Mapping, Assessment & Management of Transboundary Water Resources in the IGAD Sub-Region Project

Volume IV

GIS/DATABASE COMPONENT

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SAHARA AND SAHEL OBSERVATORY

Mapping, Assessment & Management of Transboundary Water Resources in the IGAD Sub-Region Project

Volume IV

GIS/DATABASE COMPONENT

Establishment of the Regional Database and GIS in IGAD Sub-region

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Study conducted with the support of:

SEREFACO CONSULTANTS LIMITED
6 Katonga Road, Nakasero, P. O. Box 6916, KAMPALA
Tel. 256 41 4342397 or 4255577, Fax. 256 41 4230691
E-mail:serefaco@serefacoconsultants.com

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PREFACE

The IGAD sub-region represents one of the marginal regions of the world in terms of rainfall available for natural vegetation growth and crop production. About 80% of the IGAD sub-region is arid and semi arid with low level of water use. It has a population estimated at **206 million in 2010** and projected to reach **462 million in 2050** in an area of **5.2 million km^2**.

The most obvious manifestation has been periodic droughts and desertification that have consigned millions to perpetual poverty and deaths. The populations derive their livelihoods from water and land based primary production activities such as nomadic pastoralism and subsistence agriculture in a region where rainfall variability is high. The sub-region is the home of the greatest numbers of pastoral communities estimated to be about **17 million**. Dependable water availability is therefore vital to the development of the region.

The mounting concerns over water scarcity in the IGAD sub-region have focused attention to several socioeconomic challenges of water resource management.

Firstly, as the sub-region expects to advance economically and socially, the demand for water will increase as a result of population growth, rising incomes, changing dietary patterns, urbanization and industrial development. While demand will increase in all sectors, agriculture will account for the bulk of the water and will therefore be the focal point for adjustment of demand pressure.

Secondly, there are concerns as to whether the IGAD sub-region will have enough water to meet the food security needs of a rapidly growing population. Along with food security, water security has also become a fundamental issue for human development in the sub-region

While it is a fact that water occupies pivotal position in development in the IGAD sub-region, none of the **member countries has adequate information** to manage their water resources for the attainment of economic efficiency and equity in water allocation for different uses. Yet, four IGAD countries namely **Eritrea, Kenya, Djibouti and Somalia** are in the category of those experiencing water scarcity i.e. with **less than 1000 m^3 per person per year** or less.

Indeed by the year 2025 even Ethiopia and Uganda which are presently with adequate water will be water stressed (1000-2000 m^3/person/year) while Djibouti, Eritrea, Kenya, Somalia and Sudan will be in water barrier situation «500 m3/person/year » and therefore water will be limiting any sustainable development.

None of the IGAD Member States has at the present time water per capita necessary for industrial development (2400 m^3/day). This lack of water will severely constrain food production, ecosystem maintenance and economic development among other needs and uses.

Water resources link the IGAD Member states internally and externally with adjacent regions. Six transboundary river basins and six transboundary aquifer systems have been identified in this stage of the IGAD sub-region study. **The ratio of water demands to available supply averages which is 9% in 2011 will increase to 15% in 2031** as projected by this study which is known as "*Mapping, Assessment and Management of Transboundary Water Resources in the IGAD Sub-region Project*". However, there are specific problems that call the need for adequate knowledge of surface and ground water resources.

This Study (the first sub-regional study) has provided a platform for refocusing efforts within the sub-region towards better quantification and understanding of the extent of water scarcity and other water related factors that impact socioeconomic development in the sub-region. The most significant of the drivers of water demand in all sectors is population, which in the sub-region is projected to increase by 165% between 2010 and 2030, and by 136% between 2030 and 2050. This study demonstrates that these increases will create significant increases in water withdrawals for domestic supply and for industry.

The other significant sector is agriculture, which combines irrigation and livestock. Again here population is the most important parameter of change, driving the demand for food and hence the need to raise agricultural productivity through irrigation development.

The regional process has highlighted the **low level of water use** and hence of water security currently estimated as about 3% of the annually renewable water resources as a basic indicator of the overall lack of water infrastructure development to ensure water security for the social and economy and environmental use. The IGAD sub-region is one of the most vulnerable areas to climate variability and recurrent droughts.

Hence, there is need to further understand in depth the environmental situation and consolidate IGAD capacities to monitor the linkages between climate and the water system along with identification and mapping of the water resources and the major risks associated with degradation, pollution and water quality deterioration. Policies, strategies, and objectives of cooperation and how to achieve them should be set out in a second stage of the IGAD project study.

It is important to note that the IGAD project was implemented at national and sub-regional levels with active participation of the focal national institutions by employing national and regional consultants. The project coordination is done by OSS with the establishment of national coordination units in the focal national water institutions of the IGAD Member States. Steering Committee of the project was in place and the regional coordination and facilitation was done by IGAD.

We would like to thank everyone who contributed to the success of this project: the Ministries in charge of Water and national institutions, the IGAD and OSS cooperation partners (particularly the African Water Facility), the national teams, national and

international consultants, the project team within the Executive Secretariat of OSS and The IGAD Secretariat.

Our satisfaction was to pass the ownership of all project results by national teams and the establishment within the Executive Secretary of IGAD powerful tools to ensure the continuity of the project.

This final project report is made up of 7 individual documents namely

- Introduction, Overview and General Recommendations
- Volume 1: Institutional Framework Component Report
- Volume 2: Socioeconomic Component Report
- Volume 3: Environment Component Report
- Volume 4: GIS/Database Component Report
- Volume 5: Water Resources Modelling/Hydrology Component Report
- Volume 6: IWRM Component Report

We also thank SEREFACO Consultants Limited and its team for the excellent work carried out despite all the difficulties encountered particularly the lack of reliable data.

The Executive Secretary of OSS	The Executive Secretary of IGAD
Dr. Ing. Chedli FEZZANI	Eng. Mahboub Mohamed MAALIM

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CGS	Geographical Coordinate System
CIESIN	Centre for International Earth Science Information Network
DB	Database
DCM	Data Conceptual Model
DCW	Digital Chart of the World
DEM	Digital Elevation Model
EUDASM	European Digital Archive of Soil Maps
FAO	Food and Agricultural Organisation
GADM	Spatial Database of Global Administrative areas
GIS	Geographical Information System
GLC	Global Land Cover
GLCC	Global Land Use Land Cover Characterization
GLCF	Global Land Cover Facility
GPW	Global Population of the World
GVM	Global Vegetation Monitoring
ICPAC	IGAD Climate Prediction and Applications Centre
ICT	Information and Communications Technology
IGAD	Inter-government Authority on Development
JRC	Joint Research Centre
NBI	Nile Basin Initiative
ppm	Parts per million
SCCF	Special Climate Change Fund
SEDAC	Socioeconomic Data and Application Centre
SRTM	Shuttle Radar Topography Mission
SSO	Sahara and Sahel Observatory
ToR	Terms of Reference
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Surveys
UTM	Universal Transverse Mercator
WGS	World Geodetic System

EXECUTIVE SUMMARY

The objective of the sub-component was to create the DB that will facilitate easy information access and exchange between the IGAD member countries.

The major activities of the component have been to carry out the analysis of required entities and attributes for DB development, defining entity relationship model at Conceptual level and thereafter to carry out DB installation and testing, data conversion and semantic translation, data input into the database and data output generation.

In addition, assessment of the suitability of the available data in the national reports has been made. Since the database cuts across all the sub-disciplines, the summary has been restricted to the quality aspects of the data in the reports. It is assumed that the adequacy and relevance aspects of the data will be addressed in the specific sub-discipline assessment reports.

By the end of the project, all the activities have been accomplished, with a regional DB built. The DB built included both identification and variable data/information on borehole, shallow wells, Meteorological, hydrological and river gauging stations. In total, 83,064 (Eighty three thousand and sixty four) water points have been input the regional DB.

Data provided were quite heterogeneous, different formats and semantics. The variation in data semantics was minimised greatly, but some still exist due to lack of basic meaning of those water points, example is "Source" of Djibouti and 1st class water points of Eritrea. This requires the intervention of coordinators in those countries.

Heterogeneous of the data was eliminated completely by converting all the data to Microsoft excel and thereafter importing it in Microsoft access. However, in the process of harmonizing it, some of the data fields were left out as they could not fit in the data structure.

The major shortcomings encountered during data compilation and analysis was as follows:

- Coordinates; 29% of the water do not or have wrong coordinates. This excludes them from being spatially plotted and visualised in GIS. This shortcoming is very hard and complicated to overcome without involving the Coordinators from member countries. This will be eliminated continuously when updating the DB whenever coordinates of those points are availed.
- Duplication; almost all countries had duplicates in their datasets. This was a very serious setback removing them. Duplication was in all forms (identifier, coordinates, source names, source codes) but majority were duplicated by identifier. Those which were duplicated by

all forms were eliminated from the DB and those which were duplicated by identifier were given another unique identifier.

- Lack of Identifier; most data did not have identifier key. However, these were created, an example is x_Eth_1 (meaning x=No identifier key, Eth=Ethiopia, 1=water point 1). Apart from Uganda borehole identifier (WDD or DWD), other countries had normal numbers as the identifier key. This would make the water point to be duplicate basing on identifier yet they are not. And in the process the identifier key would not be made a primary key. This was overcome by creating a unique key from the normal number, an example 10000_Eth (10000= normal number which was used as identifier in the country and Eth=Ethiopia).
- Lack of important field; for example most water points do not have the "status" field, one cannot easily identify the non functional from functional borehole in one administrative unit. This would be very misleading especially in spatial distribution of water point maps and in decision making in future if say one is following the spatial distribution.

The data conceptual model was adopted from OSS 2007, and involves the inputting all the data available and developing the data structure. It also required understanding of the following: Information sets (entities), the nature of the existing links between these sets, the management guidelines associated with these entities

The following planned rules were set which synthesises the entities and the relations:

- A borehole can pick up 1 or many aquifers.
- A borehole at a given date provides a given yield.
- A borehole can serve many users.
- A user can be supplied by many boreholes.

All water points with coordinates were plotted in ARCGIS 9.3, projection GCS-WGS 84 and for demonstration purposes most maps have been inserted in this document.

DEFINITIONS

Information system (IS): A set of elements that are dynamically interacting and organised in relation to an objective.

Database (DB): A database is a tool for collecting and organizing information relating to a specific domain. A database is governed by a model and should meet a number of specificities:

- Full independence between data and processing.
- No redundant information.
- Data integrity and coherence

DBMS: Software for manipulating, managing and using a database. Most of the DBMSs available on the market are relational, i.e. based on the set theory and consisting of all the relational algebraic operations (union, join, intersection...)

Design approach: The database design process is generally subdivided in three stages: the design stage leading to the data model definition, the logical implementation stage and the operation stage with a machine and the selected DBMS.

Design tools: The generalisation of relational databases led to devising design methodological tools which make it possible to set up performing and long-lasting systems since they are based on the mastery of basic information. These tools have operation rules, formalism and sometimes even support software to facilitate data model elaboration.

Data model (conceptual model): A highly intellectual tool used for the representation of the real world through managed information and interrelated links. Such tools provide a graphic schematisation to better symbolise the representation.

Relational model: Developed by the end of the 1970s to secure:

- Total independence between data and processing: sustainable and open systems.
- Data access through high-level nonprocedural languages.
- User views may differ from the established ones. Each user may have his own view of the database objects.

Table: A database table is similar in appearance to a spreadsheet, in that data is stored in rows and columns. As a result, it is usually quite easy to import a spreadsheet into a database table. The main difference between storing your data in a spreadsheet and storing it in a database is in how the data is organized. In our case we have tables of water points, administrative unit e.t.c.

Entity: This is an information system object with features. It is also referred to as an individual or an object. In our case a water point is an entity.

Relation: (or Association): A link which may exist between two entities and reflects the management rules into force.

Property or (attribute): Elementary information run by the information system. It is linked to an entity and sometimes to a relation. The name, the altitude and the coordinates of a water point are properties.

Identifier: Particular property which makes it possible to identify in a single way an entity. The number of classification of a water point is an identifier.

Request: it is the object of a base ACCESS which is used for posting, modifying or analyzing the data coming from one or more tables.

Form: a form is before a whole tool making it possible to seize with the keyboard of the data which are immediately introduced into one or more tables. The form is thus related to one or several tables, and it inherits their properties: types of data, properties of the fields.

Linked table (or attached): table being in another data base (that it is of type ACCESS or other).

Field: element of a table being used to contain information. A table comprises one or more fields (columns).

Primary key: single identifier of each line of a table. A key can be either a field, or a concatenation of several fields.

Referential integrity: it is the mechanism which preserves the relations defined between several tables when recordings are modified or erased. The referential integrity guarantees the coherence of the values of keys between the tables.

Report: Reports are what you use to summarize and present data in the tables. A report usually answers a specific question, such as «How much money did we receive from each customer this year?» or «What cities are our customers located in?» Each report can be formatted to present the information in the most readable way possible.

Queries: Queries are the real workhorses in a database, and can perform many different functions. Their most common function is to retrieve specific data from the tables.

GTOPO30: This is a global DEM providing terrain elevation data with a horizontal grid spacing of 30 arc seconds (approx. 1km).

1

INTRODUCTION

The task of Database (DB) and Geographic Information System (GIS) subcomponent was the establishment of IGAD region GIS database (DB) that will facilitate easy information access and exchange between the IGAD member countries.

Reports were received for five member countries of IGAD. The countries include Ethiopia, Kenya, Sudan, Uganda and Djibouti. For each country, three reports (State of the Environment, Water Resources and Social economic situation) were studied while highlighting the quality of data that has been included.

It was found out that the majority of the information existed in national reports, national databases, regional and international study reports and databases. However, it was cumbersome and so time consuming to access this information because of its scattered nature and variations in the semantics and spatial reference systems used to compile the information.

The component's work was divided in three phases: phase 1, Phase 2 and Phase 3.

The major activities of phase 1 included; System Analysis which included identify current and potential users of the regional database, identifying functions of the DB, entities and attributes and identifying entity Relationship Model at Conceptual level; Logical Design/ Physical Design which included understanding specification of Logical Model in selected software, Specifications for Hardware and software, and table structures created in the software, Equipment/software installation.

The suitability of the available data in the national reports with respect to the requirements for developing a regional database was studied. Since database development as a component, utilises data from all the other components of the project, the discussion only focuses on data quality aspects as opposed to adequacy or fitness for purpose. The assumption made in this phase was that adequacy is competently discussed in the respective reports for each sub-discipline of the project. By data quality aspects, we refer to data semantics, spatial data formats, ability of data to be presented on maps, data accessibility, and level of details for national and regional GIS analysis.

During this phase, spatial data reference was studied for later conversion to standard or easily convertible geometrical spatial reference systems. This was necessary to ensure that analyses that combine multiple GIS layers do produce accurate outputs. Variations in data formats may lead to significant visible or invisible shifts in map layers, which will in turn create errors in the positions of features in a GIS database.

Knowledge of data semantics was essential in ensuring that database objects consistently refer to the same objects in the real word for each of the member countries. This was also a very important activity in this component. For example, in the scenario of this problem, what is regarded as a borehole in one country's report may be defined as a Deep well in another country's report. One of the consequences of this is that a query for borehole to the database may generate output that ignores deep wells. The database designer therefore was required to know what meaning are attached to each object before designing a database encompassing objects in different databases/domains. All these were harmonised after the systematic study of the names used by each IGAD member countries.

In order to facilitate cross-border analysis of water resources, it was necessary to define a set of uniform and consistent indicators. Although national reports contained some unique and context specific information at a more detailed level, the regional database was developed contain cross-cutting spatially/thematically aggregated data which was developed by consistently defined uniform standard.

After these parameters were defined in the database structure, it was necessary to directly import data or reformat data or else undertake fresh data capture on the new parameters in countries where there is insufficient data.

Understanding spatialisation of data was also very important at this phase. Without coordinates spatial analysis of such data was not possible given that the locations cannot be displayed on a map.

During Phase 2 the emphasis was put on conceptualization, preliminary DB installation and testing, preliminary data conversion and semantic translation, preliminary data input into the database and preliminary data output generation. The variation is spatial reference has been addressed by adopting Geographic Coordinate System (CGS) WGS 84, datum WGS 84 and coordinate formats degree decimal. In the process of developing a regional database, the variation in semantics limitations were addressed and substantially minimized.

Phase 3 involved full scale data conversion and semantic translation, full scale data input into the database and full scale data output generation.

2

DESIGNING, ESTABLISHING AND IMPLEMENTING OF HARMONISED REGIONAL DB

1. APPROACH AND METHODOLOGY

The development of the IGAD regional DB required the following stages:

- Diagnosis phase: analysis of functions of the system; users and their requirements; data formats and semantics.
- Design phase: design of a data conceptual model/schema (DCM) and the best adapted organisational and technical solution.
- Realisation phase; he translation of DCM into a physical model depending on the Database Management System (DBMS) selected according to the previously chosen technical solution.
- Implementation phase; Implementation in the adopted organisational environment after available data transfer.

2. ANALYSIS OF DATA PROVIDED BY IGAD MEMBER COUNTRIES

The collected and analysed climatic, hydrological and hydrogeological data in the IGAD Member countries allowed identifying inconsistencies of data from the beginning and systematic correction. Data processing was done using GIS softwares which included ARCGIS 9.3, Oasis Montaj, DIVA-GIS, Microsoft Access, Excel and MapInfo. All data including those without any geographical attachment (coordinates) have been included in the DB but will not be spatially represented on maps in GIS environment.

The format of the obtained files is heterogeneous which included Microsoft Excel, Word, Maps, pdf, access, etc.

The Excel files include hydrogeological information relating to water points, piezometric levels, hydrodynamic parameters and lithology, while the maps data were mainly for Eritrea and Word data were mainly for Djibouti data.

These files include many gaps, notably missing coordinates, water points without identifier, non-informed altitudes, duplicates and wrong coordinates.

The identification of the water points coordinates is a tedious operation, requiring extensive cross-checking and interpretation. This is because each country uses different coordinate systems (Andedan, WGS84, Latitude and Longitude, and Unknown) and was in different geographic zones (zone 35 to zone 38). Thus data conversion was sometimes confusing. However, with the help of GIS softwares and Google Earth webpage, it was possible to eliminate this problem for some water points. For some water points whose origin coordinates was not stated and could not be identified, it was impossible to convert them to Longitude/Latitude for easy plotting and visualisation.

2.1. Djibouti data

The file format of Djibouti data is heterogeneous: Excel, Word and maps. It brings together geological and hydrogeological data relating to water points, piezometric data, hydrodynamic parameters, and some water table operation flow values.

The identified gaps noted are of the following type: missing coordinates, water points without an identifier, missing altitudes, missing dates of completion and acquisitions, Missing status and unknown projections of the coordinates still exist for some water points.

Below is the summary of the data which were captured and input in the DB from Djibouti (Table 1).

Site type	Number of entities
Puit Ciment	468
Puits traditionnel	463
Forage	270
Hydrodynamic Station	131
water quality	118
Retenue	72
Natural Source	52
Meteorological Station	39
Piezometric monitoring Station	10
River gauging station	6
Hydrometric	5
Guelta	3
Citerne ent	3
Micro-Dam	1
Total	**1641**

TABLE 1. Summary of water point captured in Djibouti

Djibouti data, in particular those referred to as water point characteristics, in addition to their identification information, data on coordinates, Source types and status, some of them have Variable data. The variable data collected and input in the DB include temperature data, hydrodynamic data, discharge data and rainfall data. Administrative unit information was missing, however, water points with coordinates were plotted in administrative units downloaded from DIVA-GIS[1]. By integrating water point and administration boundary, administration units for each water point was created.

2.2. Eritrea data

All Eritrea data was provided in map form, and were exported to excel before they put in the Db. The summary of the data captured from Eritrea is as shown in Table 2.

2.3. Ethiopia data

Most of Ethiopia data provided was in Excel format, and that made is analysis easy. However,

1. http://ww.diva-gis.org/datadown

the issue of wrong coordinates and duplicate entries was serious. Just like Djibouti, administrative unit were not defined so it was originated integration of administrative data from DIVA-GIS.

Some water points which have descriptive data of lithological characteristics have been captured in the DB (see Lithology table in the DB). The summary of the captured data is summarized in Table 3.

Site Type	Number of entities
Hand dug well	936
Borehole	927
Dam	134
Rain Gauge	126
River Water	78
Spring	44
Meteorological Station	39
Pond	29
River Gauging station	20
1st classs	11
Peizometric water point	5
Reservoir	2
Total	**2351**

Table 2. Summary of Eritrea data

Site type	Number of entities
Borehole	2707
Spring	1079
Meteorological Station	711
Hydrological Monitoring station	443
Hydrometric	120
Hand dug well	85
Rain Gauge	72
River Water Quality	10
Total	**5227**

Table 3. Summary of Ethiopia data captured

2.4. Kenya data

Kenya water points collected were in Excel; the summary is in Table 4. However, the challenge with the data was duplication of identity number, yet source name, code, use, owner of the source, total drilled depth (Tdepth) and total yields was different, see Table 5. This confirmed to extent that they were different water points. The unfortunate part of it is that such duplicates only one of them had coordinates. Therefore, all of them were assigned different unique identifier and were input in the DB. Also all water points with variable date were in put in the DB (see for example rainfall table in the DB, it includes daily rainfall data).

Site type	Number of entities
Borehole	14196
Water Quality	5312
River discharge Station	169
Hand dug well	107
Rain Gauge	94
Meteorological Station	76
Hydrometric	23
Dam	23
Spring	18
Wastewater Quality	8
Total	**20026**

Table 4. Summary of collected data for Kenya

2.5. Uganda data

Uganda data was all in Excel tables with administrative units clearly defined. However, the issue of duplication, wrong coordinates and missing coordinates still existed for some points. The summary of the water point collected is shown in Table 6.

ID	Code	Source name	LONGI	LAT	GRIDX	GRIDY	ALT	USE	TDEPTH	YIELD
1	C	Katani	37	-1	277461	9854385	1768	A	121	1.08
1	P	Karen					0	D	182	0.45
1	SA	Huf					0	D	31.4	0.68
2	P	Ngong					0	D	83	0.95
2	SA	Jth 8998					0	D	65	0
2	C	Katani	37	-1	277461	9854385	1661	A	123	5.28
3	C	Emali	37	-2	327620	9764133	1219	P	95	16.2
3	P	State House					0	D	250	9
4	P	Ngong					0	P	92.7	0
4	SA	Hus 0628					0	D	30.4	11.7
4	C	Kilima Kiu	37	-2	301628	9799114	1768	A	61	0
5	C	Kilima Kiu	37	-2	301626	9800961	1768	A	152	1.8
5	P	Roysambu					0	D	134	3.24
5	SA	H.T.P.3557					0	D	85	0
6	SA	Near Isiolo Town-Nya	374815	2015			1082		39.3	4.53
6	P	Ngong					0	P	72	0
6	C	Kilima Kiu	37	-2	307194	9797284	1524	A	62	0.78
7	C	Kilima Kiu	37	-2	301626	9800961	1768	A	72	0
7	P	Roysambu					0	D	22	0
7	SA	Habasweni					0	D	19	2.2
8	C	Kilima Kiu	37	-2	303472	9802809	1768	A	69	0.66
8	P	Roysambu					0	D	20	0
9	C	Kilima Kiu	37	-2	303472	9802809	1768	A	76	0
9	P	Kima Estates					0	D	72	0.6
10	P	Nairobi					0	D	61.5	0
10	SA	Garbatula					0	D	34.7	6.75
10	C	Kilima Kiu	37	-2	299770	9799112	1768	A	60	0
11	C	Kilima Kiu	37	-2	299763	9806488	1402	A	52	1.08
11	P	Kima					0	D	44.5	9
11	SA	Wajir					0	D	21.3	0.05
12	C	Kima	37	-2	299759	9810170	1646	A	109	0
12	P	Boma Ngong					0	D	96.9	1.53
13	C	Kilima Kiu	37	-2	301621	9806490	1676	A	79	0.12
13	P	Sigona					0	D	21.3	4
14	C	Kima	37	-2	299763	9806488	1432	A	20	0
14	P	Karen					0	D	89.3	9.36
15	P	Kilima Kiu Est.Ltd					0	D	46.3	10.8
15	C	Kima	37	-2	303475	9799116	1585	A	48	9
16	C	Kima	37	-2	303484	9789905	1524	A	50	0
16	P	Ngong					0	P	148	1.8
17	P	Ulu					0	D	66	0.05
17	C	Kima	37	-2	305346	9786225	1737	A	38	7.56
18	C	Kima	37	-2	307206	9784380	1585	A	47	3
18	WP	Gk Stn. Kibarani							0	0
18	P	Kilifi						P	164	0

TABLE 5. Extent of duplication of data in Kenya borehole data

Site type	Number of entities
Borehole	26844
Protected spring	15179
Shallow well	4669
Yard tap for public use	4020
Valley Tank	918
Kiosk	870
Meteorological Station	455
Dam	405
Earth Dam	141
Hydrological Monitoring station	58
Rain Gauge	51
Fish Pond	42
Pollution Impact on water sources Microbiology	25
River discharge Station	23
River Water Quality	18
Water Quality	13
Salinity Station	13
QryPWSAYB	12
Lake Water Quality	9
Pollution Impact Sampling Sites	8
Sewage Works	5
Production well	4
SWAMP	2
Natural lake	1
Rock Catcment	1
Hydrometric	1
RWT V.Tank	1
Windmill	1
Total	**53789**

Table 6. Summary of data collected from Uganda

2.6. Sudan data

Among the IGAD member countries, Sudan provided the least data for the common DB. See Table 7 below. An excel table named 1961-1991 was provided containing 28 records, without identifier and the year when the measurement was made was never provided. No addition is available in the reports provided.

Site type	Number of entities
Rain Gauge	30
Total	**30**

Table 7. Summary of Sudan data

3. INCONSISTENCIES AND SHORTCOMINGS

The gathered data come from diverse sources thus:

- Data formats were differing greatly; this was harmonised by converting all the data into the Microsoft excel and thereafter imported direct in the Microsoft Access to make the DB.
- The information level differs from one country to another; However, the regional database was developed contain cross-cutting spatially/thematically aggregated data which was developed by consistently defined uniform standard.
- The collected data were not always compatible with the DB structure, and are adjusted accordingly leaving behind some fields and yet having gaps in another fields.
- Some water points did not have coordinates and others have wrong coordinates. This excludes them from being plotted and analysed, since they are not geographically geo-referenced.
- There were duplicates by coordinates: water point with different characteristics (identifier, name,..) but with similar coordinates, and water points with same identifier but different source name, total drilled depth etc. Duplicates which were obvious were eliminated.
- Almost all IGAD member countries use different coordinate system.
- High variations in semantics; for example what is shallow well in Uganda is a borehole in Djibouti; this was reduced but was not eliminated as some where we need the intervention of country coordinators.
- Lack of identifies keys; Special identified were developed for systematic development of the regional DB.

4. ADDITIONAL INFORMATION COLLECTED DURING THE PROJECT

4.1. Transboundary aquifer[2],[3]

Six transboundary aquifers occur in IGAD members. Some details of these aquifers are as shown in Table 8.

The spatial extent of these transboundary aquifers is a shown Figure 1. No detailed research has yet been done on these transboundary aquifers except for Merit aquifer.

Merti aquifer[4] stretches from Yamicha through Habaswein to Liboi at the Kenya/Somali border. There have been a number of studies covering eastern Isiolo, Wajir and Garissa Districts. Ministry of Works of Kenya (1963) carried out a hydrogeological assessment. The report stated '… It is believed that, with the exception of areas near Mado Gashi and north-east of Habaswein, groundwater of good quality can be obtained by drilling anywhere. Subsequent studies have improved upon this assessment and shown up differences. Swarzenki et al. (1977) described the hydrogeological components of an extensive range of development

[2] Transboundary aquifer of the World Update 2009, by IGRAC at 1:50,000,000. Special edition for the 5th World Water forum; Instanbul..

[3] UNESCO, Man aging Shared Aquifer Resources in Africa, IHP-VI, Series on Groundwater No. 8, ISARM – Africa, 2004.

[4] Groundwater resources in Kenya by Fred K. Mwango, B.C. Muhangú, C.O. Juma, I. T. Githae, June 2002.

Code	Name of Aquifer	Sharing Countries	Sharing basin	Aquifer type	Area (km²)
AF35	**Upper Nile basin**	Ethiopia and Sudan	Nile		354700
AF36	**Awash Valley Aquifer**	Djibouti and Ethiopia	Danikil		163300
AF37	**Rift Valley Aquifer**	Uganda, Kenya and Sudan	Turkana-Omo	Fissured and Limited	95430
AF38	**Ogaden-Juba Aquifer**	Ethiopia and Somalia	Turkana-Omo, Juba-Shebelle, Ogaden	Intergranular and fissured	363100
AF39	**Mt. Elgon Aquifer**	Kenya and Uganda	Turkana-Omo	Fissured	104500
AF40	**Merti Aquifer**	Kenya and Somalia	Turkana-Omo, Juba-Shebelle	Unconfined and Semi confined	65750

Table 8. Summary of IGAD transboundary aquifer (Extracted from IGRAC, 2009).

project that covered the whole of North Eastern Province and Eastern Isiolo District. Part of the project's activities was the drilling of exploratory boreholes across much of the Merti Formation, thus allowing a clearer indication of the presence of portable water within it.

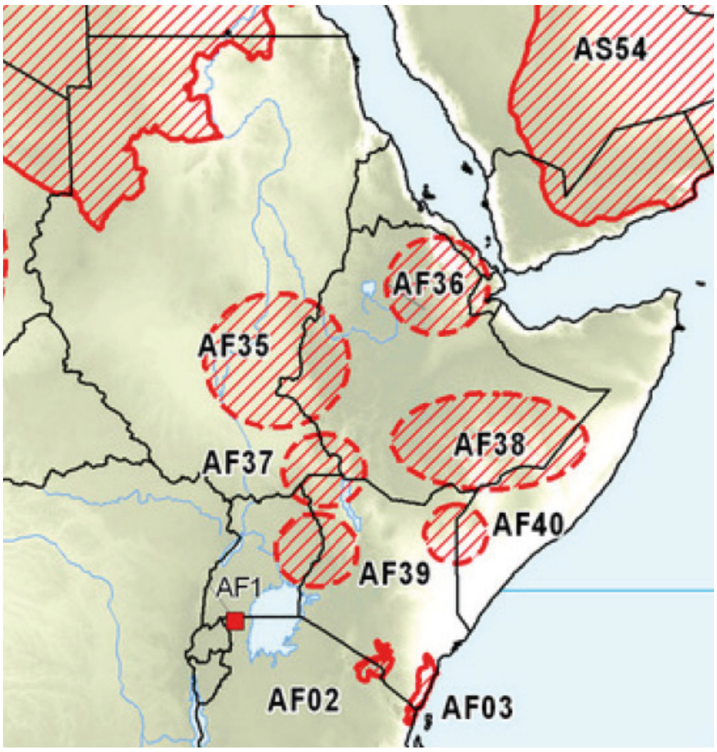

Figure 1: Major transboundary aquifers in IGAD sub-region (Extracted from IGRAC, 2009)

In respect of the Modogashe area, the report indicated that saline water would be encountered in the Modogashe-Sericho-Merti area, and to the east of Habaswein: however, the Habaswein area itself was reported to be underlain by a fresh water aquifer. Lester (1985), evaluated the results of borehole drilling undertaken in the area and recommended that a comprehensive geophysics programme to delineate the freshwater Merti Aquifer, that boreholes in the fresh water aquifer drilled not less than 110 metres below ground level Shallow boreholes adjacent to the Ewaso Nyiro to exploit alluvial aquifers and that 'No boreholes, either shallow or deep, should be drilled along the Galana Gof east of Benane. Fresh water supplies can be developed from clay fill subsurface dams in the sandy river bed'. Ministry of Water

Development of Kenya(1991) defined all the Merti Formation in the southern part of the Isiolo District as '...very poor...', stating that 'the southern part of this area offers no good chances for groundwater development as the groundwater is highly mineralised'. Lane (1995), in his thesis, attempted a synthesis of all data available on the Merti Aquifer, and broadly confirmed the findings of earlier studies. Geologists from the Water Development Department have also been carrying out hydrogeological surveys and studies at various locations within the Merti Aquifer. These surveys were conducted on demand basis or as need arise.

5. BASIC DEVELOPMENT OPTIONS

5.1. Organizational choices[5]

The organization choice was adopted and modified from (OSS 2003). To collect and manage information from IGAD sub-region, there are three levels of treatment;

Level 1: Regional database which is managed database common to the entire region, like IGAD sub-region.

Level 2: National database which is managed database common to the entire Nation

Level 3: Basin database which is managed database common to the entire basin.

Each level has specific information and more information Commons found at the upper level. Under this project, interest has been focused on all levels. It is for countries to delimit the structures of regional and update it.

The technical solution required by all country is to adjust the BD national structures (level 2) to make them truly relational, correct inconsistencies and improve the coding in place for adapt to the needs of regional DB, Figure 7.

But this choice requires the active participation of country teams and more training is

important. This will help them be able to take their own support tasks of collecting reliable information for the system, maintenance and adaptation to sub-regions' needs.

5.2. Technical choice and computer tools

The technical solution for operating the IGAD information system software is adopted by accounting for the following points:

- Availability in the seven countries' public sector.
- Implementation simplicity of control by the project national teams.
- Formats and data exchange mode with the digital model.
- Current technological trends.

[5] Systeme aquiifere du Sahara septentriional, Base de données et SIG; Volume III by OSS, June 2003.

It is highly important that the used tools are "easily accessible" to water resources administrations technicians in charge of the Database and information System. Since such new software is not available in the public sector, it would be very difficult for the IGAD information system managers to obtain the required equipment and control its use at the appropriate time.

"Implementation simplicity and control of information system management tools" are two prerequisite conditions which facilitate its mainstreaming in the countries' underground water management tools.

For the project as well, it is highly important that this tool control is done over a long training period to be able to move to the planned applications.

Given the available data heterogeneity, exhaustive volume and the need for its geo-referenced processing, it is practically very difficult to ensure its analysis by modelising and resorting to manual data entry methods only. The information geo-referenced processing is a means to validate and process it.

For such reason, "**ACCESS**" was the right choice, and whose most recent version has interesting functionalities. In its 2000 version, ACCESS has characteristics that allow it to manage databases whose volume is fairly important (up to 2G) in a network environment and even intranet.

- **Replication** allows for a central database update by regional databases. The data update by the country teams is made with the help of a mechanism which synchronizes the content of all databases and maintains data coherence.
- **Concurrent data access** in a multi-user environment
- **An enhanced data securisation** with the possibility of creating several groups with separate authorisations and access rights.
- **Easy migration possibility** to other DBMS such as SQL/SERVER by means of a simple utility programme delivered with the product.

ACCESS was then chosen because the processing nature and the data volume managed by the IGAD project do not require a more complicated DBMS. ACCESS is a component of OFFICE management system and largely used in administrations.

The member countries teams have sufficient control of it to operate and administer the database it has generated. The selection of the other IGAD information management software was made on the same grounds.

ARCGIS 9.3 was selected for data visualisation and analysis because of its easy use, powerful functionalities, perfect compatibility with ACCESS and fairly general use in the water resources field. In addition, ARCGIS is the leading GIS software in the world and is compatible with many other GIS data formats. Endowed with a strong development language, it allows for the writing of customised utility programmes which are required by GIS links-mathematical models. It is assumed that the software is used in the water resources administration in the five countries participating in the project.

5.3. Contents of the regarded information system

ARCGIS 9.3 was selected for this project because of it international usage and its functionalities and compatibility with other GIS software. Three ARCGIS desktop applications; ArcCatalog, ArcMap, and ArcToolbox were used to do this work. ArcCatalog is the application for managing your spatial data holdings, for managing your database designs, and for recording and viewing metadata. ArcMap is used for all mapping and editing tasks, as well as for map-based analysis. ArcToolbox is used for data conversion and geoprocessing. Using these three applications together, you can perform any GIS task, simple to advanced, including mapping, data management, geographic analysis, data editing, and geoprocessing.

ArcMap allows you to work with all of your geographic data in maps, regardless of the format or location of the underlying data. With ArcMap, you can assemble a map quickly from predefined layers, or you can add data from coverages, shapefiles, geodatabases, grids, TINs, images, and tables of coordinates.

There are several ESRI software applications that work in conjunction with ARCGIS to provide tools for advanced data analysis and management, including the ARCGIS extensions, ArcSDE, and ArcIMS.

Several optional ARCGIS extensions are available for more advanced analysis and visualization of GIS data.

ARCGIS Spatial Analyst provides a broad range of spatial modeling and analysis features that allow you to create, query, map, and analyze cell-based raster data.

ARCGIS 3D Analyst enables you to visualize and analyze surface data in three dimensions. ARCGIS Geostatistical Analyst lets you create a continuous surface from sparse measurements taken at sample points. In addition, Geostatistical Analyst includes tools for statistical error, threshold, and probability modeling.

ArcSDE allows you to manage geographic information in your chosen DBMS and to serve your data openly to the ARCGIS Desktop and other applications. When you need a very large, multiuser database that can be edited and used simultaneously by many users, ArcSDE adds the necessary capabilities to your ARCGIS system by enabling you to manage your shared, multiuser geodatabase in a DBMS.

ArcIMS is an Internet mapping system that provides a framework for centrally building and deploying GIS services and data. Using ArcIMS, you can deliver focused GIS applications and data to many concurrent users, both within your organization, and externally on the World Wide Web.

Because of limited time and lack of coordinates, spatial analysis was partially done. The main issues handled were data visualization and preparations of final thematic maps for print out.

Properties of the DB can visualised can be done direct by opening it in the ArcCatalog, or by "Add data" in the ArcMap, and then then select a table of interest in the DB. See Figure 2 for elaboration. For our study "Water point "table is the one that contains spatial reference, so it will be the one to be plotted.

After the data is input in the GIS, then it can be opened, view, sorted, selected by attributes, replace, e.t.c. see Table 9 below.

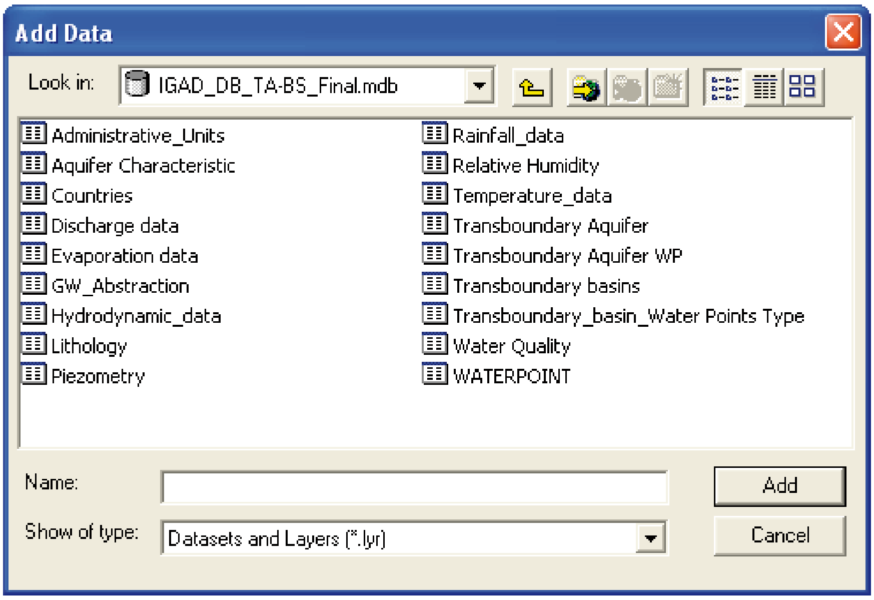

FIGURE 2: Importation of DB in the ARCGIS

Thereafter, this table is used to create point map and to analysis spatial distribution. Details of the maps made by this procedure are in sub section 6.2.2.

Attributes of WATERPOINT

SourceID2	SourceID1	Source_Nam	Ow	Country	District	Site_Type	Altitude_	Tdepth_m_	Comp_Date	UTM_X	UTM_Y	LONG	LAT	
x_Er_616	<Null>	Adi Ghinebale	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7	5/1/01	480226	1653910	38.816103	14.96	<N
x_Er_617	<Null>	Shekawedibsirat	<Nul	Eritrea	<Null>	Borehole	<Null>	18	5/1/01	479000	1653789	38.804702	14.958896	<N
x_Er_618	<Null>	Adi Shimadi	<Nul	Eritrea	<Null>	Pond	<Null>	<Null>	5/1/01	469977	1653091	38.720798	14.952498	<N
x_Er_619	<Null>	Adi Kdabet	<Nul	Eritrea	<Null>	Borehole	<Null>	32	5/30/01	475917	1646758	38.776097	14.895301	<N
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x_Er_623	<Null>	Adi Awhaza	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7.5	5/30/01	479978	1640151	38.813903	14.835599	<N
x_Er_624	<Null>	Adi Gaul	<Nul	Eritrea	<Null>	Hand dug well	<Null>	6.6	5/30/01	470996	1650966	38.730298	14.933297	<N
x_Er_625	<Null>	Gomera	<Nul	Eritrea	<Null>	Borehole	<Null>	<Null>	5/30/01	471889	1651551	38.738596	14.938596	<N
x_Er_626	<Null>	Adi Shimadi-Kumtsub	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7.4	5/30/01	472879	1652103	38.747796	14.943597	<N
x_Er_627	<Null>	Dandier+Adikne	<Nul	Eritrea	<Null>	Hand dug well	<Null>	3.2	5/30/01	476099	1645132	38.777804	14.880602	<N
x_Er_628	<Null>	Zban Una	<Nul	Eritrea	<Null>	Hand dug well	<Null>	9.3	5/30/01	480367	1642938	38.817498	14.8608	<N
x_Er_629	<Null>	Adi Awhaza	<Nul	Eritrea	<Null>	Hand dug well	<Null>	5.1	5/30/01	479859	1640118	38.812798	14.8353	<N
x_Er_630	<Null>	Abi Adi	<Nul	Eritrea	<Null>	Hand dug well	<Null>	8.2	5/30/01	473952	1649094	38.757804	14.916403	<N
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x_Er_632	<Null>	Adi Kdabet	<Nul	Eritrea	<Null>	River Water	<Null>	<Null>	5/30/01	474369	1646936	38.761703	14.896896	<N
x_Er_633	<Null>	Geza Ghebo	<Nul	Eritrea	<Null>	Borehole	<Null>	24.7	5/31/01	477687	1653149	38.792497	14.953099	<N
x_Er_634	<Null>	Mibrakawi	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7.8	6/1/01	480456	1646721	38.818297	14.895004	<N
x_Er_635	<Null>	Adikelom+Adikesemti	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7.3	1/3/01	480677	1653633	38.820299	14.957499	<N
x_Er_636	<Null>	Mibrakawi	<Nul	Eritrea	<Null>	Hand dug well	<Null>	6.4	6/1/01	480015	1646809	38.814196	14.895796	<N
x_Er_637	<Null>	Adi Mengoti	<Nul	Eritrea	<Null>	Hand dug well	<Null>	6	6/1/01	477917	1645462	38.794702	14.883601	<N
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x_Er_639	<Null>	Enda Amanuel	<Nul	Eritrea	<Null>	Hand dug well	<Null>	8	5/28/01	484201	1648775	38.853102	14.9136	<N
x_Er_640	<Null>	Adifinie	<Nul	Eritrea	<Null>	Borehole	<Null>	49	5/29/01	493246	1651016	38.937196	14.9339	<N
x_Er_641	<Null>	Kudo chira	<Nul	Eritrea	<Null>	Hand dug well	<Null>	3	5/29/01	487428	1649691	38.883102	14.921899	<N
x_Er_642	<Null>	Aregit Mekrem	<Nul	Eritrea	<Null>	Hand dug well	<Null>	4.65	5/29/01	490773	1651017	38.9142	14.933901	<N
x_Er_643	<Null>	Shiha	<Nul	Eritrea	<Null>	Pond	<Null>	<Null>	5/29/01	495074	1649666	38.954197	14.921698	<N
x_Er_644	<Null>	Kilowlie	<Nul	Eritrea	<Null>	Hand dug well	<Null>	1.5	5/28/01	482879	1650070	38.840801	14.9253	<N
x_Er_645	<Null>	Adi Gehad	<Nul	Eritrea	<Null>	Hand dug well	<Null>	5.6	5/19/01	478149	1641071	38.796896	14.843903	<N
x_Er_646	<Null>	Newih ziban	<Nul	Eritrea	<Null>	Borehole	<Null>	<Null>	5/29/01	493428	1644590	38.938904	14.875801	<N
x_Er_647	<Null>	Kudo Felasi	<Nul	Eritrea	<Null>	Borehole	<Null>	50	5/29/01	483412	1643986	38.845796	14.870296	<N
x_Er_648	<Null>	Kilowlie	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7	5/28/01	478189	1648747	38.797203	14.913304	<N
x_Er_649	<Null>	Azerna Tahtay	<Nul	Eritrea	<Null>	Spring	<Null>	<Null>	5/28/01	482460	1650557	38.836902	14.9297	<N
x_Er_650	<Null>	Berak	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7	5/19/01	478031	1641126	38.795799	14.844399	<N
x_Er_651	<Null>	Garma	<Nul	Eritrea	<Null>	Hand dug well	<Null>	7.2	5/19/01	478128	1641071	38.796701	14.843903	<N
x_Er_652	<Null>	Garma	<Nul	Eritrea	<Null>	Hand dug well	<Null>	8	5/19/01	478096	1641071	38.796403	14.843902	<N
x_Er_653	<Null>	Berak	<Nul	Eritrea	<Null>	Hand dug well	<Null>	9.7	5/19/01	477881	1641159	38.794404	14.844696	<N
x_Er_654	<Null>	Adi Ghehad	<Nul	Eritrea	<Null>	Hand dug well	<Null>	3.29	5/28/01	478031	1641380	38.795797	14.846696	<N
x_Er_655	<Null>	Kilowlie	<Nul	Eritrea	<Null>	Hand dug well	<Null>	6	5/28/01	482071	1648998	38.833296	14.915602	<N

Record: 1 Show: All Selected Records (0 out of 2048 Selected) Options

TABLE 9. View of Water point table in GIS.

6. COMMON GEOGRAPHIC DATA

6.1. Topography and basic maps

The geographic information related to this topographic map is as follows:

Rivers and Lakes; the rivers in IGAD region are of two types Perennial/Permanent and Non-Perennial/Intermittent/Fluctuating, Road networks: Primary Route, Secondary Route and some are unknown, main agglomerations: capital, Roadway; main, secondary, railways, track.

The topographic data which was used to make base map for the IGAD member countries were downloaded from Digital Chart of the World (DCW).The DCW is a comprehensive 1:1,000,000 scale vector base map of the world with many thematic layers including drainage systems, Roads and Railroads, Populated Places (urbanized areas and points), Vegetation and Land cover. The base map is as shown in Figure 3.

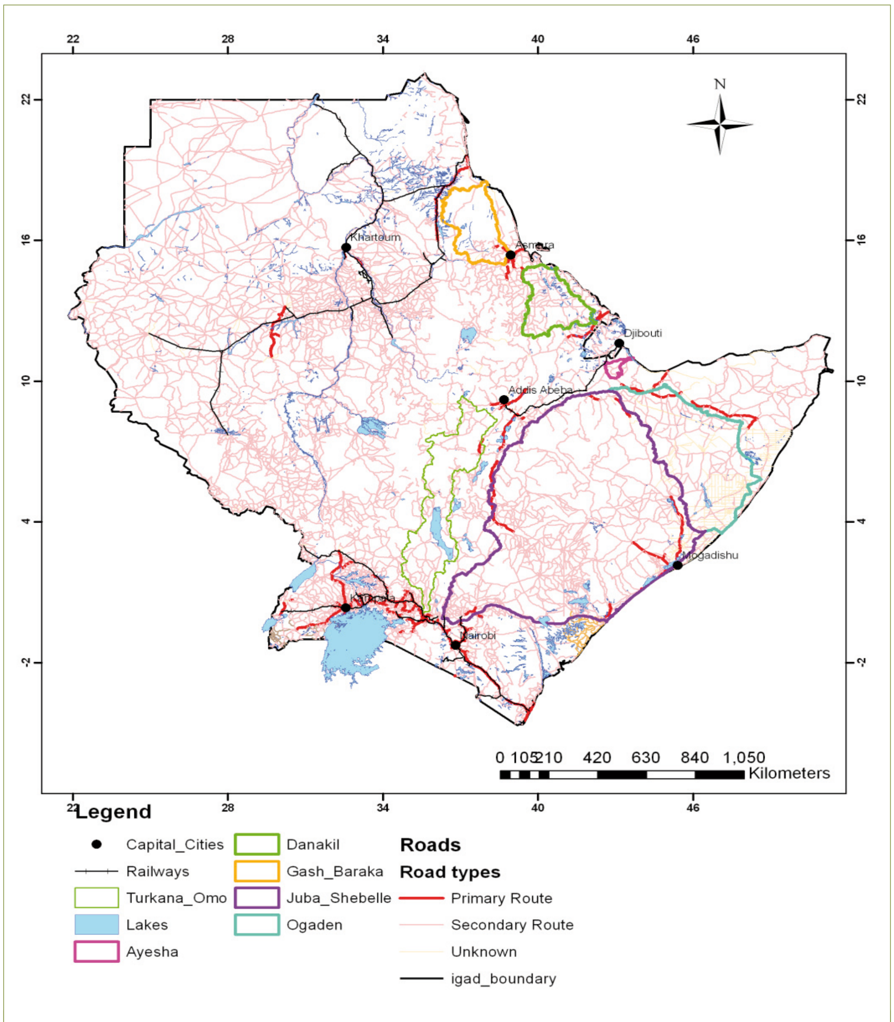

FIGURE 3: Base map of study area

6.2. Digital elevation model (DEM)

To generate the DEM and contour lines for the sub-region, Shuttle Radar Topography Mission (SRTM) GTOP030 was downloaded from http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp webpage, covering the whole IGAD member countries. The downloaded image was then imported in ARCGIS 9.3, where contour lines of IGAD member countries where extracted by spatial analysis tools at an interval of 100m as shown in the Figure 4. The altitude is expressed in meters from the sea average level.

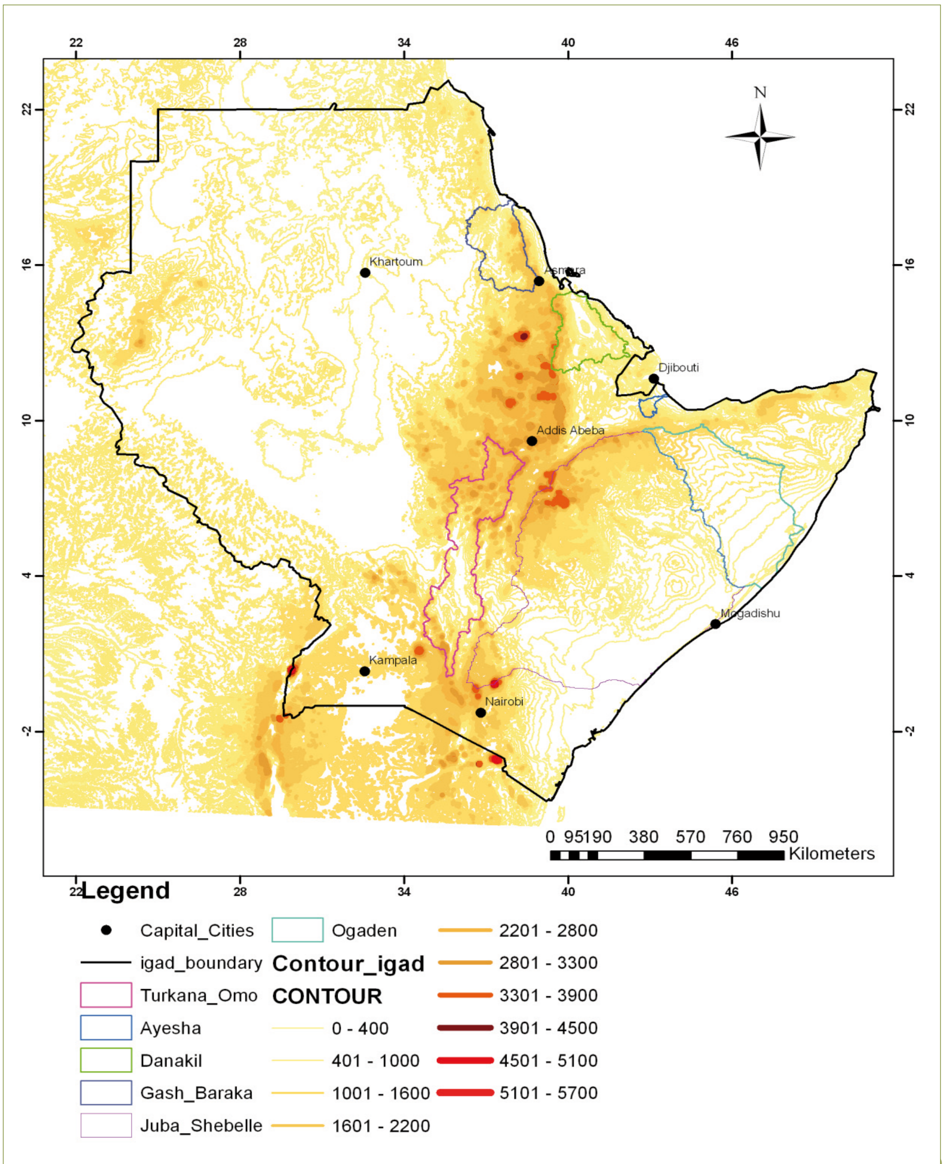

FIGURE 4: Contour line map of the IGAD countries derived from SRTM

6.3. Geology

Published large scale geology map exist for each member country. This is however complicated to join due to different semantics used, different data levels e.t.c. Thus, regional geological map of Africa[6] at a scale of 1:10,000,000. Thus, the map digitized and integrated with transboundary basins to produce the map shown in Figure 5.

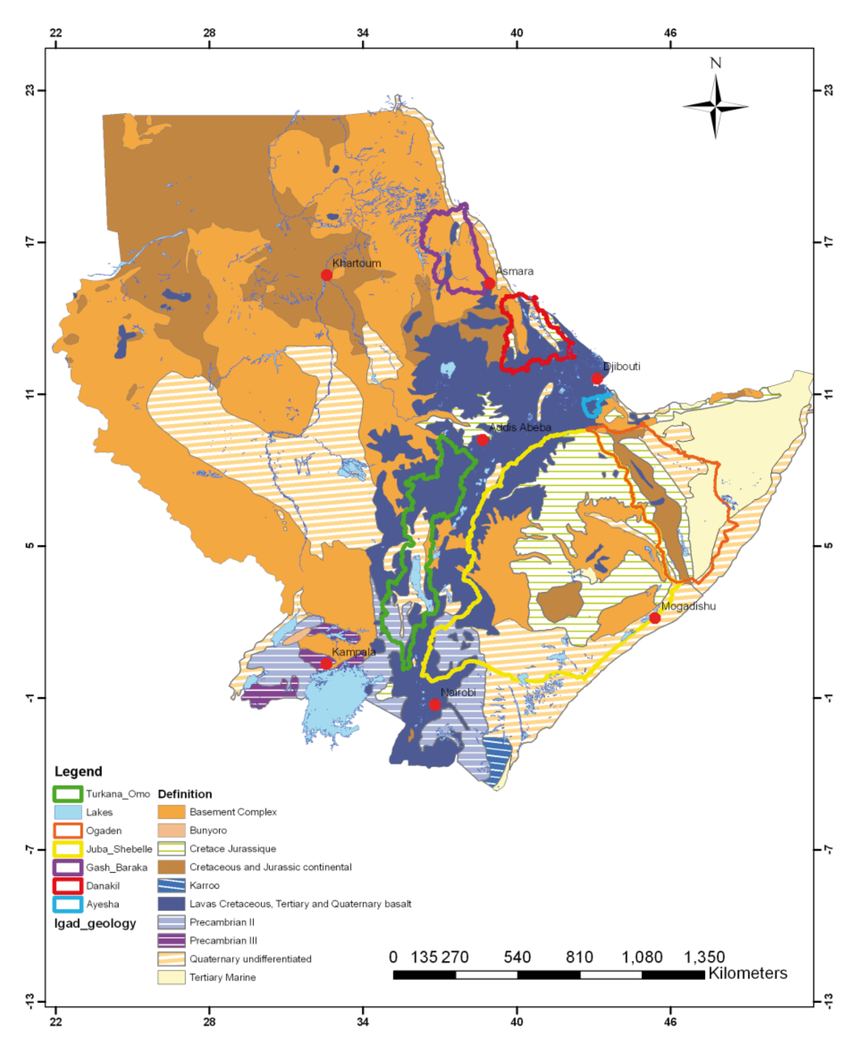

FIGURE 5: General geology of IGAD member countries

6.4. Soil map

Just like geology, each IGAD member state has published soil maps, however, for the regional mapping, they cannot be joined due to differences in data semantics, level, projections e.t.c. Thus, regional Africa soil map[7] was used to extract the soil map of IGAD sub-region shown in Figure 6.

6. Geology map of Africa (Esquisse structurale provisoire de l'Afrique).

7. Soil Map of Africa.(FAO - UNESCO 1974).

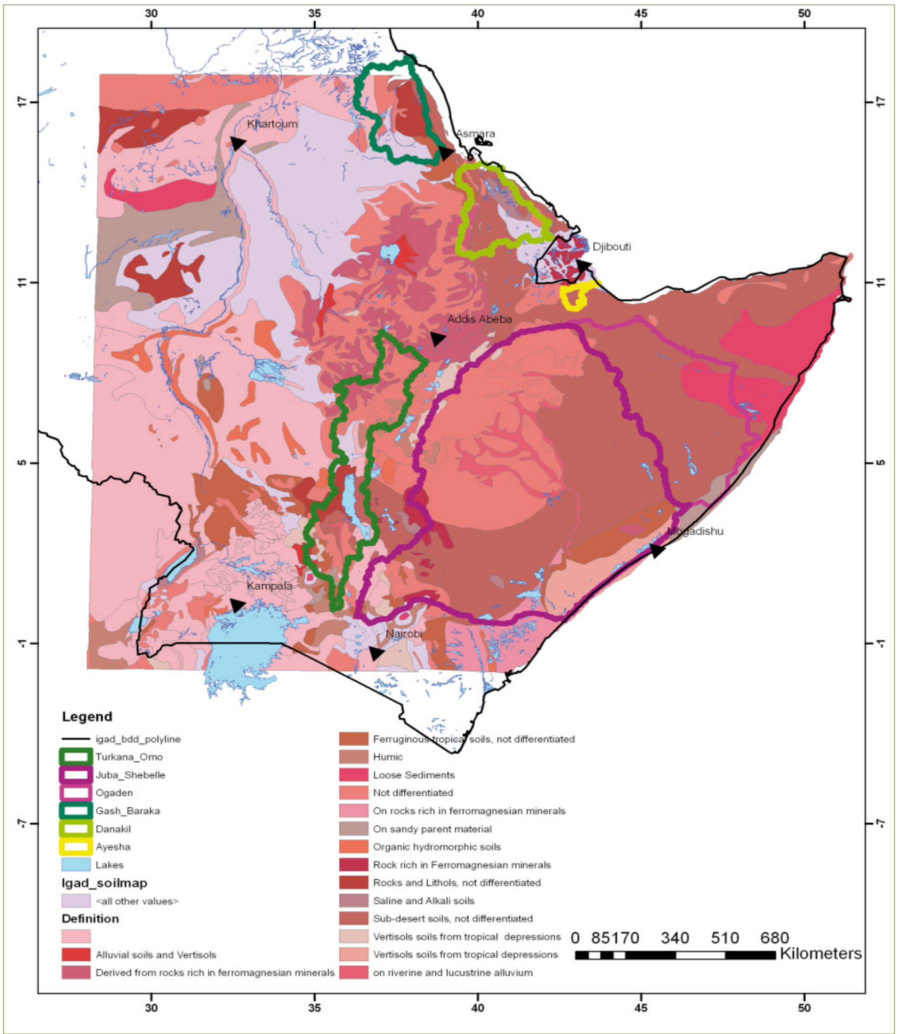

FIGURE 6: General Soil map of IGAD member countries

3

DESCRIPTION OF IGAD DB (SYNTHESIS)

The conceptual model of the IGAD sub-region common database responds to the following objectives:

- Harmonization of the data acquired from various sources and compiled in different formats in country reports;
- Geo-referencing and representation of the data using GIS as elements of decision making for regional planning;
- The global modelling of the water resources (surface and ground water resources);
- Development of water resources maps/charts; and
- To come-up with a set of strategies, recommendations, and action plans to enable member states to implement and operate an integrated trans-boundary water resources management process.

The proposed conceptual data model developed for transboundary water resources management is aiming at capturing the semantics of geographic phenomena, which are related with water resources management, such as Borehole, shallow well, springs, reservoirs, rivers, channels, lakes, water withdrawal, water discharge, riverhead and monitoring-station climatic data and hydrological data.

The main source of data for DB development is country reports from member countries. Other possible source of data is internet, FAO and UN reports. This model involved identifying the source and format so as to convert the data in common agreed format (Figure 7).

1. IGAD DB general architecture[8]

The IGAD Common DB Data Conceptual Model DCM) was adopted from OSS 2007, and involves the inputting all the data available and developing the data structure. To obtain an open and scalable information system, one should first forget about the processing procedures, which are subject to changes; the stress should be put on the most stable data part by accurately understanding:

- Information sets (entities);
- The nature of the existing links between these sets; and

[8] A common DB of the Iullemeden Aquifer System (IAS) by OSS, Dec 2007.

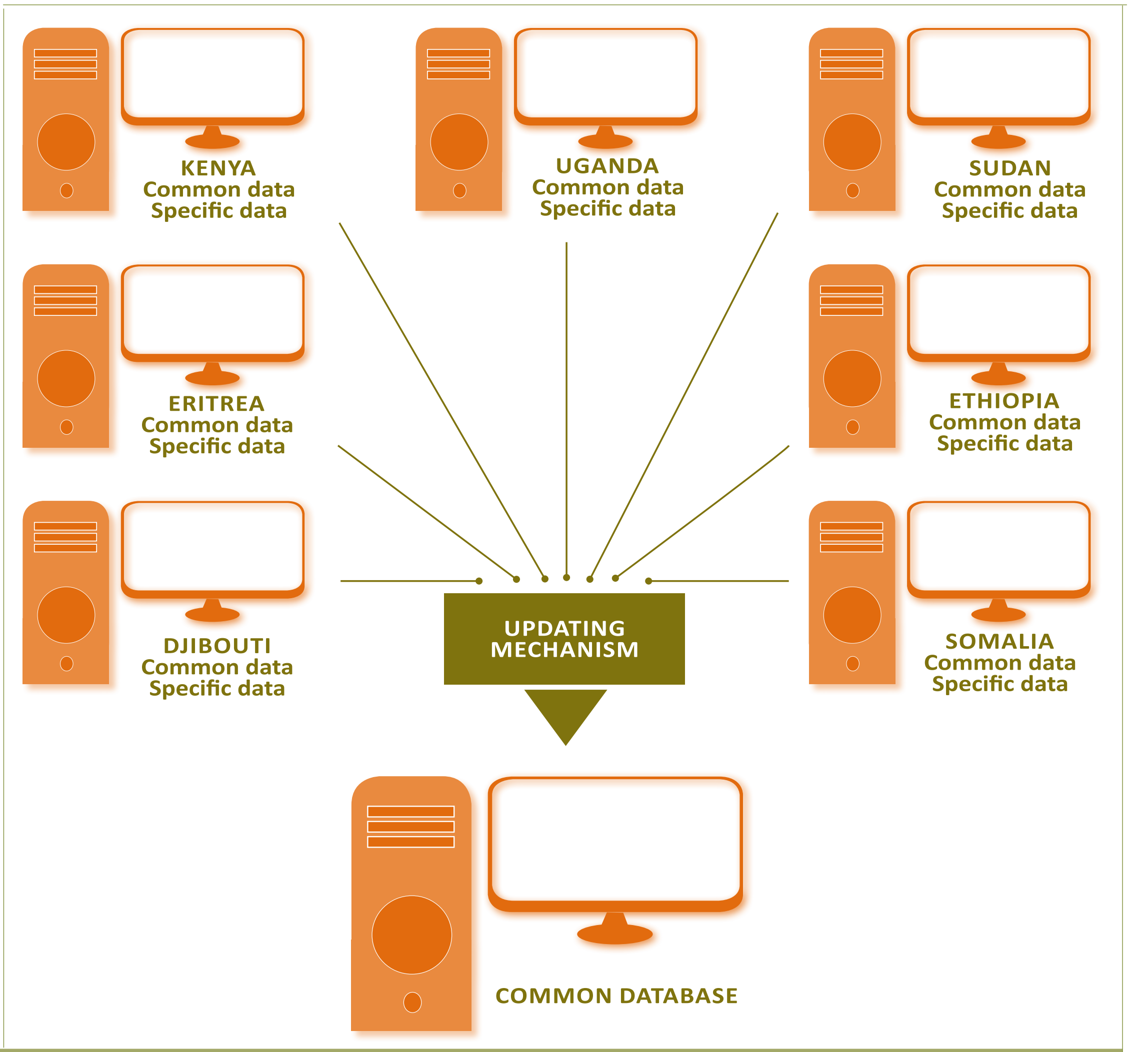

FIGURE 7: Total organisational solution of the IGAD database

- The management guidelines associated with these entities.

Such approach allows for designing the closest possible representation of the perceived reality. It aims at producing a DCM (Figure 8) which synthesises the entities and the relations with the help of a formalism derived from the following planned rules:

- A borehole can pick up 1 or many aquifers.
- A borehole at a given date provides a given yield.
- A borehole can serve many users.
- A user can be supplied by many boreholes.

The identification of relations between the different elements of the data model requires the greatest attention so that the applications deriving from it can meet the needs of the expected information. This structure offers the advantages of the possibility of use in a multi-user environment and a better system stability to guarantee openness.

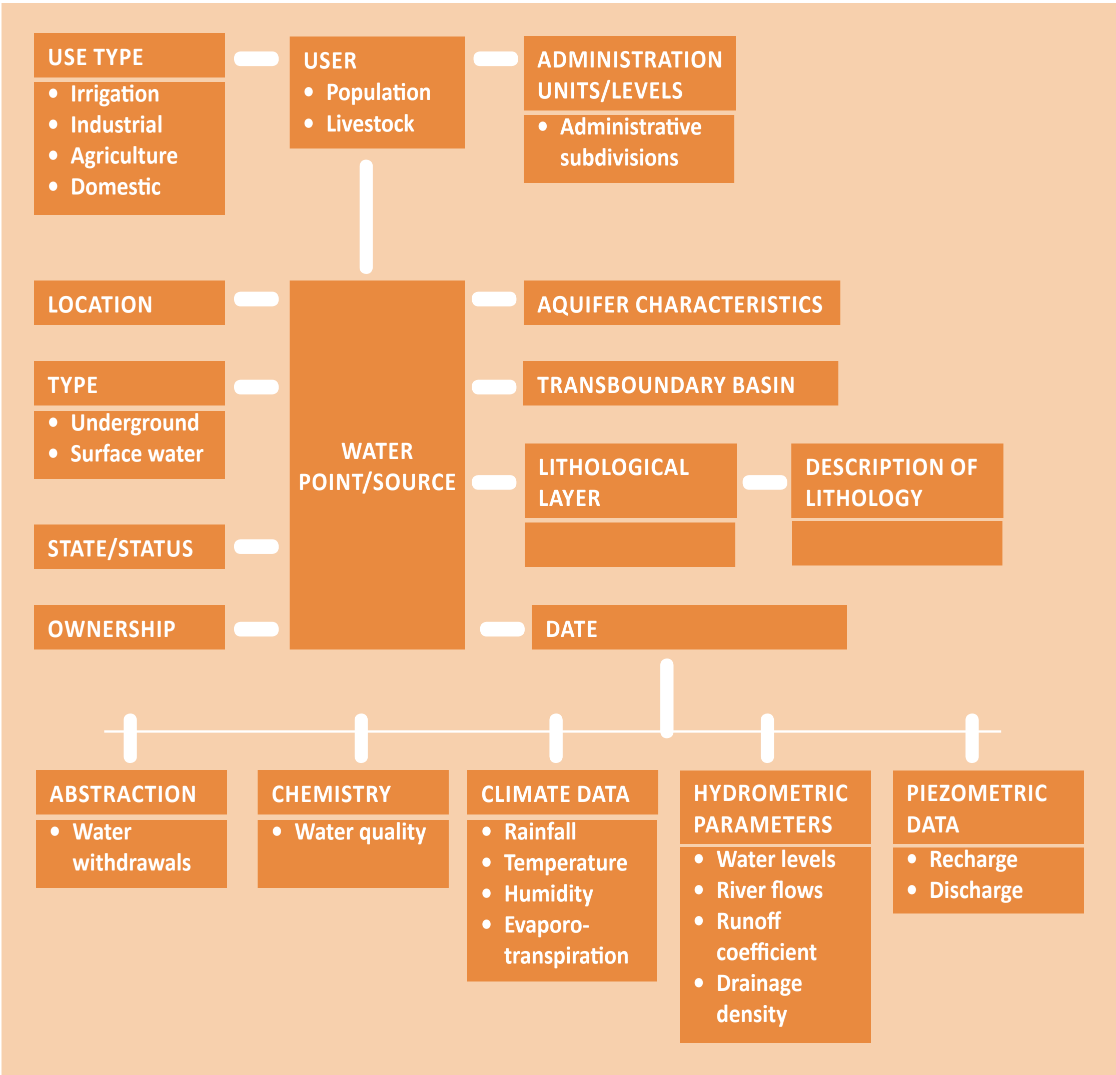

Figure 8: IGAD Data Conceptual Model (Adopted from OSS, 2007)

2. DATABASE DESCRIPTION

On the basis of a relational DB for IGAD member countries design was done with a structure where water points/sources are a major key/primary table to access information. The general DB schema is designed in several interrelated 'tables' by univocal and multiple relations to process specific information (hydrometric, rainfall, aquifer characteristics, hydrodynamic etc).

The DB covered the following seven thematic domains:

- groundwater resources
- Surface water resources (and hydraulic infrastructures)
- Climatology
- Administrative units

- Groundwater resources users
- Social and Economic aspect.

The underground water field includes the data which describe:

- Hydraulic infrastructure implemented in the basin.
- Aquifer characteristics (name, identifier, area, direction, transmissivity, permeability, storage coefficient and so on).
- Measured piezometric data.
- Aquifer withdrawals.
- Recorded hydrochemical data.
- Completed isotope analyses
- Hydrodynamic parameters
- Zone geological information
- Geophysical data
- Water quality.
- Water Chemistry

The surface water field includes the following data which describe:

- Hydraulic infrastructure (dams) implemented in the basin.
- Description of the aquifer watershed (name, identifier, area drainage density, runoff coefficient, slope)
- Water streams.
- Lakes.
- List of hydrometric stations.
- River flows and sediments.
- Recorded hydrochemical data.
- Completed isotope analyses
- Water quality.
- Water Chemistry.

The climatology field includes the data which describe:

- Climatological stations.
- Rainfall.
- Temperatures
- Evapotranspiration

The administrative unit field includes data which describe:

- Administrative subdivisions.

- Growth rate by period.
- Localities

The water user's field includes data relating to:

- Populations
- Irrigated areas.
- Industrial zones.
- Domestic drinking water consumption.
- Agricultural consumption (Irrigation and livestock).
- Industrial consumption
- Institutional and Commercial establishment
- Transport (stretches of water that are navigable)
- Energy-Cooling water in thermal plants

The Social Economic data relating to:

Population data:

- Population distribution by rural and urban location
- Rural and urban population densities
- Rural and urban settlements

Agriculture:

- Land use: farmland – cropland (arable and permanent), commercial and subsistence farms,
- Irrigated and non-irrigated land: major and minor irrigation projects
- Livestock resources – livestock distribution and densities, stock routes, watering sources (lakes, rivers, streams, ponds, dams, spring wells, etc)
- Infrastructure, industry and environment development:
- Roads, rail, airports and navigation water ways,
- Power projects, dams,
- Public facilities – education, health, commercial, industries and urban development,
- Details of projects that are in the transboundary basin such as irrigation projects, large farms, factories and large institutions in the project basin.
- Water quality details for the water points.
- Population graphics that identify the high concentrations of people etc.

The natural resources data relating to:

- Forest cover,
- Desert cover,

- Conservation areas – national parks and reserves, wildlife distributions
- Land cover including, Rangelands/Grasslands distribution, Woodlands and forests – natural and planted, Bushlands and shrubs, Lakes and Rivers
- Erosion exposure,
- Geological information and remote sensed data.

2.1. DB schema

The DB schema is a conceptual model of data (DCM) during the design phase. This schema (Figure 9) shows the central role of the 'points' table, which is linked to the identification table (location, hydrodynamic aspects, administrative unit and transboundary basin) and variable tables (geology, quality, exploitation, aquifers, usages, etc). The relations which link the 'points' table to the other tables can be univocal (1 to 1) or multiple (1 to many) as shown in Figure 9 below.

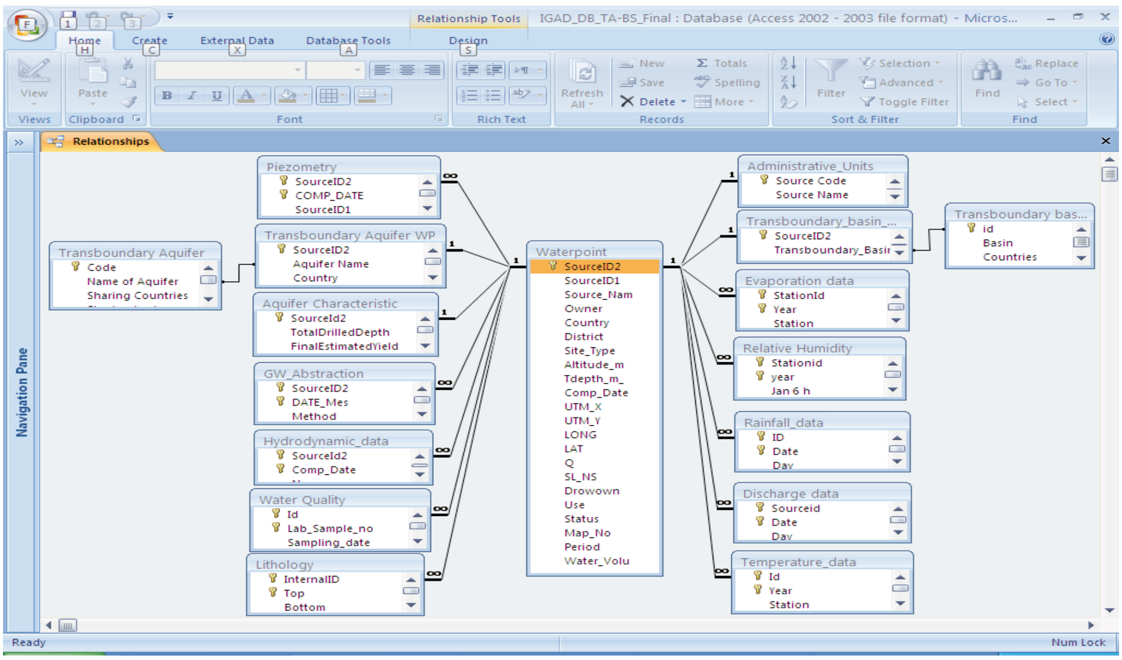

FIGURE 9: IGAD DB architecture

2.2. Relational model

The relational model is based on the principle that the DBMS is structured on a set of 'tables', each one of which includes a set of 'fields', and that the whole set is run by defined relations without any confusion or ambiguity (See Figure 9 above). The accomplishment of the relational model is a phase which paves the way for implementing a DCM on DBMS. According to the nature of relations, and on the basis of the cardinalities originating from the management guidelines, transit procedures are applied (OSS 2003). The relational model is tested, in each table and for the set of tables, in view of defining the different relations between the 'field' and the tables enabling combination and data processing.

The nature of relations linking the two entities can be summed up as follows:

Case number 1: relation "1-1" to "0-n"

The relation shows the fact that administrative regions have zero or many boreholes. Consequently, a borehole forcibly belongs to one administrative region.

Case number 2: Relation "0-n" à "1-n"

Between the 'Borehole' and 'User' entities, the link can be formulated as follows:

The same borehole can be supplied by one or many boreholes. As for the user, he can be supplied by one or many boreholes.

2.3. Tables

In this type of DB organisation, the tables are grouped according to specific similarities (boreholes, rainfall, discharge, and so on). They are the means to bring together the countries' data under one section to ensure critical analysis, harmonisation and use or exchange, through the established links. The tables are basic entities for data updating and processing. They must respond to specific formats in which data and the searched aspects are displayed.

The IGAD common DB tables consist of two parts:

- An identification part (water point table) which includes data allocation to a geographical origin or an aquifer level (country, user status etc).
- A variable part which allows one to assess the timely values of the considered variable (Rainfall, hydrodynamic, temperature, aquifer etc) in space and time.

The combination of certain fields or columns of two or many tables makes it possible to extract a new table to refer to these common keys.

3. GIS DESCRIPTION

3.1. GIS Data provided

Since the data/information provided was heterogeneous, some of the data/information provided by the member countries was shape files as follows;

GIS Data from Djibouti:

- Climate shape file map in zonal format, six zones but no exact reading indicated
- Evapotraspiration shape files for each region. This was joined to map one map for the country but no units for the readings
- Vegetation map for each region, this was also joined to make one map for the country as shown in Figure 10 below.
- Mean average precipitation
- Geology (each lithology in separate file). This was joined to make a geology map of Djibouti.
- Soil shape file map for the whole country as shown in Figure 11 below.

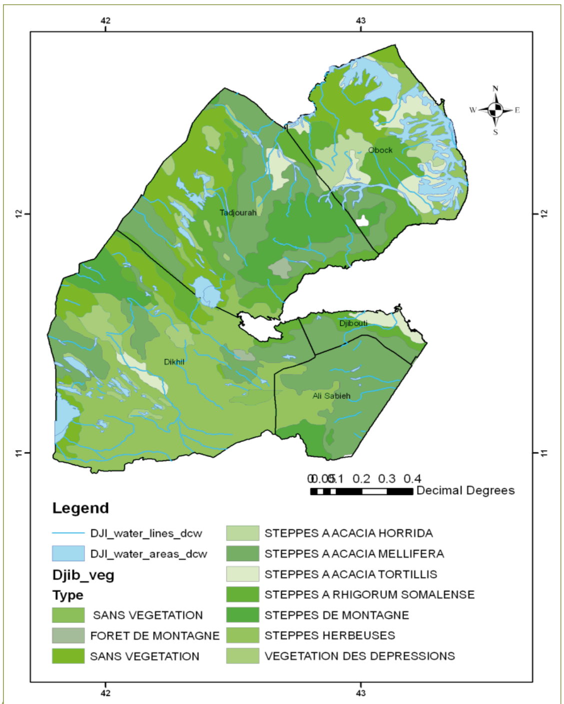

FIGURE 10: Vegetation cover of Djibouti

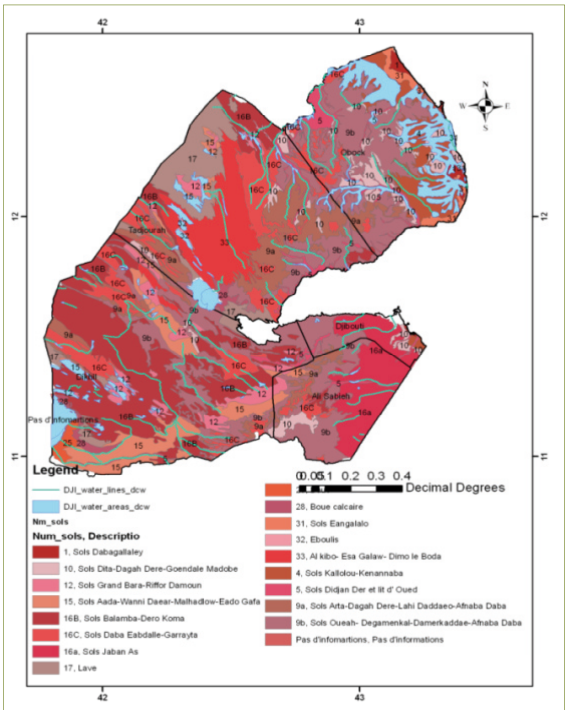

FIGURE 11: Soil map of Djibouti

GIS data from Kenya;

- Erosion hazards vector polygon map from Kenya soil survey of 1995 with the following classes; Very severe hazard, severe hazard, moderate hazard, slight hazard, very slight hazard, non-hazard, water body as shown in Figure 12 below.

- Land cover map in form of vector polygon map from Kenya soil survey of 1995.
- Geology map without explanatory legend.

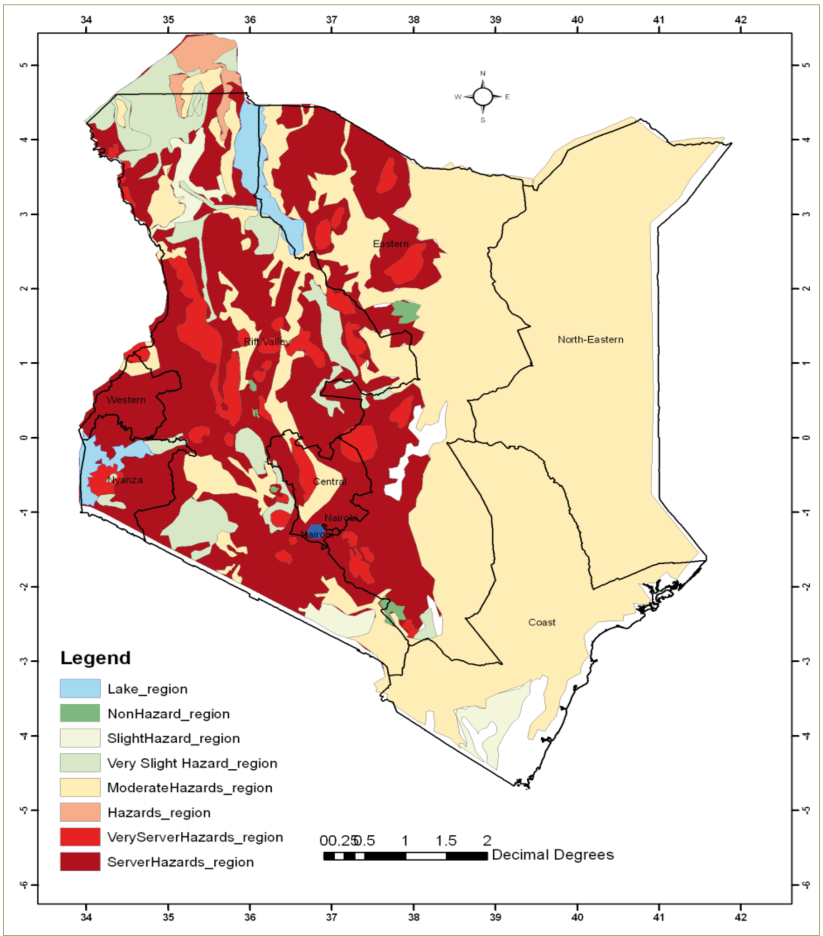

Figure 12: Hazard map of Kenya

GIS data from Sudan;

- Land resources shape file map of Sudan
- Mean annual precipitation shape file map of 1961_1990
- Mean annual Temperature shape file map.

4

CONTENT SYNTHESIS

The project has made it possible to collect, format and homogenise the set of existing IGAD information from IGAD member states. In fact, a relational, coherent, and scalable database structure allowing for an easy data processing was set up at the level of the IGAD member countries.

Among the most important benefits of the established system, one can cite:

- A common database for the whole basin: structure, codification, processing procedures.
- A common geographic reference shared by the member countries: projection system, basic layers and DEM.

For once, the set of information specific to the IGAD transboundary basin is harmonised and can be shared by the member administrations managing the basin water resources. This information can thus be used to help with decision making on basin water resource development planning. Its adaptation to mapping at the catchment area scale provides it with an added value in relation to its status in the seven countries' national databases.

1. THE DATABASE SYNTHESIS

Country	No. of Water Point
Djibouti	1641
Eritrea	2351
Ethiopia	5227
Kenya	20026
Sudan	30
Uganda	53789
Total	**83064**

TABLE 10. Distribution of water points

By the end of the project the total number of water points collected from the IGAD member countries and included in the water points table of the IGAD regional DB is 83,064 (Eighty three thousand and sixty four) distributed as shown in Table 10. This number of water points include: borehole and dug well/shallow well springs, meteorological station, hydrodynamic data e.t.c. The accumulation of such information did not miss reflecting some redundancies resulting from the diverse data collection sources. This is the price to pay to have all the available data and useful information in the DB.

2. WATER POINT CHARACTERISTICS

The water point in IGAD DB included all information on entities concerning water resources in the member countries. This table is the main in the DB and it link to all other variable ata in the DB. Some of the important data fields in the water point table are as shown in Table 11 below.

SourceID2	SourceID1	Source Name	Site type	Altitude (m)	Total depth (m)	Completion date	UTM (X)	UTM (Y)	LONG	LAT	Use	Status	Period

Table 11. Water Point characteristic.

SourceID1 column contains original identify key. New unique keys were created for each entry which did not have sourceID1, and are stored in **SourceID2**. If Identity key is unique for example DWD001 then it was maintained in both columns. If the identify key was just integer which could be repeated in other member country, then a unique identity key was created. For example if water point had identity key as "200", and is from Ethiopia, then the unique identification key created would be 200_Eth. If the source did not have any identification key at all, then a new unique one would be created. An example x_Eth_1, meaning that the water point is from Ethiopia, it is the first one without an id (x). All these were done to keep all our data in DB and to avoid duplication. Thus, Sourceid2 was a **primary key** and so was repeated in all tables for easy linking and relationship creation.

Source Name defines the local name given to water source, in some places it is the same as village name but in some places it differs. Sometimes this source name defines the people/ group of using the source.

Site type describes what type of source it is. In IGAD DB, these include borehole, shallow wells, meteorological stations, river gauging station e.t.c.

Altitude (m) means height of the location above sea level.

Total depth (m) represents drilled depth for those water points which are borehole, shallow wells or hand dug wells.

Completion data represents dates when construction of water points were completed. If it is a borehole, it means when the borehole completed and one could pump water out. If it is water quality it means when sampling was done.

UTM_X and UTM_Y represents the original local coordinates which were provided by the member countries and later were converted to **Long/Lat**. Long/Lat coordinates are plotted to produce the map shown in Figure 13 below. Water points without Long and Lat coordinates were not plotted and their spatiality is unknown.

Different water source are used differently. Though majority are communities where they are constructed, some specific ones are for irrigation, Industrial e.t.c, and all that is represented in the "**Use**" column.

"**Status**" column contains information about the functionality of water source. Some water points worked for period of time while other worked for only specific period or recording were made for specific period. All that information is stored in column "**period**".

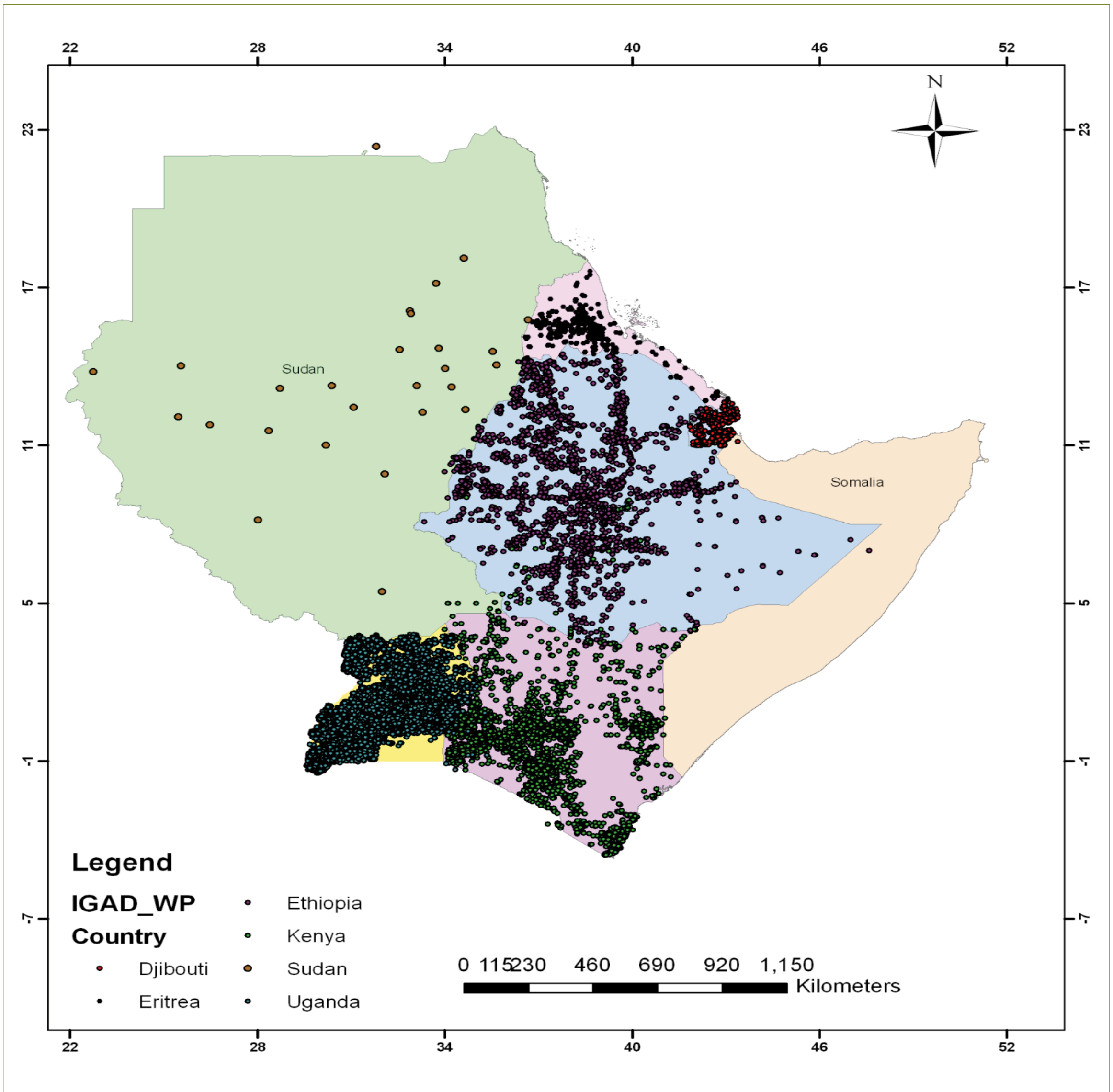

Figure 13: Map showing spatial distribution of Water points in IGAD member countries

2.1. Distribution by administrative unit

The geographical information distribution is a basic option which allows its subsequent identification given that this approach is the one used by the administration to classify water points and track water resources in these member countries. The choice of the basic administrative unit is dictated by the country's adopted administrative classification (Table 12), while bearing in mind the need for scale harmonisation among countries to avoid providing too many details or lacking accuracy in the data restitution for the different applications used within the project's framework.

For this project, all administrative unit data was downloaded from Spatial Database of

Global Administrative areas (GADM)[9]. GADM is a spatial database of the location of the world's administrative areas (or administrative boundaries) for use in GIS and similar software. Administrative areas in this database are countries and lower level subdivisions such as administrative state, region, province, zone and district. The level of subdivision varies between IGAD countries as shown in the Table 12. All sources with coordinates were plotted on the map and so their administrative units defined up to the lowest one possible.

Subdivision	Adm0	Adm1	Adm2	Adm3	Adm4	Adm5
Djibouti	Country	Region	Zone			
Ethiopia	Country	Region	Zone	Wareda		
Kenya	Country	County	District	Division	Location	Sub location
Sudan	Country	State	Locality	Rural administrative Unit		
Uganda	Country	Region	District	County	Sub-county	Parish
Eritrea	Country	Region	Zoba	Sub-Zoba		

TABLE 12. Summary of the administrative subdivisions in IGAD member countries

2.2. Distribution by transboundary basin

The distribution of water point in transboundary basin as shown in region is as shown in the table below with Table 13 below. The total number of water points in transboundary basin is 33, 089 (Thirty three thousand, eighty nine). This is about 40% of the total water points captured during the project. Among the data collected, majority is from Nile basin, this can be explained by previously ongoing projects in the Nile basin and the size of the basin being big. Otherwise some basins like Ayesha and Ogaden have less than 10 water points.

Transboundary Basin	No. of Water point
Ayesha	1
Danakil	166
Gash_Baraka	110
Juba_Shebelle	2015
Nile Basin	28945
Ogaden	7
Turkana_Omo	1845
Total	**33089**

TABLE 13. No. of water point in transbounday basin

2.3. Distribution by aquifer

The total number of water points in transboundary aquifers is 11,948 (Eleven thousand, nine hundred and forty eight) which is about 14% of the total water points collected during the project, see Table 14 below.

Aquifer Name	No. of Water points
Awash Valley Aquifer	1435
Merti Aquifer	37
Mt. Elgon Aquifer	9548
Ogaden-Juba Aquifer	287
Rift Valley Aquifer	147
Upper Nile basin	494
Total	**11948**

TABLE 14. Water points in transboundary aquifer

9. GADM database of Global Administrative Areas

2.4. Distribution by type

Borehole type of water points were the majority is the DB. It is about 54% of the total water points collected during the project. More details on the percentage of water sources are in Statistical analysis chapter.

2.5. Variable parameters

Variable parameters could be divided in spatial and temporal variables. In IGAD DB, these include Hydrodynamic, Hydrometric, Lithology, Rainfall data, e.t.c.

Hydrodynamicparameters. The '**Hydrodynamic**' table brings together the data relating to the hydrodynamic characteristics of the region aquifers (transmissivity and storage coefficient) in particular the transmissivity values deduced from the interpretation of the pumping test. The hydrodynamic data was provided by two countries as shown in Table 15 below.

Lithology. The "Lithology" table contains data from drilling logs. The table was arranged in such a way that both the lithological boundaries (Top and bottom are captured) and the description of the geology in the hole. Few countries provided this type of information as shown in Table 16.

Rainfall data. the "rainfall data" table contains data for both daily data and monthly averages. Kenya has the majority of records because it provided the daily data. The Table 17 below summarize the records of rainfall data per country.

Discharge Data. in "discharge data table", we find information relating to river flows (in and out), sedimentation, catchment and sub-catchment of the rivers, soil loss e.t.c. Kenya and Uganda provide daily data, that is why this Kenya has the highest records as shown in Table 18 below.

Evaporation. Evaporation data table contains monthly averages from meteorological stations. Only Djibouti and Kenya provided the data on evaporation, see Table 19 below.

Country	No. of records
Djibouti	130
Kenya	12689
Total	**12819**

TABLE 15. Number of record on Hydro-dynamic data per country

Country	No of records
Djibouti	28
Ethiopia	3173
Total	**3201**

TABLE 16. Number of record on lithological data per country

Country	Number of records
Djibouti	873
Ethiopia	72
Kenya	67286
Sudan	27
Total	**68258**

TABLE 17. Number of record on Rainfall data per country

Country	Number of records
Djibouti	182
Ethiopia	160
Kenya	65535
Uganda	1959
Total	**67836**

TABLE 18. Number of record on Discharge data per country

Country	No. of records
Djibouti	133
Kenya	76
Total	**209**

TABLE 19. Number of record on Evaporation data per country

Groundwater extraction. Scanty information was provided on groundwater extraction with many fields un informed/without data. The information provided mainly was yields at the date of completion of the water sources. No other yields were measured. See Table 20 below.

Country	No. of records
Ethiopia	985
Kenya	9772
Total	**10757**

TABLE 20. Number of record on Ground Water Extraction data per country

Water Quality. Water quality data table, good information was collected. Most basic water quality analysis information was provided, these included information on, Ph, Temperature, colour, Conductivity, Total Dissolved Salts (TDS), Turbidity, Total hardness, Na, K, SO4, CO3, N, Cl, SiO4, Mg, Fe, e.t.c. Table 21 is the summary water quality of records per country.

Country	No. of records
Djibouti	125
Eritrea	1522
Ethiopia	10
Kenya	14688
Sudan	1
Uganda	553
Total	**16899**

TABLE 21. Number of record on Water Quality data per country

Other data on temperature, relative humidity, Aquifer characteristics and Piezometric data were also input in the DB. These four dataset was scarce and was mainly from Uganda, Djibouti and Kenya.

3. GEOGRAPHICAL INFORMATION SYSTEM (GIS) SYNTHESIS

The IGAD geographical information system (IGAD GIS) is a set of software to produce a cartographic representation of existing data in the common database. The support for the required digitized maps for this representation was developed as a separate activity by different contractor in the project framework.

The GIS used to represent the IGAD GIS is designed as an integrated part of the overall information System (designed for very large needs), as all the descriptive information of geographical objects is planned in the database structure. The primary aim is to store each piece of information in one area (no redundancy).

3.1. Projection system

To integrate the collected data from seven IGAD member countries, the common coordinate system is required. The seven countries are covered by about eight Universal Transverse Mercator (UTM) coordinate system as shown Figure 14.

The UTM Coordinate System is a grid-based method of specifying locations on the surface of the Earth that is a practical application of a 2-dimensional Cartesian coordinates system. It is a horizontal position representation, i.e. it is used to identify locations on the earth independently of vertical position, but differs from the traditional method of latitude and longitude in several respects. The UTM system is not a single Map projection. The system instead employs a series of sixty zones, each of which is based on a specifically defined traverse Mercator projection.

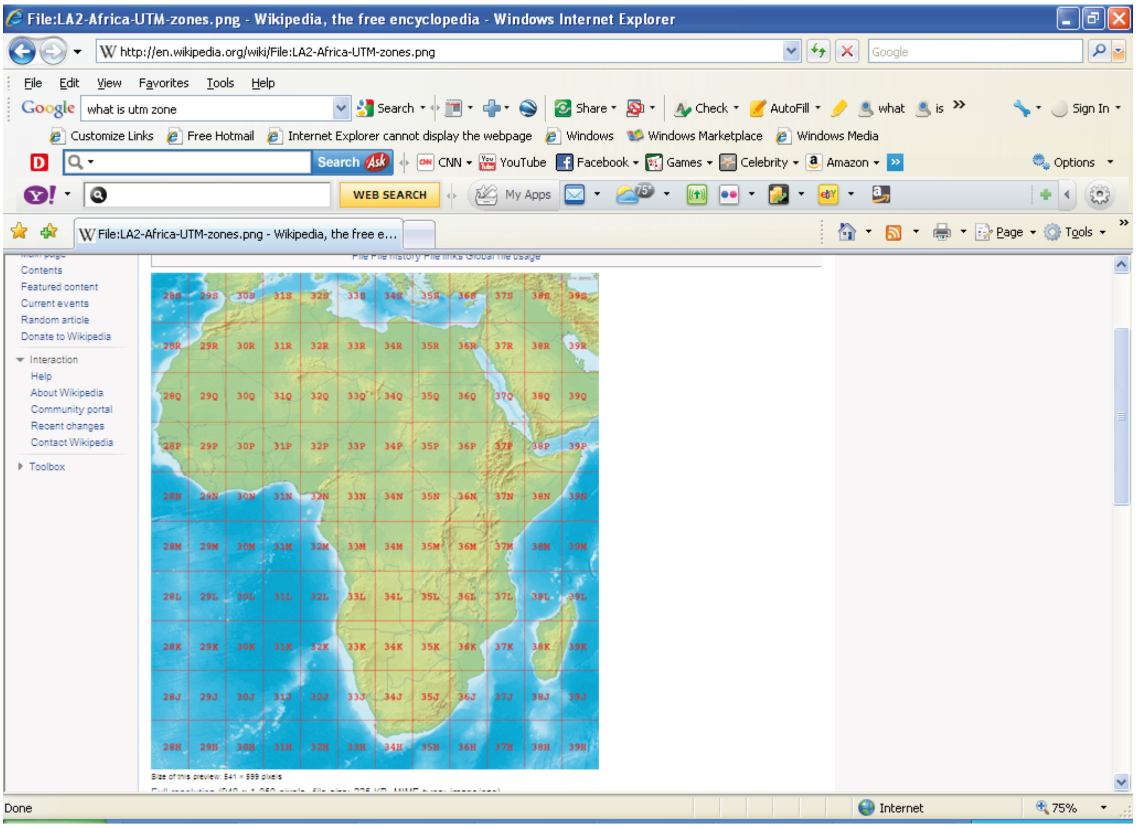

FIGURE 14: UTM for African Countries

Because of challenge of various zones in UTM coordinate system, Geographic Coordinate System (GCS), WGS 1984 projection was adopted for this project.

A geographic coordinate system (GCS) uses a three-dimensional spherical surface to define locations on the earth. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid). The spheroid defines the size and shape of the earth model, while the datum connects the spheroid to the earth's surface.

In GCS a point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth's centre to a point on the earth's surface. The angles often are measured in degrees (or in grads). The following illustration shows the world as a globe with longitude and latitude values:

Thus, all the coordinates provided in UTM were converted in the adopted GCS, in order to be plotted on the common maps. In order to facilitate the process of converting geographic layers to GCS, Longitude and Latitude, the abovementioned parameters were integrated in Oasis Montaj software and later on transferred ARCGIS 9.3.

3.2. Coordinates

The numbers of water points with coordinates were 71%, this excludes 29% from being displayed, visualized and analyzed spatially, see Table 22 below. And most of them who's their administrative units were not defined, could not be defined.

4. DATA DISPLAY AND VISUALISATION

Having captured all water points provided by IGAD member countries, it is now the right time to display and visualise them for easy generation of comment on their spatial distribution.

Water point without coordinates	23871	28.73808
Water point with coordinates	59193	71.26192
Total	83064	

TABLE 22. Coordinates distribution

The display and visualisation was done in ARCGIS 9.3 which accepts direct input of the table from the BD.

Below is spatial distribution of water points per member countries;

4.1. Djibouti

The water points are well distributed in the country (Figure 15); these included hydrodynamic stations, meteorological sta-tions, Piezometric monitoring stations and river gauging stations. However, those without coordinates could not be plotted.

4.2. Eritrea

The borehole distribution is concentrated in the central region (Maekel), and this is the region where capital city of Eritrea is located (Figure 16). It is also possible that population density in this area is high compared to other regions also.

The distribution of rain gauge station is quite uniform in the north on Eritrea, though there is none in the south while meteorological stations (rainfall station) follow the trend of borehole distribution (Figure 17).

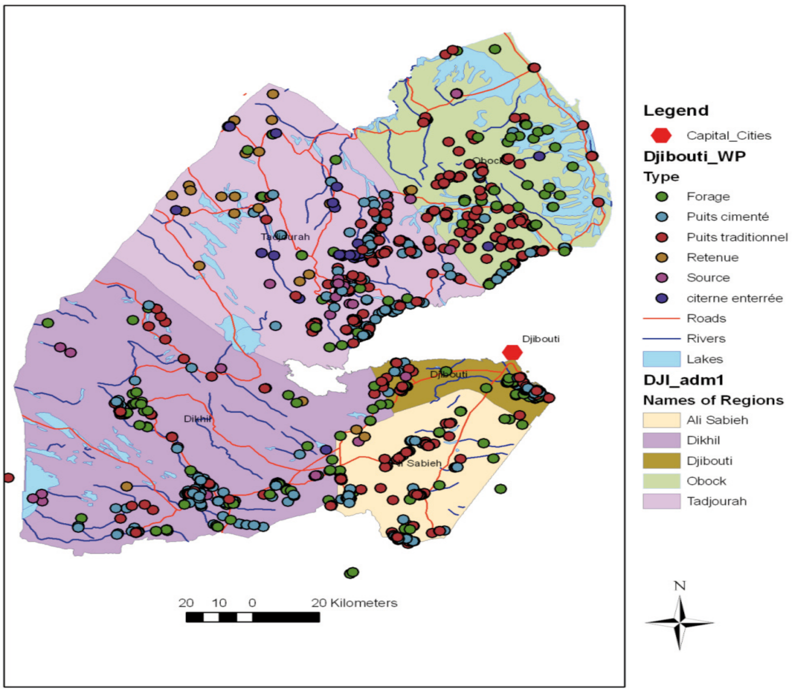

FIGURE 15: Showing the distribution of water points in of administrative unit 1 (region) in Djibouti (DJI_adm1).

4.3. Ethiopia

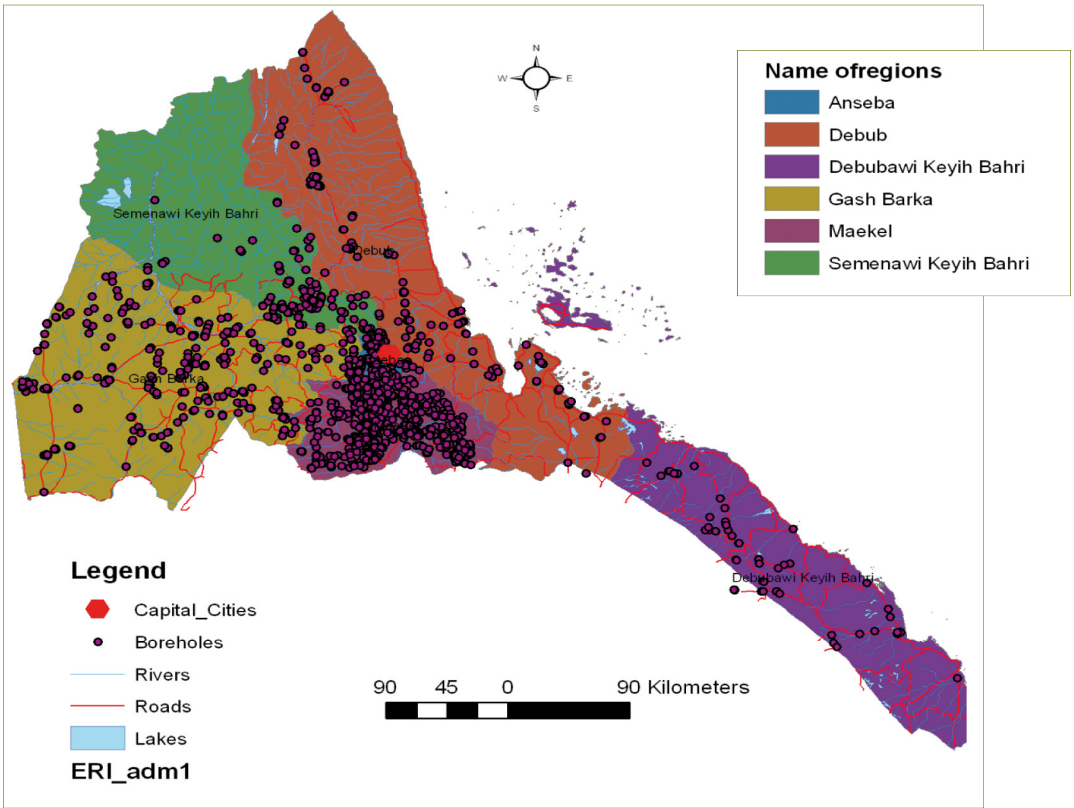

Figure 16: Showing the distribution of Boreholes in administrative unit 1 (region) in Eritrea ERI_adm1).

The spatial distribution of boreholes is not uniform (Figure 18). There are very few boreholes in South Eastern Ethiopia. Instead, boreholes are concentrated in Central and North West. And for meteorological Stations, it is even worse, as they plot only in central and south eastern part Ethiopia only (Figure 19Figure 19). Springs also follow the same trend; they are more concentrated in central and north western part of Ethiopia (Figure 20).

4.4. Kenya

The spatial distribution of Kenya boreholes is quite good, though; the centre and Rift Valley Region have more boreholes compared to other parts of the country (Figure 21).

4.5. Uganda

The distribution of shallow wells in Uganda is not uniform (Figure 22); one wonders whether they were dug in specific districts. This is because as shown below in the map, they exist only in specific districts and in clusters. This applies also to protected springs (Figure 23). Discharge stations are located by the rivers location (Figure 24). For meteorological stations, the distribution is quite uniform, though we have too many of the stations plotting outside Uganda (Figure 25).

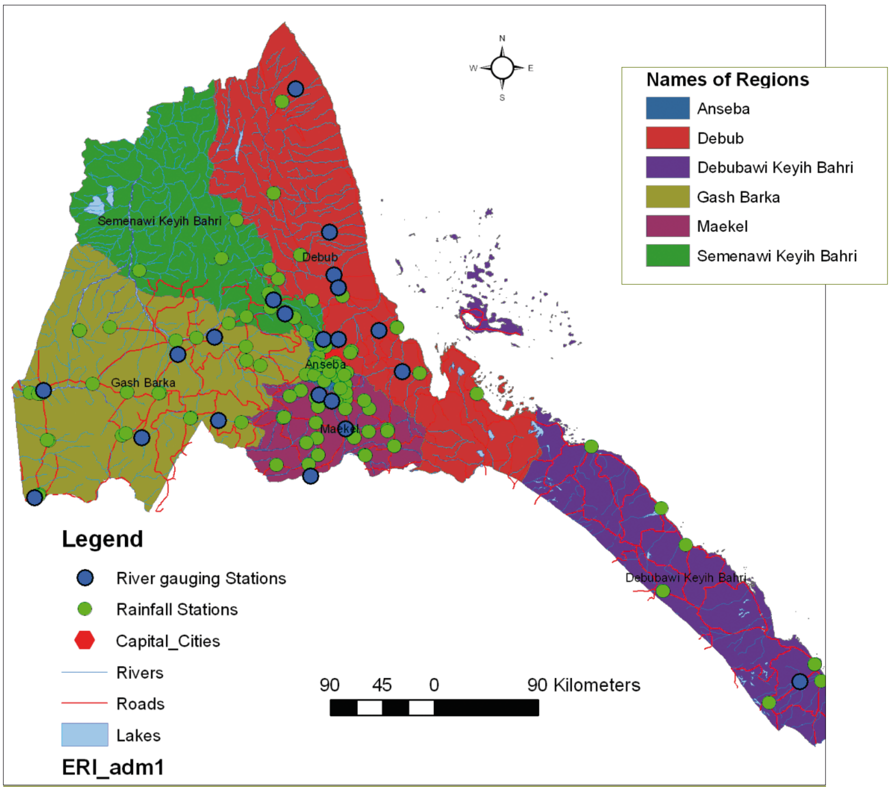

FIGURE 17: Showing the distribution of river gauge stations in administrative unit 1 (region) in Eritrea ERI_adm1.

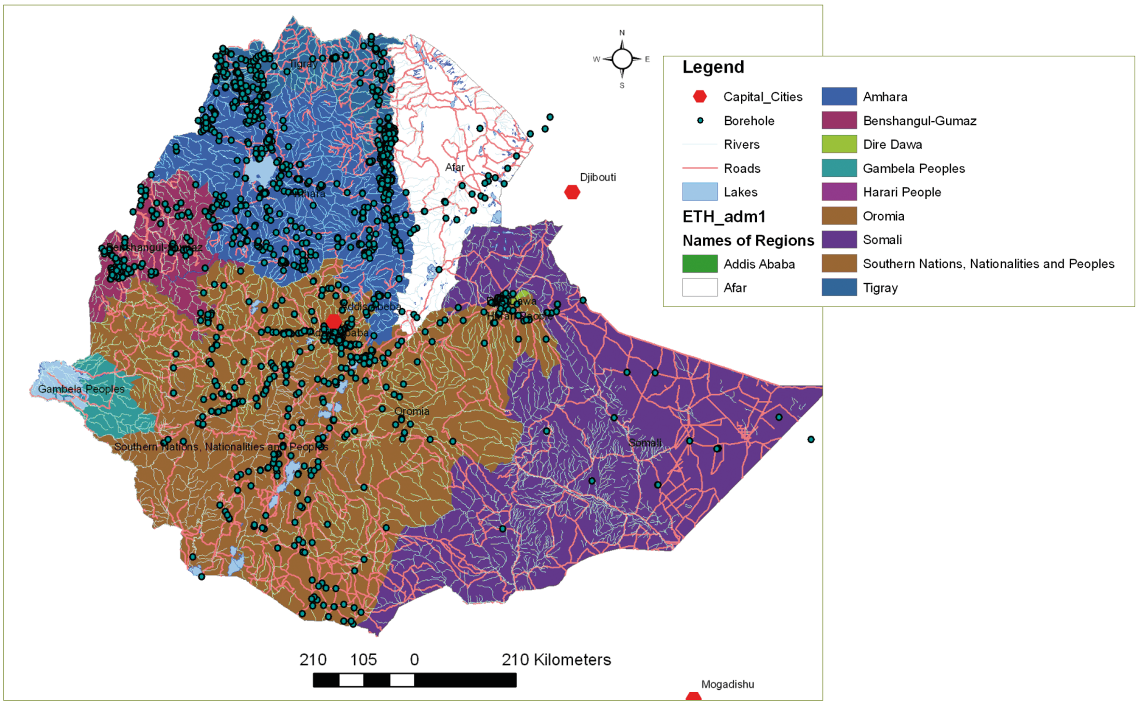

FIGURE 18: Showing the distribution of Boreholes in administrative unit 1 (adm. state) in Ethiopia ETH_adm1).

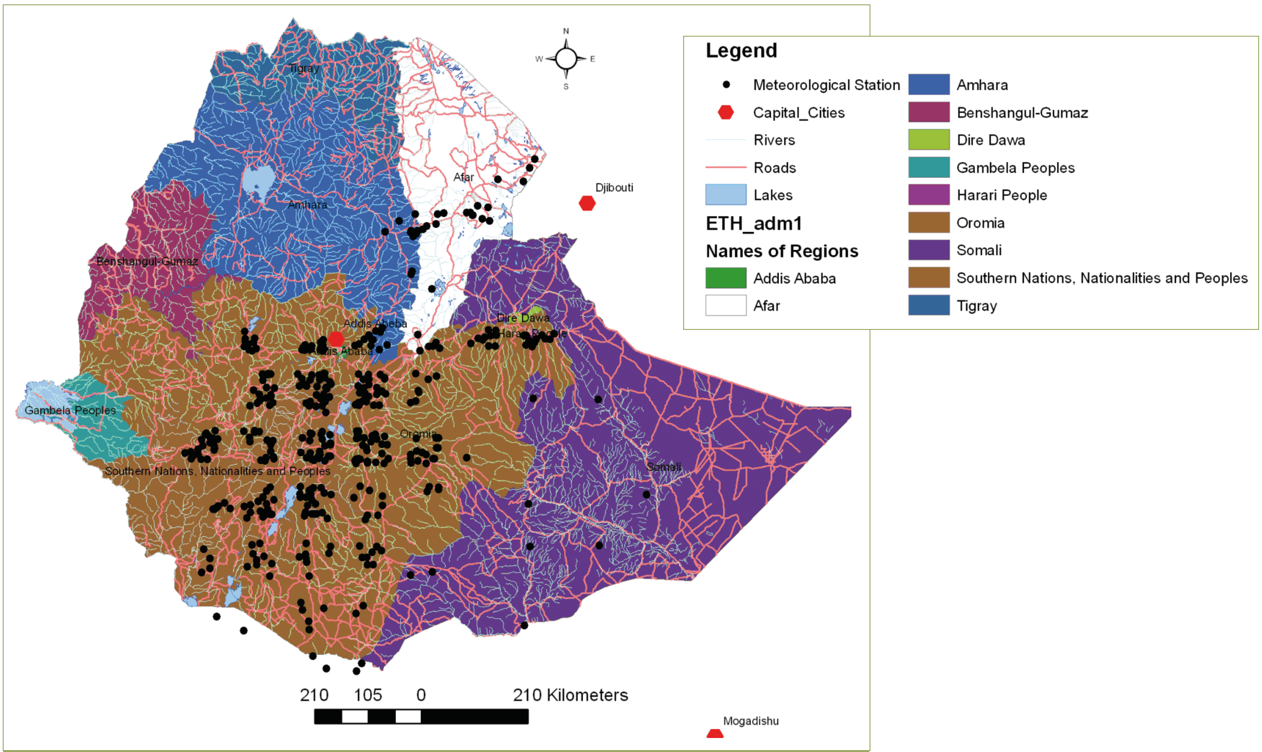

FIGURE 19: Showing the distribution of meteorological Stations in administrative unit 1 (adm. state) in Ethiopia ETH_adm1).

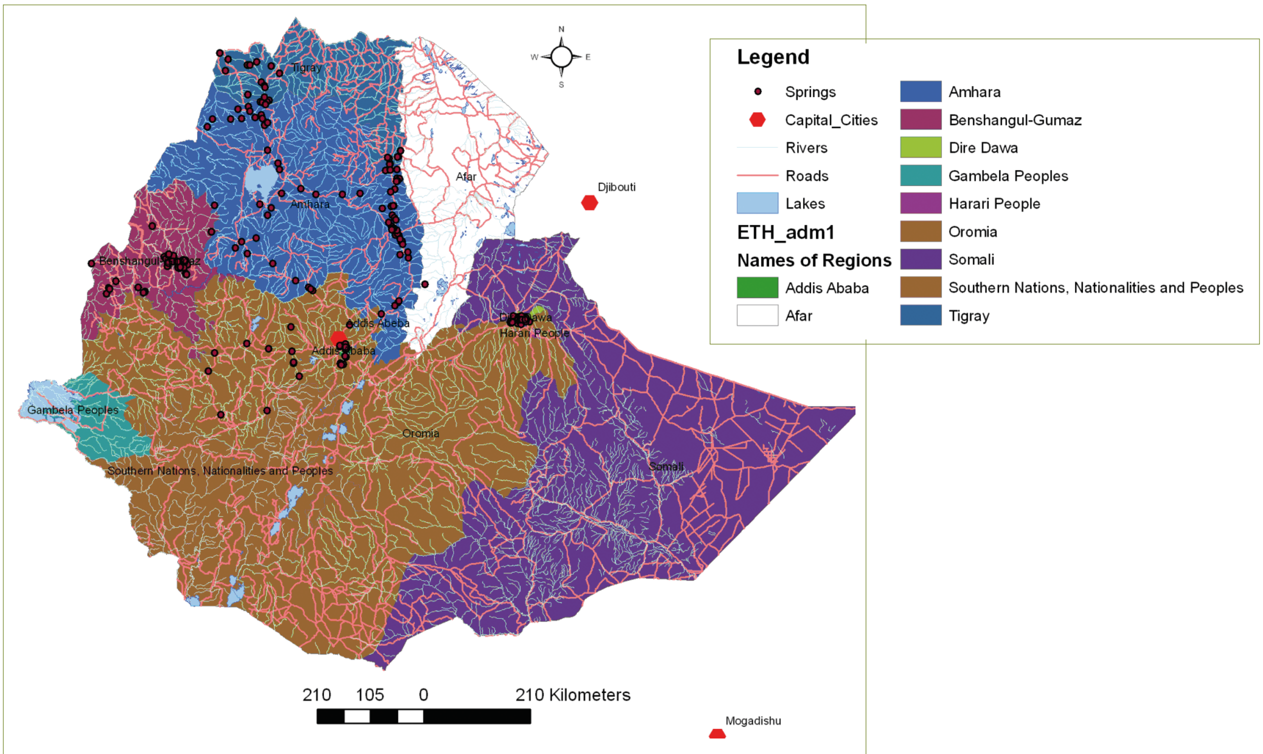

FIGURE 20: Showing the distribution of springs in administrative unit 1 (administrative state) in Ethiopia ETH_adm1).

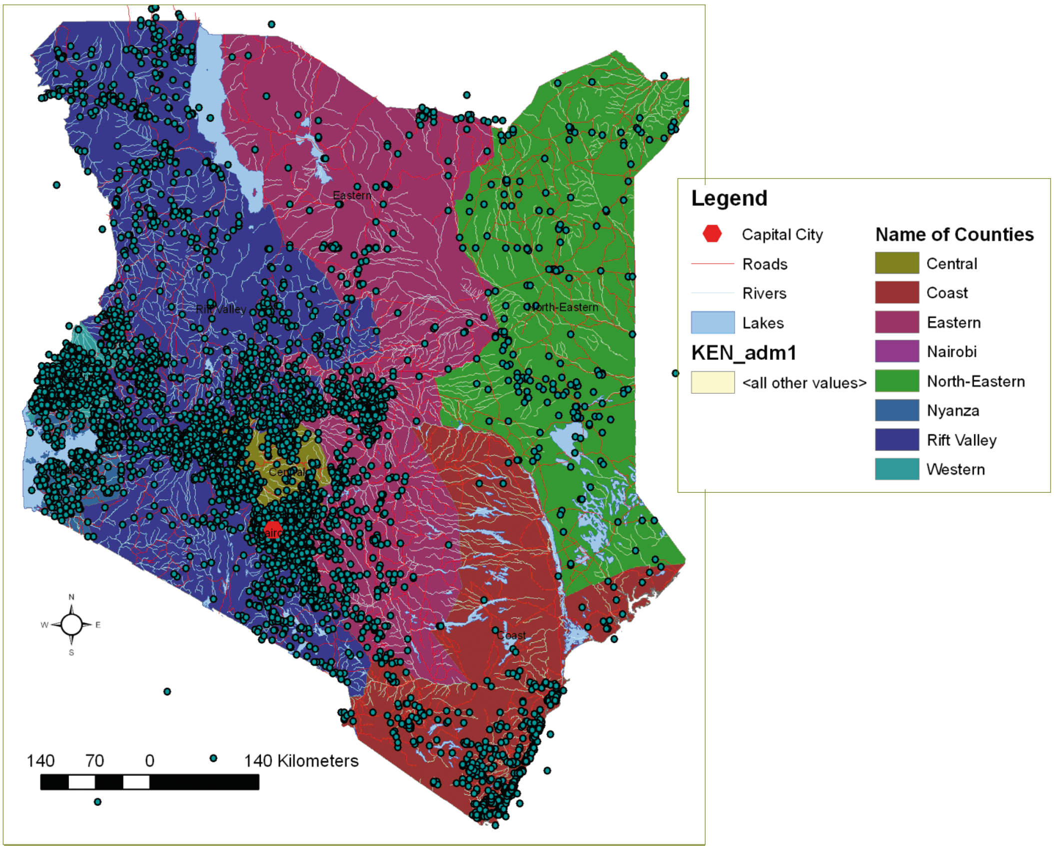

Figure 21: Showing the distribution of boreholes in administrative unit 1 (Country) in Kenya KEN_adm1).

4.6. Sudan

Sudan rainfall points elicit little comment; the distribution map is shown in Figure 26.

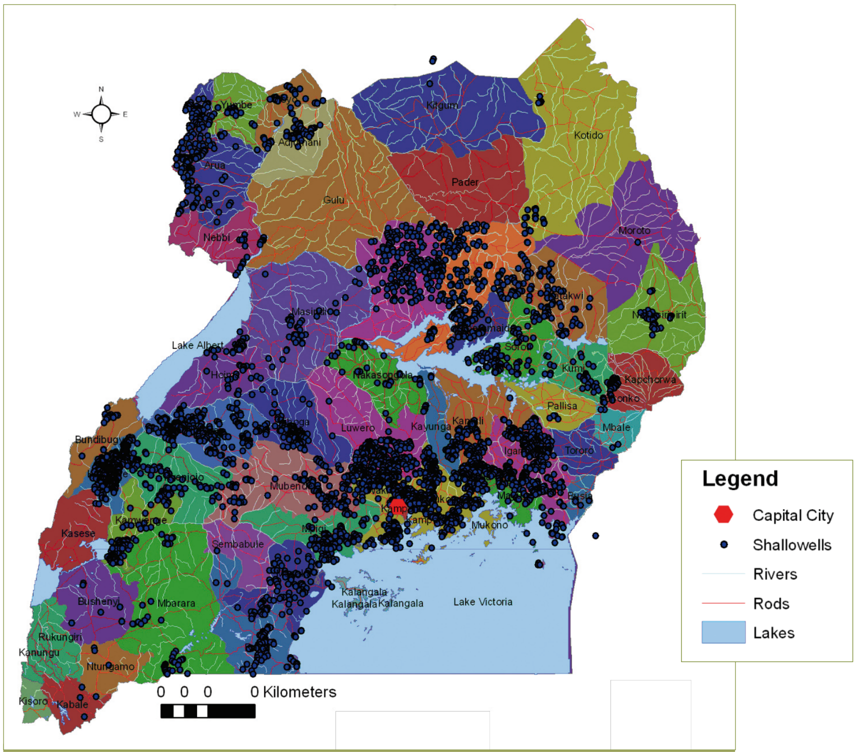

FIGURE 22: Showing the distribution of Shallow wells in administrative unit 1 (District) in Uganda UGA_adm1).

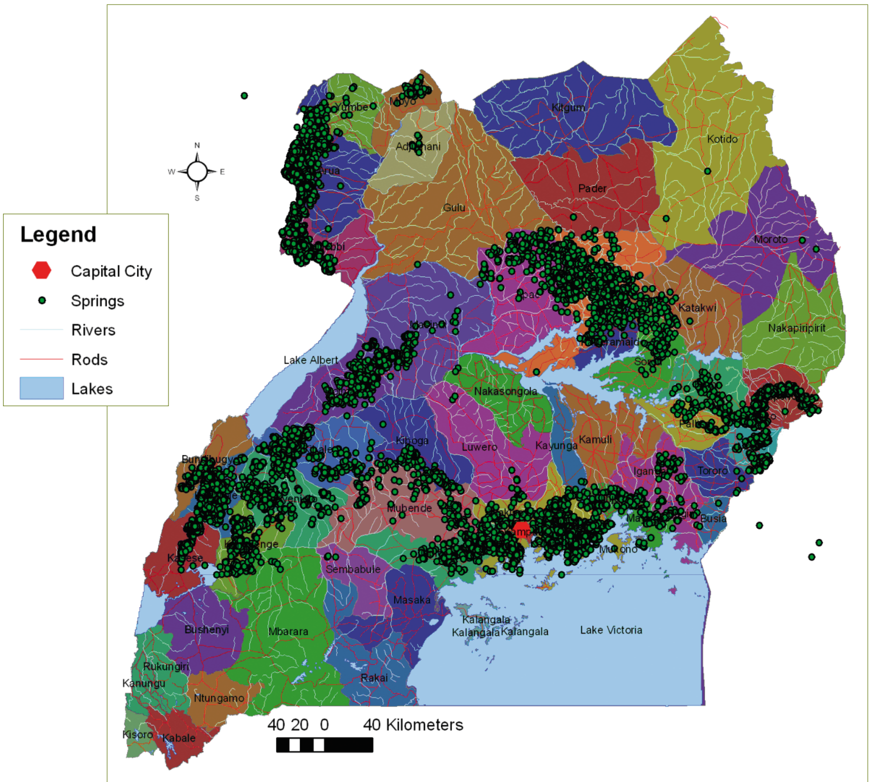

FIGURE 23: Showing the distribution of springs in administrative unit 1 (district) in Uganda (UGA_adm1).

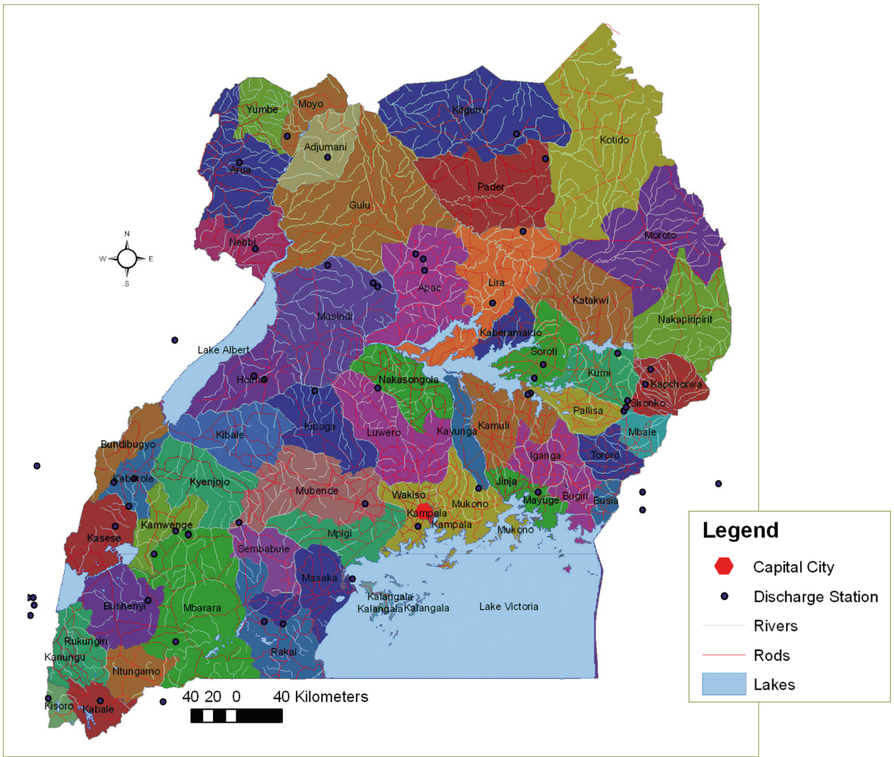

Figure 24: Showing the distribution of discharge stations in admin. unit 1 (District) in Uganda (UGA_adm1).

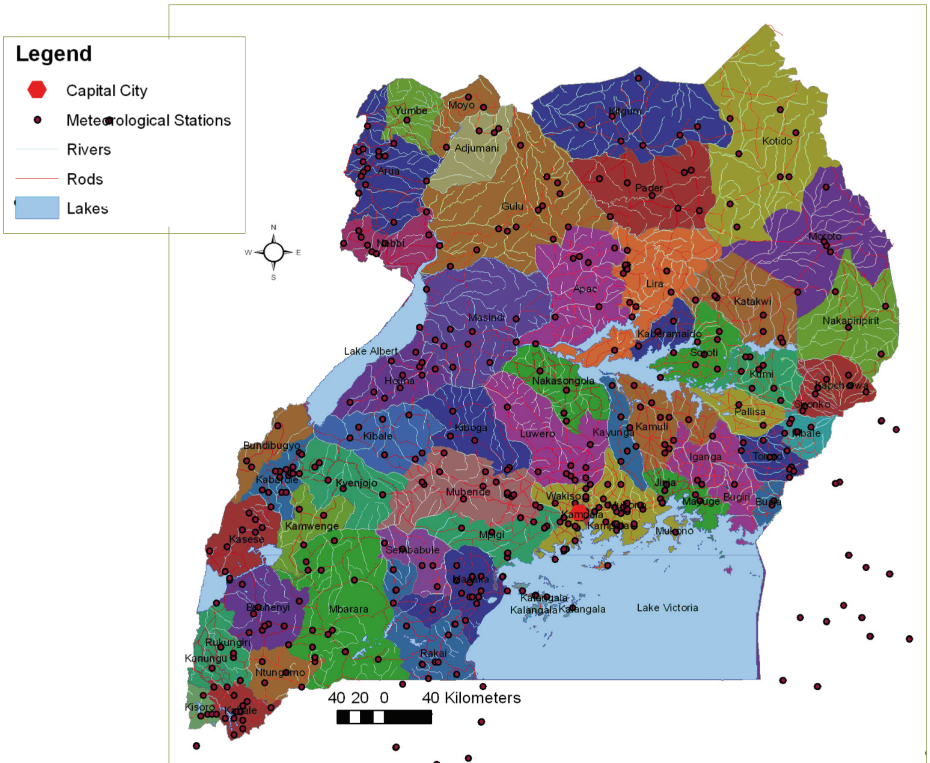

Figure 25: Showing the distribution of meteorological stations in admin. unit 1 (District) in Uganda UGA_adm1).

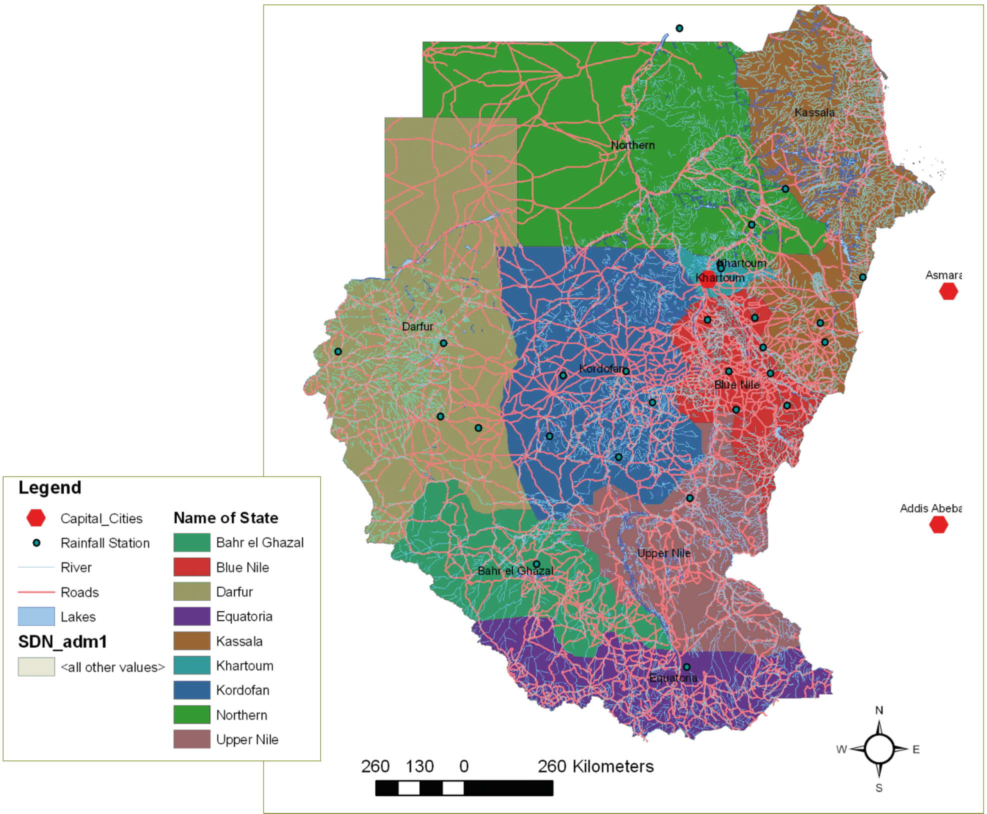

FIGURE 26: Showing the distribution of rainfall stations in admin. unit 1 (Region) in Sudan (SDN_adm1).

5. SPATIAL DISTRIBUTION OF WATER POINTS PER TRANSBOUNDARY BASIN

Apart from Nile basin which is covered under different project, majority of the water point are spatially Juba-Shabelle and Turkana-Omo. Other basins have limited water points with Ayesha having only one borehole. See Figure 27 below for details.

6. SPATIAL DISTRIBUTION OF WATER POINTS PER TRANSBOUNDARY AQUIFER

14% of the water points fall in transboundary basin within the biggest percentage, 80% falling in Mt. Elgon (AF39) aquifer system which is shared by Uganda and Kenya. The rest have less than 15% each of the basin. Figure 28 below shows the spatial distribution of water points in those aquifer systems. The boundaries of the transboundary aquifer were extracted from Transboundary aquifer of the world by IGRAC[10].

10. Transboundary aquifer of the World Update 2009, by IGRAC at 1:50,000,000. Special edition for the 5th World Water forum; Instanbul

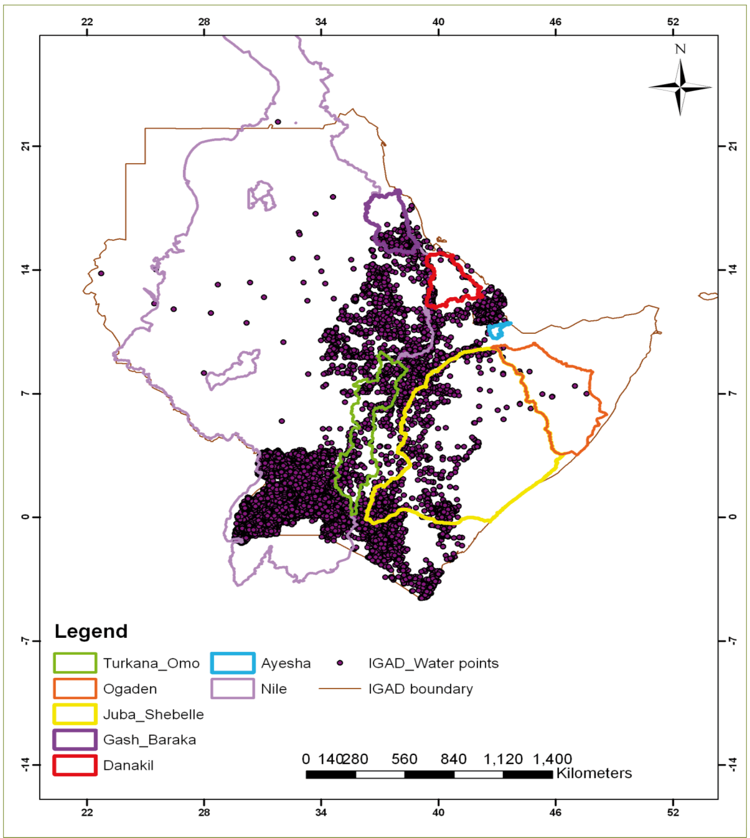

Figure 27: Spatial distribution of water points in Transboundary basin and the surrounding.

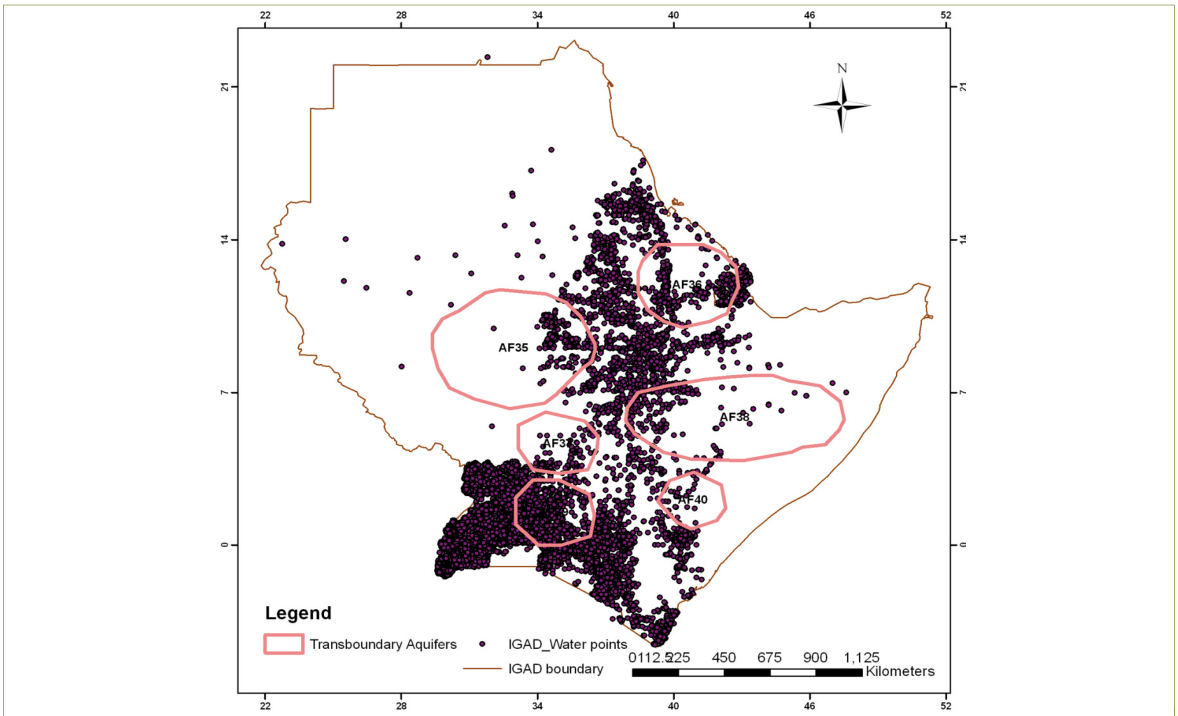

Figure 28: Spatial distribution of water points in transboundary aquifer and the surrounding (boundaries of transboundary aquifer extracted from IGRAC, 2007)

5

SUMMARY STATISTICS OF THE DATA

1. NUMBER OF WELLS PER COUNTRY

The distribution of water points per country as shown in Table 23. 64.76% of the total data in the DB were collected from the Uganda, 24% from Kenya and the least was from Sudan with about 0.04%. This is bad indicator for Sudan as it will be misrepresented in the regional DB.

Country	No. of water point	% per country
Djibouti	1641	1.98
Eritrea	2351	2.83
Ethiopia	5227	6.29
Kenya	20026	24.11
Sudan	30	0.04
Uganda	53789	64.76
Total	**83064**	

Table 23. Distribution of water points in the IGAD member countries.

2. NUMBER OF WELLS PER TRANS-BOUNDARY BASIN

The summary of spatial distribution of water points in the basin are as shown in Table 24. As explained in previous chapters, the highest coverage is from Nile basin which takes about 91%, this is followed by Juba-Shebelle with 6.33% and Turkana-Omo with 1.76% of the total records covered by transboundary basins. From analysis it can be seen that water points in transboundary basin constitute 40% of the total data/records in the DB, thus 60% of the record are not in the DB but are in the IGAD member countries. The 60% of the WP which are not within any basin also constitute those which did not have coordinates and so could not be plotted.

Transboundary_Basin	No. of Water points	%age to basin	% age to the total DB
Ayesha	1	0.003	0.001
Danakil	166	0.522	0.200
Gash-Baraka	110	0.346	0.132
Juba-Shebelle	2015	6.336	2.426
Nile Basin	28945	91.011	34.847
Ogaden	7	0.022	0.008
Turkana-Omo	560	1.761	0.674
Total record in the basin	**31804**	**100.000**	**38**
Total records in Regional DB	**83064**		

Table 24. Number of wells per transboundary basin

3. NUMBER OF WELLS PER COUNTRY PER TRANSBOUNDARY BASIN

Below in the Table 25 shows the distribution of water points per transboundary basin per country. As can be seen from table Ayesha has only one water point from Ethiopia, majority of Danakil basin WP is from Ethiopia and some other WP from Eritrea. Turkana-Omo and Juba-Shabelle majority WP comes from Kenya.

Transboundary Basin	Country	No. of water point	% age to basin
Ayesha	Ethiopia	1	0.003
Danakil	Eritrea	17	0.051
Danakil	Ethiopia	149	0.450
Gash_Baraka	Djibouti	5	0.015
Gash_Baraka	Eritrea	104	0.314
Gash_Baraka	Sudan	1	0.003
Juba_Shebelle	Ethiopia	256	0.774
Juba_Shebelle	Kenya	1759	5.316
Ogaden	Ethiopia	7	0.021
Turkana_Omo	Ethiopia	290	0.876
Turkana_Omo	Kenya	221	0.668
Turkana_Omo	Uganda	49	0.148
Total		**2859**	

TABLE 25. Distribution of water points per basin per country

4. NUMBER OF WATER POINT PER TYPE

Below in Table 26 is the summary of number of water points per type. As can be seen, boreholes are the majority of water points. The majority of water type is borehole and is about 54%, followed by 18% of the total WP in the DB.

Site type	No. of water point	%
Borehole	44674	53.783
Protected spring	15179	18.274
Water Quality	5443	6.553
Shallow well	4660	5.610
Yard tap for public use	4020	4.840
Meteorological Station	1320	1.589
Spring	1141	1.374
Hand dug well	1137	1.369
Valley Tank	918	1.105
Kiosk	870	1.047
Dam	562	0.677
Puit Ciment	468	0.563

Site type	No. of water point	%
Puits traditionnel	463	0.557
Hydrological Monitoring station	501	0.604
Rain Gauge	373	0.449
FORAGE	270	0.325
River discharge Station	192	0.231
Hydrometric	149	0.179
Earth Dam	141	0.170
Hydrodynamic Station	131	0.158
River Water	78	0.094
Retenue	72	0.087
Natural Source	52	0.063
Fish Pond	42	0.051
Pond	29	0.035
River Water Quality	28	0.034
River Gauging station	26	0.031
Pollution Impact on water sources Microbiology	25	0.030
Salinity Station	13	0.016
QryPWSAYB	12	0.014
1st Class	11	0.013
Piezometric monitoring Station	15	0.018
Lake Water Quality	9	0.011
Pollution Impact Sampling Sites	8	0.010
Wastewater Quality	8	0.010
Sewage Works	5	0.006
Production well	4	0.005
Citerne ent	3	0.004
Guelta	3	0.004
Reservoir	2	0.002
SWAMP	2	0.002
Micro-Dam	1	0.001
Natural lake	1	0.001
Rock Catcment	1	0.001
RWT V.Tank	1	0.001
Windmill	1	0.001
Total	**83064**	**100**

Table 26. Distribution of water points per type

5. Number of WP per type per country

Table 27, is the summary of WP per type per country, and the majority are boreholes and protected spring from Uganda equivalent to 32% and 18% respectively. This is followed by

Kenya with 17% of the WP in the DB.

Country	Site Type	No. of Water Point	% of the total
Eritrea	1st class	11	0.013
Eritrea	Borehole	927	1.116
Ethiopia	Borehole	2707	3.259
Kenya	Borehole	14196	17.090
Uganda	Borehole	26844	32.317
Djibouti	Citerne ent	3	0.004
Eritrea	Dam	134	0.161
Kenya	Dam	23	0.028
Uganda	Dam	405	0.488
Uganda	Earth Dam	141	0.170
Uganda	Fish Pond	42	0.051
Djibouti	FORAGE	270	0.325
Djibouti	Guelta	3	0.004
Eritrea	Hand dug well	936	1.127
Ethiopia	Hand dug well	85	0.102
Kenya	Hand dug well	107	0.129
Uganda	Hand dug well	9	0.011
Djibouti	Hydrodynamic Station	131	0.158
Ethiopia	Hydrological Monitoring station	443	0.534
Uganda	Hydrological Monitoring station	58	0.070
Djibouti	Hydrometric	5	0.006
Ethiopia	Hydrometric	120	0.144
Kenya	Hydrometric	23	0.028
Uganda	Hydrometric	1	0.001
Uganda	Kiosk	870	1.047
Uganda	Lake Water Quality	9	0.011
Djibouti	Meteorological Station	39	0.047
Eritrea	Meteorological Station	39	0.047
Ethiopia	Meteorological Station	711	0.856
Kenya	Meteorological Station	76	0.091
Uganda	Meteorological Station	455	0.548
Djibouti	Micro-Dam	1	0.001
Uganda	Natural lake	1	0.001
Djibouti	Natural Source	52	0.063
Eritrea	Peizometric monitoring Station	5	0.006
Djibouti	Piezometric monitoring Station	10	0.012
Uganda	Pollution Impact on water sources Microbiology	25	0.030
Uganda	Pollution Impact Sampling Sites	8	0.010
Eritrea	Pond	29	0.035
Uganda	Production well	4	0.005

Country	Site Type	No. of Water Point	% of the total
Uganda	Protected spring	15179	18.274
Djibouti	Puit Ciment	468	0.563
Djibouti	Puits traditionnel	463	0.557
Uganda	QryPWSAYB	12	0.014
Eritrea	Rain Gauge	126	0.152
Ethiopia	Rain Gauge	72	0.087
Kenya	Rain Gauge	94	0.113
Sudan	Rain Gauge	30	0.036
Uganda	Rain Gauge	51	0.061
Eritrea	Reservoir	2	0.002
Djibouti	Retenue	72	0.087
Kenya	River discharge Station	169	0.203
Uganda	River discharge Station	23	0.028
Djibouti	River Gauging station	6	0.007
Eritrea	River Gauging station	20	0.024
Eritrea	River Water	78	0.094
Ethiopia	River Water Quality	10	0.012
Uganda	River Water Quality	18	0.022
Uganda	Rock Catcment	1	0.001
Uganda	RWT V.Tank	1	0.001
Uganda	Salinity Station	13	0.016
Uganda	Sewage Works	5	0.006
Uganda	Shallow well	4660	5.610
Eritrea	Spring	44	0.053
Ethiopia	Spring	1079	1.299
Kenya	Spring	18	0.022
Uganda	SWAMP	2	0.002
Uganda	Valley Tank	918	1.105
Kenya	Wastewater Quality	8	0.010
Djibouti	water quality	118	0.142
Kenya	Water Quality	5312	6.395
Uganda	Water Quality	13	0.016
Uganda	Windmill	1	0.001
Uganda	Yard tap for public use	4020	4.840
Total		**83064**	

TABLE 27. Distribution of water points per type per country

6. NUMBER OF WATER POINT PER TRANSBOUNDARY AQUIFER

Table 28 is the summary of WP per transboundary aquifer, and the majority of the records are from Mt. Elgon Aquifer, which constitute about 80% of the WP in the aquifers and

11%of the total records in the regional DB. WP in the transboundary aquifer constitutes 14% of the total records in the regional DB.

Aquifer Name	No. of Water points	%age to Aquifer	% to the total DB
Awash Valley Aquifer	1435	12	2
Merti Aquifer	37	0	0
Mt. Elgon Aquifer	9548	80	11
Ogaden-Juba Aquifer	287	2	0
Rift Valley Aquifer	147	1	0
Upper Nile basin	494	4	1
Total Coverage by Aquifer	**11948**	**100**	**14**
Total records in Regional DB	**83064**		

Table 28. Distribution of water points per type per transboundary Aquifer

6

CONCLUSIONS AND RECOMMENDATIONS

- An harmonised and standardised IGAD Sub regional database have been developed,
- The Concept Model was developed and the Data base structure was defined that include data from surface and groundwater resources, Climatology, Administrative units, Social and Economic aspect and natural resources in IGAD sub-region,
- The developed database would improve access, exchange and sharing of data and information in the sub-region,
- Database was geo-referenced and represented on maps using ArcGIS 9.3 and was integrated on water resources maps for visualisation and analysis.
- Out of 83,068 water points in put in the database 71% has coordinates and 29% of Water points do not have coordinates and /or have wrong coordinates,
- The data captured would be very useful for IGAD and member countries in planning and decision making.
- There was some data imbalance; some countries provided more data than the others. Those countries which provided little data will be misrepresented; an example is Sudan which provided 0.04% of the total data in the database.

The shortcomings which were encountered during the data capture were as follows:

- About 29% of the water points input in the DB are still without coordinates and wrong coordinates. This excludes them from being plotted in GIS and analyzed, this requires the attention of coordinators from IGAD member countries;
- There was much duplication however, these were reduced except for those which were not easy to easy to identify because of some indifferences from some of the fields; Thus, duplication was minimised greatly.
- There are still many uninformed fields; this uninformed could have been neglected when they were compiling country reports thinking that they were not necessary. This create gaps in the BD, however, this can continuously be fielded/updated as one gets the information. In addition, some very important field like status are missing yet these would help in spatial distribution analysis.
- Variation in semantics was greatly reduced, though not removed completely, due to lack of the local knowledge of the meanings of some water points, especially water points from Djibouti and Eritrea. This surely requires the intervention of the coordinators in the IGAD member countries.

The regional DB made will require continuous updating to fill in the gaps and add in new data to eliminate completely the above mentioned shortcomings so that it can fully be a functional and sustainable DB.

With continuous collection of data, there will be a need to upgrade this DB. This is because at present, Microsoft Access which is easily accessible and available to all countries, have been used. But with the collection and input of more data this DB might be small, as in Access you can only input 2GB size, beyond which a new one has to be developed.

There were no specific requirements for the DB for the member countries apart from storage, but with continuous sensitisation and filling in the gaps, the DB will be useful for modelling the water coverage, water needs/shortage and excess and for planning purposes in the member countries.

In addition, the DB will facilitate easy information access and exchange between the IGAD member countries.

Capacity building is the requirement for the sustainability of this great work for the personnel who is going to handle updating and help in disseminating the information in GIS and DB. The training requirements will be basics of DB and GIS in relation to water resources management. The trained personnel will also help in routine updating of the DB and GIS. In additional he/she should be trained in basics of software and hardware for GIS and DB.

Standardised data capture is recommended. This will eliminate the issue of formats, semantics, missing and wrong coordinates and unfilled gaps.

We recommend Geographic Coordinate System (GCS), WGS 1984 projection should be used in the IGAD member countries.

Protocol on data sharing should be passed to eliminate the issue of data imbalance in the database in the IGAD member countries.

To be able to collect, store, archive and retrieve all the data collected in the IGAD secretariat, a GIS and BD section should be established in IGAD secretariat, with well equipped GIS software and high speed computer.

LITERATURE SOURCES

DEM; http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp

Administrative unit data for the IGAD Member countries; http://ww.diva-gis.org/datadown

The water steam and Lakes data in Digital Chart of the world at http://www-sul.stanford.edu/depts/gis/DCW.html. http://www.maproom.psu.edu/dcw/

Transboundary aquifer information; www.igrac.net and www.isarm.net

Population density map; http://www.ciesin.org/download_data.html and http://sedac.ciesin.columbia.edu/gpw/global.jsp

Mapping, Assessment & Management of Transboundary Water Resources in the IGAD Sub-Region Project

IV

GIS/DATABASE COMPONENT

The major activities of the Database component have been to carry out the analysis of required entities and attributes for Database development, defining entity relationship model at Conceptual level and thereafter to carry out Database installation and testing, data conversion and semantic translation, data input into the database and data output generation.

Since this is the first sub-regional database for the IGAD member countries, a huge work have been done to come up with this useful tool for data management which cuts across several water resources (surface and groundwater) sub-disciplines. The Database built included both identification and variable data/information on borehole, shallow wells, Meteorological, hydrological and river gauging stations. In total, 83,064 (Eighty three thousand and sixty four) water points have been input the regional Database.

Data provided were quite heterogeneous, different formats and semantics. Efforts were made to harmonize them before their introduction into the Database. This operation can be improved by continuous treatment. The established GIS database enrichment will allow in the future updating the thematic maps produced by the project. This will also serve for national use and support for decision making.

The major shortcomings encountered during data compilation and analysis was as follows: lack of, or wrong coordinates; duplication; Lack of Identifier, etc.. There is a need to overcome the shortcomings and the lack of data by involving the national Coordinators from member countries. As Database construction is a continuous and dynamic process, this issue will be addressed in a further stage of the project ■

Sahara and Sahel Observatory
Bd du Leader Y. Arafat, BP 31, 1080 Tunis Carthage, Tunisia
Tel. : (+216).71.206.633 - Fax : (+216).71.206.636
URL : www.oss-online.org - Email : boc@oss.org.tn

African Water Facility
Banque Africaine de Développement, BP 323 – 1002 Tunis(ia)
Tel. : (+216).71.103.971 - Fax : (+216).71.348.670
URL : www.africanwaterfacility.org - Email : africanwaterfacility.org

Intergovernmental Authority on Development
Avenue Georges Clemenceau, P.O. Box 2653 Djibouti
Tel. : (+253).354.050 - Fax : (+253).356.994
URL : www.igad.int