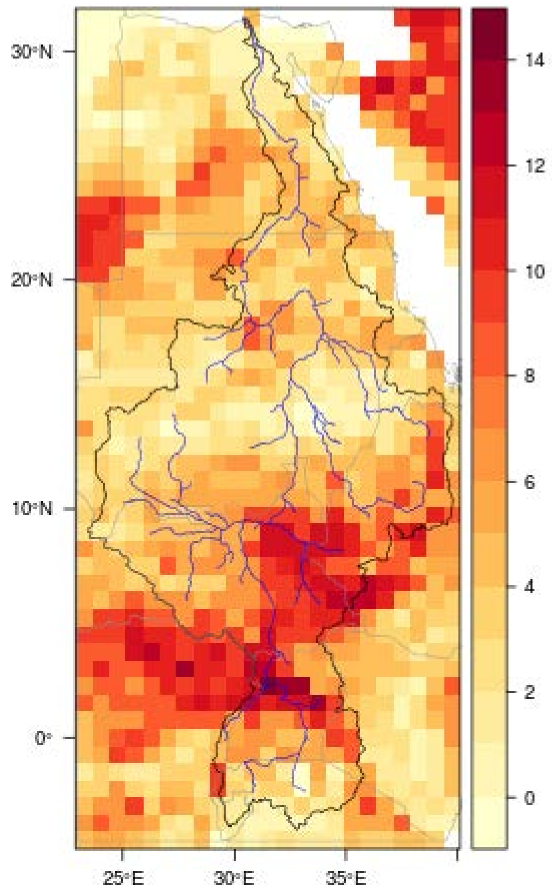

Figure 38 - Number of years with heat magnitude index greater than 4 in Nile Basin

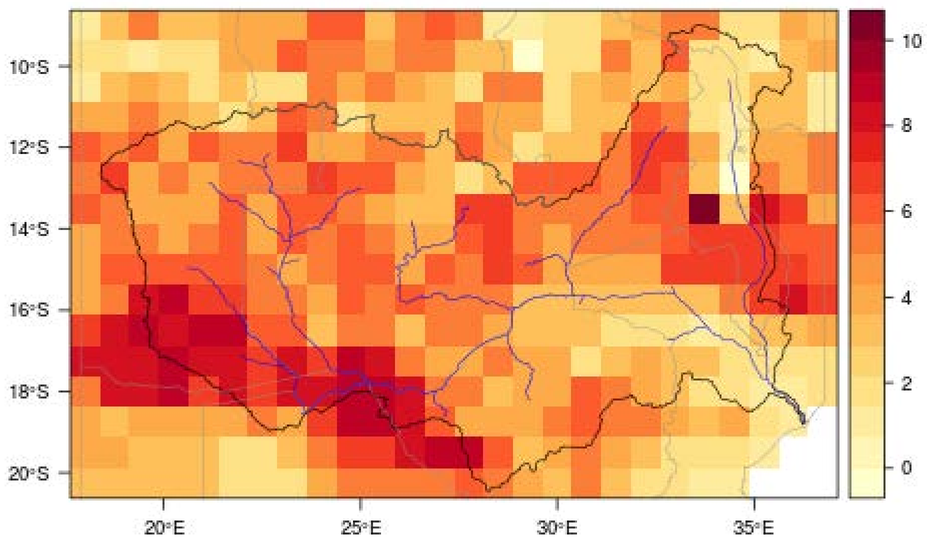

Figure 39 - Number of years with heat magnitude index greater than 4 in Zambezi River Basin

4 Conclusions

This report introduces a comprehensive collection of data for the analysis of hydro-climatological changes and water related socio-economic activities for the African continent. A former activity (Crestaz et al., 2017) focused, further to the database design, also on the preliminary collection and organization of WEFE nexus , aimed at design of the hydro-climatological database and the prelimnary collection of metadata/data (Crestaz et al., 2017) was updated with newly available data sources, including both large scale and locally specific data provided by the ACEWATER2 project scientific partners.A front-end application, extending the Aquaknow knowledge sharing platform, based on DRUPAL and MySQL database, has been presented as well. The application enables end users to upload, query and download both metadata and data, through access to protected user groups, which were setup for the three networks (SANWATCE, WANWATCE and CEANWATCE). Dataset privacy concerns were properly addressed in the system implementation.

The database stores both metadata and data, at different spatial scales, ranging from world, continental, regional, basin, and local scales. Freely available datasets mainly refer to web data sources. CoE provided more detailed data, remote sensed and ground based, as collected and organized in the framework of their own scientific activities.

Metadata were designed to be concise, while providing full descriptive information, such as: licensing or copyright limitations, origin, web references for original data access; and quantitative information, as spatial extent, resolution, and temporal frequency. A rough classification by category supports users' fast search.

The majority of available or referenced data sets come in raster formats (i.e. GeoTiff, NetCDF), including raw data, processed remotely sensed images or by-products resulting from analysis or modelling. Other data include vectorial ones, as borehole or gauging stations location (i.e. in ESRI shape format), and text formats or spreadsheet (i.e. time series in MsExcel or text files).

The database serves the project purpose of sharing spatio-temporal relevant information, whether freely available data sources or ground based data made available by the CoE in the framework of ongoing project scientific undertakings. The database acts as a central repository to facilitate the access to a common set of information (metadata) and data for all the CoE and the relevant stakeholders. The distribution of information was implemented respecting copyright and data ownership concerns trough the implementation of specific password protected working groups.The system is designe to be continuously updated with new information. As new datasets are identified and made available, the users can autonomously submit metadata and upload data to the system.

Finally, a climate variability analysis, focused on precipitation and temperatures, was implemented based on CHIRPS and ERA-Interim datasets.

For the precipitation, frequency analysis, based on L-Moments, was focused on regional and basin scale, consistently with selected study areas in the framework of the ACEWATER2 project (Zambezi, Nile and the entire Western Africa, including the Senegal, Gambia, and Niger river basins).

In most cases, the analysis highlighted higher precipitation variability for areas with lower precipitation, generally the poorest and driest ones, strongly dependent upon rainfall for both water supply and rainfed agriculture.

For the temperature, analysis focused on the computation of heat waves magnitude index, with the same geographical scope. Analysis outcomes reveal the north-western part of the Niger River Basin; the White Nile area between South Sudan and Congo and the southern part of the Zambezi river basin as the most critical ones.

Spotted heat waves can have relevant impacts on people life and health, in both country side and densely populated areas.

5 The way forward

The regional hydro-climatology database was implemented with the aim to store, query and access relevant metadata and datasets, whether freely available or produced by the NEPAD Water CoEs as part of their contractual scientific contributions to the ACEWATER 2 project.

As new datasets will be collected, the information will then be made available within the specific network related to the data owner institution.

In order to provide continuous support to system users and improve their usability experience, JRC is committed to provide:

- System Maintenance.

  Reported issues on the system use will be investigated and fixed by systems engineers. This service will complement the continuous effort to guarantee Aquaknow maintenance and update the system in line with the state-of-the-art technology. Among others, the commitment to preserve data confidentiality by enforcing security policies is paramount.

- Data documentation and updating support.

  Support for both metadata compilation and data uploading to the system is guaranteed to system users in the framework of the ACEWATER2 project.

  The main objective is to maintain the completeness and consistency of both metadata and uploaded datasets. While the overall Aquaknow architecture framework is based on a relational database schema and engine, the datasets themselves are inevitably stored in the file system, following a logical architecture. Great attention will continue to be focused on limiting risks of data duplication and overlapping, promoting a centralized verification over uploaded datasets.

- Architecture improvement.

  The Aquaknow system architecture, including both its GUI facilities and underlying relational database scheme, will be the object of any major improvements, which may be needed to address, for example, the release of major updates of the underlying Drupal framework. The commitment is, of course, to guarantee a smooth transition from any former version, mantaining retro-compatibility and consistent user interfaces.The regional hydro climatology database and specific GUI facilities aimed at supporting the CoE, both during the ACEWATER2 project and in the medium-long term, will be updated consistently.

  As detailed in the chapter on spatial databases, tests are already ongoing for the design and development of a spatial native database and supporting facilities for data cleaning and tidying activities, and database uploading. This activity, which is still at its early stages, is expected to evolve and possibly be released as a complete open source solution.

An example of regional hydro-climatological analysis, presented in this report, focused on the climate variability analysis based on precipitation and heat waves assessment at regional scale.As scientific deliverables on the WEFE nexus analysis are developed by the NEPAD Water CoEs, new data and knowledge covering also the climate variability topic will be made available. In particular, the Un. of Botswana is conducting a climate variability analysis at Zambezi river basin scale, the UCAD/Senegal is focusing on climate assessment for both Senegal and Gambia river basins in Western Africa, and the ICPAC/Kenia is committed to support the regional WEFE nexus analysis in eastern Africa and the hydrological modeling of the lake Victoria basin. The database infrastructure presented in this report will host the products of these analyses and facilitate the interactions among the scientific community working on common domains.Synergies are promoted between JRC and the CoEs, particularly for the climate analysis topic. Refinement of climate variability analysis at regional scale, addressing the need for multi scale integration and detailed assessment at basin level (Zambezi, Senegal, Gambia, Niger, Nile) is already ongoing and will be further documented.

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7 List of abbreviations

ACD	Armed Conflict Database
ACEWATER	African networks of Centers of Excellence in Water
ACLED	Armed Conflict Location and Event Dataset
AGRHYMET	Centre Regional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationnelle
ANBO	African Network of Basin Organisations
AQUASTAT	FAO's Information System on Water and Agriculture
ARA Zambeze	Administracao Regional de Aguas do Zambeze
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTGDEM	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM)
AU	African Union
BGS	British Geological Survey
CEANWATCE	Central Eastern African Water Centres of Excellence
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CIFOR	Center for International Forestry Research
CMIP5	Coupled Model Intercomparison Project Phase 5
CMS	Content Management System
CoE(s)	Centre(s) of Excellence
COW	Correlates of War
CSIR	Council for Scientific and Industrial Research
DEM	Digital Elevation Model
DHI	Danish Hydraulics Institute
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DNA	Direcção Nacional da Água
DTM	Digital Terrain Model

EAR	Entity-Attribute-Relationship diagram
EC	European Commission
ECOWAS	Economic COmmunity of West African States
ERA-Interim	ECMWF Re-Analysis-Interim
ESA	European Spatial Agency
ESA-CCI	ESA-Climate Change Initiative
ESDAC	European Soil Data Centre
EU	European Union
FAO	Food and Agriculture Organization
FGDC	Federal Geographic Data Committee
GADM	Global Administrative Areas
GAM	Global Accessibility Map
GCM	Global Circulation Model
GDP	Gross Domestic Product
GeoEPR	Geographical Ethnic Power Relations dataset
GeoTiff	Geographical Tagged Image File Format
GHS	Global Human Settlement
GLC2000	Global Land Cover 2000
GLDAS	Global Land Data Assimilation System
GLHYMPS	GLobal HYdrogeology MaPS
GLW	Gridded Livestock of the World
GMES	Global Monitoring for Environment and Security
GMIA	Global Map of Irrigated Areas
GPW4	Gridded Population of the World version 4
GRACE	Gravity Recovery and Climate Experiment
GRanD	Global Reservoir and Dam
GSOD	Global Summary of the Day
GUI	Graphical User Interface

HCB	Hidroelectrica de Cahora Bassa
HID	Historical Irrigation Dataset
HyDIS	Hydrologic Data and Information System
HydroSHEDS	Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales
HWSD	Harmonized World Soil Database
IFPRI	International Food Policy Resaerch Institute
IFTD	International Freshwater Treaties Database
IGAD	InterGovernmental Authority on Development
IIASA	International Institute for Applied Systems Analysis
IISS	International Institute for Strategic Studies
IRCC	International Water Cooperation and Conflict
ISARM	Internationally Shared Aquifer Resources Management
ISO	International Organization for Standardization
IWRM	Integrated Water Resource Management
JRC	Joint Research Centre
LISFLOOD	LISFLOOD - Distributed Water Balance and Flood Simulation Model
LP DAAC	Land Processes Distributed Active Archive Center
MAP	Malaria Atlas Project)
MapSPAM	Spatial Production Allocation Model
MCOW	African Ministers' Council on Water
MERIS	MEdium Resolution Imaging Spectrometer
MESA	Monitoring for Environment and Security in Africa) EU programmes
METI	(Japan's) Ministry of Economy, Trade, and Industry
MODIS	Moderate Resolution Imaging Spectroradiometer)
MoU	Memorandum of Understanding
MSWEP	Multi-Source Weighted-Ensemble Precipitation
NASA	(US) National Aeronautics and Space Administration

NBA	Niger Basin Authority
NBI	Nile Basin Initiative
NDA	Non- Disclosure Agreement
NEPAD	New Partnership for Africa's Development
NetCDF	Network Common Data Form
NGO	Non-Governmental Organizations
NOAA	National Oceanic and Atmospheric Administration
OGC	Open Geospatial Consortium
OMVS	Organisation pour la mise en valeur du fleuve Sénégal
PGF	Princeton Global Meteorological Forcing Dataset for land surface modeling
RBO	River Basin Organization
RCP	Representative Concentration Pathway
REC(s)	Regional Economic Communitie(s)
SADC	Southern African Development Community
SADC-GIP	SADC Groundwater Information Portal
SADCO	Sothern African Data Centre for Oceonography
SANWATCE	Southern African Water Centres of Excellence
SCAD	Social Conflict Analysis Database
SEI	Stockholm Environment Institute
SOTER	SOil and TERrain database programme
SRTM	Shuttle Radar Topography Mission
SRTM30	Shuttle Radar Topography Mission (30-meter resolution)
TFDD	Transboundary Freshwater Dispute Database
WANWATCE	Western African Water Centres of Excellence
WDI	World Development Indicators
WEFE	Water-Energy–Food-Ecosystem
WGI	Worldwide Governance Indicators
WHYMAP	World-wide Hydrogeological Mapping and Assessment

	Programme
WTD	Water Table Depth
WWF	World Wildlife Fund
ZAMCOM	Zambezi Watercourse Commission
ZAMWIS	ZAMcom Water Information System

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